UNIVERSITY OF PIRAEUS **ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ**

ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ

ΣΗΜΑΣΙΟΛΟΓΙΚΟ ΠΛΑΙΣΙΟ ΓΙΑ ΤΗΝ ΑΦΑΙΡΕΤΙΚΟΤΗΤΑ ΑΝΤΙΚΕΙΜΕΝΩΝ ΚΑΙ ΕΦΑΡΜΟΓΩΝ ΣΤΟ ΔΙΑΔΙΚΤΥΟ ΤΟΥ ΜΕΛΛΟΝΤΟΣ

Δημήτριος Γ. Κελαϊδώνης

Πτυχιούχος Τμήματος Ψηφιακών Συστημάτων

Πανεπιστημίου Πειραιώς

Κάτοχος Μεταπτυχιακού τίτλου σπουδών Τμήματος Ψηφιακών Συστημάτων

Πανεπιστημίου Πειραιώς

Πειραιάς, 2016

UNIVERSITY OF PIRAEUS **ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ**

PHD DISSERTATION

SEMANTIC FRAMEWORK FOR ABSTRACTION OF THINGS AND APPLICATIONS IN THE FUTURE INTERNET

Dimitrios G. Kelaidonis
B.Sc. department of Digital Systems
University of Piraeus
M.Sc. department of Digital Systems
University of Piraeus

Piraeus, 2016

UNIVERSITY OF PIRAEUS **ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ**

ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ

Δημήτριος Γ. Κελαϊδώνης

Πτυχιούχος Τμήματος Ψηφιακών Συστημάτων
Πανεπιστημίου Πειραιώς
Κάτοχος Μεταπτυχιακού τίτλου σπουδών Τμήματος Ψηφιακών Συστημάτων
Πανεπιστημίου Πειραιώς

ΣΗΜΑΣΙΟΛΟΓΙΚΟ ΠΛΑΙΣΙΟ ΓΙΑ ΤΗΝ ΑΦΑΙΡΕΤΙΚΟΤΗΤΑ ΑΝΤΙΚΕΙΜΕΝΩΝ ΚΑΙ ΕΦΑΡΜΟΓΩΝ ΣΤΟ ΔΙΑΔΙΚΤΥΟ ΤΟΥ ΜΕΛΛΟΝΤΟΣ

Συμβουλευτική Επιτροπή:

Α. Ρούσκας, Αναπ. Καθηγητής Παν. Πειραιώς
Γ. Ευθύμογλου, Αναπ. Καθηγητής Παν. Πειραιώς
Α. Μηλιώνης, Επικ. Καθηγητής Παν. Πειραιώς

Εγκρίθηκε από την επταμελή Εξεταστική Επιτροπή την 1η Ιουλίου 2016

Α. Ρούσκας
Αναπληρωτής Καθηγητής
Πανεπιστημίου Πειραιώς

Γ. Ευθύμογλου
Αναπληρωτής Καθηγητής
Πανεπιστημίου Πειραιώς

Α. Μηλιώνης
Επίκουρος Καθηγητής
Πανεπιστημίου Πειραιώς

Γ. Στασινόπουλος
Καθηγητής ΕΜΠ

Μ. Θεολόγου
Καθηγητής ΕΜΠ

Μ. Αναγνώστου
Καθηγητής ΕΜΠ

Α. Αλεξίου
Αναπληρώτρια Καθηγήτρια
Πανεπιστημίου Πειραιώς

....

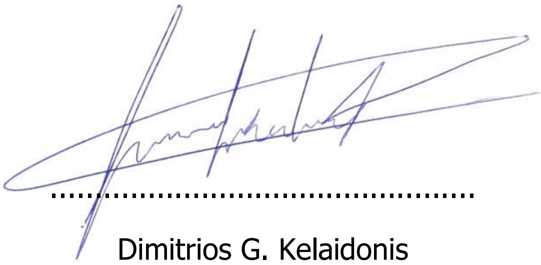
Δημήτριος Γ. Κελαϊδώνης

Πτυχιούχος Τμήματος Ψηφιακών Συστημάτων

Πανεπιστημίου Πειραιώς

Κάτοχος Μεταπτυχιακού τίτλου σπουδών Τμήματος Ψηφιακών Συστημάτων

Πανεπιστημίου Πειραιώς



....

Dimitrios G. Kelaidonis

B.Sc. department of Digital Systems

University of Piraeus

M.Sc. department of Digital Systems

University of Piraeus

Στους γονείς μου και τη σύντροφο της ζωής μου Μόνικα

ABSTRACT

The rapid evolution of the Internet technologies leads to the deployment of the new infrastructures that allow the interconnection of an increasingly larger number of devices and machines on the Internet. The dramatically increasing number of devices and machines that embed Information and Communication Technology (ICT) capabilities has led to a new era for the Internet that is known as "Internet of Things" (IoT) and it will constitute core part of the Future Internet. The huge amounts of the real world things/objects that will be part of the IoT, the heterogeneity of the communication technologies, as well as the requirements for the provision of composite functional capabilities and complex IoT services and applications, require the design and the development of innovative technological solutions that will enable the management of heterogeneous IoT infrastructures.

The abstraction of things and the application constitutes the milestone for the deployment of innovative IoT solutions, by realizing the vision of real world things that will be complemented by semantically enriched "virtual abstract representations", making them available in the IoT world. The development of "virtual abstract representations" requires the composition of techniques, methodologies and technologies from the fields of the "Virtualization", for the software abstraction of things and applications functionalities, and the "Semantics", for the semantically enriched description of the virtualized entities' capabilities. Furthermore, the management and the exploitation of the functional capabilities provided by the virtualized entities, requires the introduction of cognitive technologies, for the cognitive management, in different functional levels, ranging from the virtual things level to the level of the services and the applications.

Considering the above, this dissertation focuses on the design and the development of a "Semantic Framework for the abstraction of things and applications for the Future Internet". The architectural design of the proposed framework composes technologies from the "Semantics", the "Cognitive Management", as well as from the "Virtualization" and by extension from the field of the Cloud computing. These technological fields are composed so as to structure an innovative solution as the outcome of this dissertation. Aiming to this achievement, the framework initially introduces concepts of the semantic modelling and the virtualization of things, as the enablers for the abstraction and the aggregation of the functional capabilities of the real world things, creating virtual abstract representations complemented by

semantic descriptions. The building blocks of the "Semantic Abstraction and Virtualization of Things", and the "Semantic Storage System" support the software virtualization and the semantic description data management, of the semantically enriched abstract virtual representations, respectively. The cognitive management of the virtualized things, in terms of their deployment, composition and control, for the provision of composite functional capabilities is achieved by the "Cognitive Management and Composition of Virtual Things" building block. Complementing the last building block with the "Cognitive Management of Services" building block, the proposed framework allows the cognitive management of (composite) virtual things and services. The services are realized based on the composite virtual things and provide complex functional capabilities that satisfy advanced IoT requirements, supporting in the same time the provision of innovative IoT applications. Moreover, the cloud computing architectural principles are adopted, allowing the introduction of an integrated Cloud-IoT framework that ensures high-performance, availability and support scalability features. Finally, this dissertation aims to the validation of the proposed framework as an appropriate solution for the Future Internet challenges.

Keywords: Semantic Technologies, Future Internet, Internet of Things, Virtualization, Cloud Computing, Cognitive Management, Cloud-IoT

ΠΕΡΙΛΗΨΗ

Η αλματώδης εξέλιξη των διαδικτυακών τεχνολογιών έχει οδηγήσει στην ανάπτυξη νέων υποδομών που επιτρέπουν την διασύνδεση όλο και περισσότερων συσκευών και μηχανών στο διαδίκτυο. Ο θεαματικά αυξανόμενος αριθμός συσκευών και μηχανών με δυνατότητες διασύνδεσης στο διαδίκτυο έχει οδηγήσει στην εκκίνηση μιας νέας εποχής του διαδικτύου, που αναφέρεται ως το «Διαδίκτυο των Αντικειμένων» - "Internet of Things" (IoT), το οποίο και θα αποτελέσει κύριο κορμό του Μελλοντικού Διαδικτύου. Το μεγάλο πλήθος αντικειμένων, του πραγματικού κόσμου, που δύναται να γίνουν μέρος του IoT, η ποικιλία των δικτύων και των επικοινωνιών που θα πρέπει να υποστηρίζονται, καθώς και οι απαιτήσεις για την παροχή σύνθετων λειτουργικών δυνατοτήτων και IoT υπηρεσιών και εφαρμογών, απαιτούν τον σχεδιασμό, την ανάπτυξη και την χρήση νέων τεχνολογιών που θα καταστήσουν δυνατή την αποτελεσματική διαχείριση ετερογενών IoT υποδομών.

Η «αφαιρετικότητα» - "abstraction" αντικειμένων και εφαρμογών αποτελεί ακρογωνιαίο λίθο για την αποτελεσματική υποστήριξη των απαιτήσεων στο IoT, πραγματοποιώντας την ιδέα κατά την οποία, κάθε αντικείμενο που είναι διαθέσιμο, προσβάσιμο και ελέγξιμο στον πραγματικό κόσμο, μπορεί να έχει μια σημασιολογικά εμπλουτισμένη «εικονική αναπαράσταση» – "virtual representation" στο IoT. Για την ανάπτυξη «εικονικών αναπαραστάσεων» - "virtual representations" απαιτείται ο συνδυασμός τεχνικών, μεθοδολογιών και τεχνολογιών από το πεδίο της «εικονικοποίηση» - "virtualization", για την βασιζόμενη στο λογισμικό αφαιρετικότητα των αντικειμένων και των εφαρμογών, και της «Σημασιολογίας» - "Semantics", για την ανάπτυξη σημασιολογικών περιγραφών των λειτουργικών δυνατοτήτων των εικονικοποιημένων οντοτήτων. Επιπλέον, η διαχείριση και αξιοποίηση των λειτουργικών δυνατοτήτων των εικονικών αντικειμένων, απαιτεί την εισαγωγή γνωσιακών τεχνολογιών διαχείρισης σε διαφορετικά επίπεδα λειτουργικότητας, κυμαινόμενα από το επίπεδο εικονικών οντοτήτων, στο επίπεδο υπηρεσιών και εφαρμογών.

Λαμβάνοντας υπόψη τα παραπάνω, η παρούσα διατριβή εστιάζει στο σχεδιασμό και την ανάπτυξη «Σημασιολογικού Πλαισίου για την αφαιρετικότητα αντικειμένων και εφαρμογών στο Διαδίκτυο του μέλλοντος». Ο αρχιτεκτονικός σχεδιασμός του προτεινόμενου πλαισίου συνδυάζει τεχνολογίες από το χώρο της «Σημασιολογίας» - "Semantics", της «Γνωσιακής διαχείρισης» – "Cognitive Management", καθώς και του πεδίου της «εικονικοποίησης»-"Virtualization" και κατ' επέκταση από το χώρο του

«Υπολογιστικού νέφους» - "Cloud Computing". Τα παραπάνω τεχνολογικά πεδία συνθέτονται προκειμένου να δομήσουν μια καινοτόμο λύση που θα προκύψει ως αποτέλεσμα της παρούσας διατριβής. Στοχεύοντας στη επίτευξη αυτού του στόχου, το προτεινόμενο πλαίσιο εισάγει τις έννοιες της σημασιολογικής μοντελοποίησης και της εικονικοποίησης των αντικειμένων, ως τα στοιχεία που θα επιτρέψουν την αφαιρετικότητα και την ενοποίηση των λειτουργικών δυνατοτήτων των αντικειμένων του πραγματικού κόσμου, αναπτύσσοντας αφαιρετικές εικονικές αναπαραστάσεις που συμπληρώνονται από την σημασιολογική τους περιγραφή. Τα αρχιτεκτονικά δομικά τμήματα «Σημασιολογικής Αφαιρετικότητας και Εικονικοποίηση Αντικειμένων», και «Σημασιολογικού Συστήματος Αποθήκευσης», υποστηρίζουν την εικονικοποίηση και την διαχείριση των σημασιολογικών δεδομένων των σημασιολογικά εμπλουτισμένων εικονικών αναπαραστάσεων, αντιστοίχως. Η γνωσιακή διαχείριση των εικονικών αντικειμένων, υπό τις έννοιες της σύνθεσης και ανάπτυξης τους, καθώς και του ελέγχου τους, για την παροχή σύνθετων λειτουργικών δυνατοτήτων, επιτυγχάνεται από το δομικό τμήμα «Γνωσιακής Διαχείρισης και Σύνθεσης Εικονικών Αντικειμένων». Το τελευταίο δομικό τμήμα, σε συνδυασμό με αυτό της «Γνωσιακής Διαχείρισης Υπηρεσιών», επιτρέπουν την εισαγωγή δυνατοτήτων γνωσιακής διαχείρισης σύνθετων εικονικών οντοτήτων και υπηρεσιών από το προτεινόμενο πλαίσιο. Οι υπηρεσίες προκύπτουν ως αποτέλεσμα και βασίζουν τις λειτουργικές τους δυνατότητες στη σύνθεσης των εικονικών οντοτήτων, παρέχοντας σύνθετες λειτουργικές δυνατότητες που ικανοποιούν τις απαιτήσεις του IoT, υποστηρίζοντας επιπλέον την παροχή προηγμένων IoT εφαρμογών. Επιπροσθέτως, οι αρχές του «Υπολογιστικού Νέφους» υιοθετούνται στα πλαίσια του προτεινόμενου πλαισίου, επιτρέποντας την ανάπτυξη του ως Cloud-IoT υποδομή, εξασφαλίζοντας υψηλή διαθεσιμότητα, αποδοτικότητα και επεκτασιμότητα της υποδομής. Τέλος, βασικός στόχος αυτής της διατριβής είναι να επικυρώσει ότι το «Σημασιολογικό Πλαίσιο» είναι κατάλληλο για την αντιμετώπιση των προκλήσεων του «Μελλοντικού Διαδικτύου».

Λέξεις – Κλειδιά: Σημασιολογικές Τεχνολογίες, Μελλοντικό Διαδίκτυο, Διαδίκτυο των Αντικειμένων, Εικονικοποίηση, Υπολογιστικό Νέφος, Γνωσιακή Διαχείριση.

FOREWORD

The completion of this PhD dissertation was a long and difficult process, which often required both effort and total dedication. Despite the adversities and difficulties I managed to gain valuable knowledge in the field of Semantics, Internet of Things, Cloud computing, telecommunication networks and services, since I was given the opportunity to participate in many important research projects and study significant articles in this field. None of the above would have been achieved without the actual support of many people whose contribution to my research, in various ways, was important and deserve special mention.

First of all, I would like to gratefully acknowledge my supervisors Associate Prof. Angelos Rouskas, as well as Assistant Prof. Vera Stavroulaki and Prof. Panagiotis Demestichas, whose dedication to this dissertation and my research work, as well as their academic experience have been invaluable to me during the accomplishment of this effort. In every sense, none of this work would have been possible without their presence. I would also like to thank my co-supervisors, Associate Prof. Georgios Eftymogloy and Assistant Prof. Apostolos Milionis, who supported me and advised me at every stage of this dissertation. Moreover, I would like to thank the members of the examination committee Prof. Georgios Stasinopoulos, Prof. Michail Theologou, Prof. Miltiadis Anagnostou, and Associate Prof. Angeliki Alexiou.

I am also grateful for the support of Dr. Panagiotis Vlacheas, Dr. Kostas Tsagkaris, Mr. George Poulios, Dr. Vassileios Foteinos, as well as Dr. Aimilia Mpantouna, Dr. Andreas Georgakopoulos, for the interesting discussions we had all this time.

Of course it is needless to mention that all this effort and academic course would have been impossible to be concluded without the effective support of my family. I am forever grateful for their undivided support and understanding all these years.

Sincerely,

Dimitrios G. Kelaidonis

ΠΡΟΛΟΓΟΣ

Η ολοκλήρωση αυτής της διδακτορικής διατριβής ήταν μια μακρά και δύσκολη διαδικασία, η οποία απαιτούσε συχνά τόσο προσπάθεια όσο και απόλυτη αφοσίωση. Παρά τις δοκιμασίες και τις δυσκολίες κατάφερα να αποκτήσω πολύτιμες γνώσεις στον τομέα της Σημασιολογίας, του Διαδικτύου των Αντικειμένων, του Υπολογιστικού Νέφους, των τηλεπικοινωνιακών δικτύων και υπηρεσιών, καθώς μου δόθηκε η ευκαιρία να συμμετάσχω σε πολλά σημαντικά ερευνητικά προγράμματα και να μελετήσω σπουδαία άρθρα σε αυτόν τον τομέα. Τίποτα όμως από τα παραπάνω δε θα είχε επιτευχθεί χωρίς την έμπρακτη υποστήριξη πολλών ανθρώπων των οποίων η συμβολή στην έρευνα μου, με διάφορους τρόπους, ήταν σημαντική και αξίζουν ειδικής μνείας.

Πρώτα απ' όλα, θα ήθελα να εκφράσω την ευγνωμοσύνη μου στους επιβλέποντές μου, Αναπληρωτή Καθηγ. Άγγελο Ρούσκα, καθώς και Επίκ. Καθηγ. Βέρα Σταυρουλάκη και Καθηγ. Παναγιώτη Δεμέστιχα, των οποίων η αφοσίωση τους στη παρούσα διατριβή και το ερευνητικό μου έργο, καθώς και η ακαδημαϊκή τους εμπειρία ήταν πολύτιμη για μένα κατά τη διάρκεια της υλοποίησης αυτής της προσπάθειας. Τίποτα δε θα ήταν δυνατό χωρίς την παρουσία τους. Θα ήθελα να ευχαριστήσω τους συνεπιβλέποντες, Αν. Καθηγ. Γεώργιο Ευθύμογλου και Επίκουρο Καθηγ. Απόστολο Μηλιώνη, οι οποίοι με στήριξαν και με συμβούλεψαν σε κάθε στάδιο αυτής της διατριβής. Επιπλέον, θα ήθελα να ευχαριστήσω τα μέλη της εξεταστικής επιτροπής Καθηγ. Γεώργιος Στασινόπουλος, Καθηγ. Μιχαήλ Θεολόγου, Καθηγ. Μιλτιάδης Αναγνώστου, Αν. Καθηγ. Αγγελική Αλεξίου.

Είμαι επίσης ευγνώμων για την υποστήριξή τους και θα ήθελα να ευχαριστήσω τους Δρ. Παναγιώτη Βλαχέα, Δρ. Κώστα Τσαγκάρη, κ. Γιώργο Πούλιο, Δρ. Βασίλειο Φωτεινό, καθώς και τους Δρ. Αιμιλία Μπαντούνα, Δρ. Ανδρέα Γεωργακόπουλο, για τις ενδιαφέρουσες συζητήσεις που είχαμε όλο αυτό το διάστημα.

Φυσικά, είναι περιττό να αναφέρω ότι όλη αυτή η προσπάθεια και ακαδημαϊκή πορεία θα ήταν αδύνατο να ολοκληρωθεί χωρίς τη στήριξη της οικογένειάς μου. Είμαι για πάντα ευγνώμων για την αμέριστη υποστήριξή τους και την κατανόηση όλα αυτά τα χρόνια.

Με εκτίμηση

Δημήτριος Γ. Κελαϊδώνης

Table of Contents

List of Figures

List of Tables

1 INTRODUCTION

1.1 Research Area – Motivation

The rapidly evolving Internet technologies introduce a new era of Internet and networking infrastructures that will allow the interconnection of heterogeneous entities with Information and Communication Technology (ICT) capabilities and non-ICT capabilities to be part of the so called Future Internet. The Internet of Things (IoT) is presented as one of the main visions of the Future Internet, that is comprised and continuously growing by the vast amount of heterogeneous interconnected devices, communication technologies and objects/things. The handling of the amount of entities that will be part of the IoT requires suitable architecture and technological foundations. The Internet-connected sensors, actuators and other types of smart devices and objects need a suitable communication infrastructure. At the same time, the lack in terms of management functionality and means to overcome the technological heterogeneity and complexity of the pervasive networks calls for the definition of mechanisms for enhanced context-awareness, to provide high reliability through the ability to use heterogeneous objects in a complementary manner for reliable service provision, for energy-efficiency through the selection of the most efficient and suitable objects from the set of heterogeneous ones and for security in these distributed networks of cooperating objects. The sheer numbers of objects and devices that have to be handled and the variety of networking and communication technologies, as well as administrative boundaries that have to be supported do require a different management approach. The idea of the IoT is to enable seamless and interoperable connectivity amongst heterogeneous number of devices and systems, by allowing not only communications, as it happens in the current Internet structure, but enabling the data exchange and re-use by different things/object for the creation of applications for the end-users with more complex capabilities [1].

In the current era, there is a wide range of technologies that have been introduced for the realization of the IoT. The Radio Frequency Identification (RFID) and the Wireless Sensor Networks (WSN) among other capabilities, support the unique identification of the real-world things. Moreover, the introduction and the exploitation of the Semantic Technology [2][3] capabilities allows the design and the development of abstract virtual representations of the real-world things, as well as it enables the interoperability and the integration among heterogeneous objects in ubiquitous computing environments. However the communication between the heterogeneous real-world objects over the Internet in a world-wide level could constitute a critical problem for the ubiquitous computing, due to the wide variety of the technological heterogeneity combined with the limited human capabilities [4]. Following the paradigm of the "7 trillion devices for 7 billion people" [5] complemented by the continuously growing number of heterogeneous objects, it is obvious that the technical and technological heterogeneity constitutes one of the key requirements that should be address in the context of the IoT [6] and by extension for the realization of the Future Internet. In the same time, the heterogeneity of the applications that are designed and deployed, using the Internet so as to communicate with each other, constitute an additional important factor that should be considered in the research topic of the heterogeneity application communication and management over the Internet.

The abstraction of the things and the applications constitutes the milestone for the effective managements of the above problems, by realizing the idea that a thing/object, which is accessible and manageable in the real-world over the Internet, will have a virtual representation in the IoT world.

The application of the Semantics in the Internet was based on the requirement for the introduction of an innovative technology, capable to support the vast amount of data that is related with the World Wide Web or Web [7]. The introduction of the Semantic in the Web leaded to the "Semantic Web" [8][9] that essentially constitutes the extension of the current Web, with difference that the information is provided in well-defined way that allows simultaneously and with the high-performance value, the more effective Human-to-Machine (H2M) and Machine-to-Machine (M2M) collaboration. In the same time, by elaborating the current use of the "Semantic Web Technologies", they are introduced as key enablers for the "Hardware and Software virtualization" as "Web Resources" available and accessible over the Internet and/or over any networking infrastructure. At this point it should be highlighted that the concept of the virtualization is one of the key features that are used in the context of the "Cloud Computing" [10] that the Internet constitutes the main communication infrastructure for the Cloud-based entities. The integration of the "Semantic web Technologies" with the "Cloud Computing" technologies will support the provision of innovative complex services, with high Quality-of-Service (QoS) able to respond to the contemporary technological requirements of the IoT and the Future Internet.

The deployment of technological solutions that will be based on the composition of "Semantic Technologies" with the "resources virtualization techniques" (virtualization of resources, Platform-As-a-Service (PaaS) [11][12] and Infrastructure-As-a-Service (IaaS)[13][14]), as well as the large-scale data management technologies combined with the "Cloud Storage Services" [15][16] will constitute a stable base for the support of the future technological and industrial requirements in the Future Internet.

Taking into account the above, it is concluded that the combination of different contemporary semantic and cloud technologies is key feature that will help us to overcome the barriers that are associated with the integration and the management of the heterogeneous information and/or data that is included in the Future Internet domains. This dissertation deals with the combination between the "Semantic Web Technologies" and "Cloud Technologies", that are technologies of the Future Internet, for the overcoming of the technological heterogeneity problems, allowing the seamless interoperability among heterogeneous virtualized things/object and applications of the IoT.

The "Semantics" and the "Semantic Web" refer to two different application fields [17][18]; a) techniques for heterogeneous data collection/acquisition and b) heterogeneous data modelling. The "heterogeneous data acquisition" part focuses on the investigation, the design and the deployment of integrated technological solutions for the collection of data from heterogeneous distributed resources. The second one that refers to the "data modelling" elaborates the issues that are associated with the structuring of heterogeneous data that is associated with different things/objects from the real-world. Through the observation of the above two key features it is concluded that the "Semantics" could ideally fulfil the requirements that are associated with Future Internet in the level of the representation heterogeneous things/objects related data, as well as in the level of the data handling produced by heterogeneous data sources. Consequently, the introduction of the "Semantics" could ideally contribute to the realization of the idea for the "virtual representations" of things and application in the IoT. The last will lead to the deployment of innovative and high-quality "resource virtualization" services, supporting the Hardware and Software Virtualization, and building in the same time the basic principles for the realization of the IoT and by extension of the Future Internet.

The introduction of technologies from the "Cloud Computing" field comes to enhance in an effective manner the deployment of the "Semantic Web Technologies" in the Future Internet. In particular, this dissertation will elaborate the introduction and combination with the "Semantic Web Technologies", of the Cloud technologies that focus on the "virtualization" and the "distributed resources management". Such technologies will be based on the OpenStack Cloud [19], the Apache CloudStack [20] and the Docker [21]. The main aim of the above dissertation's proposed approach is the achievement of the design and the deployment of high-performance, accurate, reliable and high-quality of innovative "Semantic Mechanisms" for the IoT. The "Semantic Mechanisms" will be part of the "Semantic Framework", and they will be provided as distributed mechanisms with scalability capabilities, making in this way the "Semantic Framework" a "Cloud-based Semantic Framework".

1.2 Dissertation's Contribution

This dissertation deals with the "Semantic Framework for abstraction of Things and Applications in the Future Internet". The dissertation aims to enable the abstraction of IoT entities, such as devices, applications and services, through the integration of Semantic, Virtualization and Cloud technologies. Furthermore, the dissertation aims to the design, the implementation and the evaluation of Cloud semantic-based virtualization and cognitive management mechanisms that will be included in different architectural/functional building blocks of the proposed Semantic Framework, highlighting the innovation aspects and the dissertation contribution.

In this respect, the dissertation contribution and innovation aspects, in comparison to existing work, could be classified in the following topics:

- **Semantic Abstraction and Virtualization of Things:** this topic deals with the introduction and the combination of semantic and virtualization technologies. The main contribution and innovation of the dissertation lies on the concept of an "abstract semantic data model" that allows the semantic description of heterogeneous real world things, such as sensors, actuators, smart phones, wearables, etc. Moreover, through the exploitation of the semantic description data the framework allows the dynamic creation of "virtual representations" as software modules that arise through the instantiation of appropriate software templates filled by semantic data related to the virtual thing specifications and functional capabilities. Different research works and activities, such as the [22]-

[34] deal with this topic proposing data models, which however cannot support the description of a wide range of real world things, whereas they follow a more use case specific design approach. In addition, regarding the instantiation of virtual things there are different approaches such as the [35]-[43] that follow a semi-dynamic deployment approach of predefined/pre-structured software modules that correspond to different device types. Essentially, the dissertation aims to contribute to the field of the dynamic semantic-based deployment of virtual things representations, evolving the currently used semi-dynamic approaches. Such approaches exploit semantics mainly for search and/or discovery purposes without supporting the dynamic exploitation of the meta-data information (e.g. for the dynamic creation of software modules that implement virtualized entities). Additionally, the proposed approach contributes, by hiding the technological heterogeneity and complexity of the processes by the end-users, including stakeholders and developers.

- **Semantic-based Cognitive Management of Virtual Things and Services**: this contribution aspect deals with the introduction of cognitive mechanisms that allow the semantic-based composition of Virtual Things, for the creation of new, composite functional capabilities that will allow the deployment of complex IoT services over distributed environments, such as multi-Cloud ecosystems. The Composite Virtual Things may be formed according the end-user requirements and/or based on particular policies, whereas the complex services, that are created based on these composite virtual things, can support the provision of innovative IoT applications. The main differentiation of the dissertation contribution, in comparison to existing literature works, refers to the support of the design and the deployment of Cognitive Management mechanisms that base their capabilities on semantic description data and semantic data modeling framework's capabilities. Specifically, various existing works, such as [44]-[57], focus on the deployment of customized (use case oriented and/or technology specific) collaborative software agents to support requirements in dynamic IoT environments. On the other hand, the Composite Virtual Things and the Services are described by particular semantic data models and their semantic data is exploited by advanced cognitive algorithms (e.g. Decision Making, Coordination, Self-management (configuration, optimization, healing), etc.) for the provision of innovative cognitive management capabilities. Such capabilities may be associated with the natural language processing of user requests, the dynamic composition of virtual things and services, the knowledge based instantiation of services, etc. Essentially, dissertation's contribution relates to the achievement of dynamic composition, the cognitive management and the re-usability of the virtual thing and the services, even outside of the context and domain for which they were originally developed. Moreover, the proposed approach contributes to the deployment of intelligent services, fulfilling requirements, while details and complexity are hidden from end-users (e.g. developers, stakeholders, etc.).

- **Semantic Storage System for Cloud-IoT infrastructures:** the contribution of the dissertation in this topic deals with more technical aspects, with respect to the implementation of designed specification for the deployment of a scalable, distributed storage and management system for the semantic data that is associated with the (composite) virtual representations and the (complex) IoT services and/or applications. The dissertation contribution focus on the implementation of distributed semantic databases that allow the store, the managements (e.g. queries and modifications) and the federation (e.g. federated queries) of heterogeneous semantic data (aka meta-data) that corresponds to the available (Composite) Virtual Things and Services across the framework. The dissertation contribution differs than other related works, such as the [58]-[68] on the approach of the deployment of the storage system mechanisms and the management of the federated semantic data. Specifically, the semantic storage system, as it is designed and implemented in the dissertation context, includes a set of different mechanisms that support the semantic data modeling and management requirements. These mechanisms are implemented as REST APIs that can be deployed over different types of Cloud infrastructures that support either hypervisor-based [69] or Container-based virtualization [70] techniques. These APIs support the interaction with semantic data management endpoints (e.g. performance of queries, modifications, etc.), allowing in advance the interaction with the rest of the framework's mechanisms and external third-party entities. Essentially, the semantic storage system in comparison to existing solutions structures and provides a generic HTTP-REST Front-End communication interface between the Semantic Framework and its client entities, towards a federation of schema-less semantic databases (e.g. RDF stores).

Finally, the dissertation contribution will be evaluated through the experimental validation over different IoT and Cloud-IoT environments, including Smart Home/Buildings and Smart Cities.

1.3 Dissertation Structure

The dissertation is structured in chapters, each of which provides a detailed description on the research activities performed with regards to the topics noted in Section 1.2. A brief description of them follows in the next paragraphs.

Chapter 2 The investigation and the detailed elaboration of the existing research work that has been performed so far in the fields of the semantics, the virtualization and the cloud computing for the IoT, constituted one of the initial aims for this dissertation. Through the examination of the existing research work, the dissertation aims to the achievement of the design, the implementation and the validation of an integrated innovative technological solution that will not reinvent the wheel but it will exploit the existing work by combining its result in order to enable the evolution of the IoT. Towards this direction, three main areas are investigated: a) "Semantic Abstraction and Virtualization of Things in the Future Internet", b) "Cognitive Management of Virtual Things and Services in the Future Internet" and c) "Cloud Internet of Things environments". Each area is complemented by the detailed overview of the related research activities that have been recorded in the scientific bibliography, up to today.

Chapter 3 This thesis focuses on the design and the development of a "Semantic Framework for abstraction of Things and Applications in the Future Internet", through the composition of Semantics, Virtualization, Cognitive and Cloud technologies. This chapter describes the proposed framework and analyzes its main architectural blocks and components. Specifically, it is presented a detailed description of the functional capabilities and/or the mechanisms that are supported by each architectural block. Having introduced and analyzed the proposed framework the next chapters present the research work on the proposed solutions, resulted in a set of different scientific publications. The research work has been classified in three particular conceptual areas that relate to this dissertation work: a) "Semantic Modelling for the deployment of Virtual Things in the Future Internet", b) "Cognitive Management of (Composite) Virtual Things and Services in the Future Internet" and c) "Cloud-IoT infrastructures for the Future Internet". Each research area is complemented by particular related publications that introduce, describe, validate and evaluate the architectural blocks of the proposed framework.

Chapter 4 This chapter presents the application of the semantic framework mechanisms, for the achievement of the abstraction of Virtual Things in the IoT. For the abstraction of real world things, were applied semantic technologies for the semantic data modeling of the devices, applications and services, as well as techniques for the virtualization of IoT entities as RESTful Web Services (WS), allowing their distributed manipulation though abstract software modules and integrated mechanisms. The main concepts focus on the design and development of semantic data models, design and implementation of software modules for the representation of real world devices, as well as on the design of security principles and mechanisms for the semantic-based access control management on the virtual things / IoT entities. Amongst others, it is elaborated the application of various framework components and functional capabilities in different proof-of-concepts, such as the virtual things for the smart energy management of wireless technologies and mobile applications in contemporary IoT environments.

Research on the proposed solutions, as they are described in the context of the semantic framework, resulted in the following publications:

- Kelaidonis, Dimitris, et al. (2012, November). "Virtualization and cognitive management of real world objects in the internet of things". In Green Computing and Communications (GreenCom), 2012 IEEE International Conference on the Internet of Things (pp. 187-194). IEEE.
- Tilanus, Paul, Ran, Bob, Faeth, Matthias, Kelaidonis, Dimitris, & Stavroulaki, Vera. (2013, June). "Virtual object access rights to enable multi-party use of sensors". In World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2013 IEEE 14th International Symposium and Workshops on a (pp. 1-7). IEEE.
- Kelaidonis, Dimitris, et al. (2014, August). "Smart energy management of wireless technologies and mobile applications". In Wireless Communications Systems (ISWCS), 2014 11th International Symposium on (pp. 848-852). IEEE.

Chapter 5 Having introduced and described the proposed solution for the semantic-based abstraction and virtualization of real world things, this chapter focuses on the cognitive management of (Composite) Virtual Things and Services in the Future Internet. Specifically, it is elaborated the introduction of a cognitive management framework for the IoT that includes a set of different mechanisms the introduction of cognition in the IoT environments. The cognitive management framework includes different instances of the technological solutions and/or mechanisms that are proposed by the Semantic Framework, such as the Semantic Storage System capabilities, the (Composite) Virtual Objects and the cognitive management of IoT services and applications.

Research on the proposed solutions, as they are described in the context of the semantic framework, resulted in the following publications:

- Vassilis Foteinos, Dimitris Kelaidonis, George Poulios, Panagiotis Vlacheas, Vera Stavroulaki, and Panagiotis Demestichas. (2013). "Cognitive management for the Internet of things: A framework for enabling autonomous applications". Vehicular Technology Magazine, IEEE, 8(4), 90-99.
- Panagiotis Vlacheas, Raffaele Giaffreda, Vera Stavroulaki, Dimitris Kelaidonis, Vassilis Foteinos, George Poulios, Panagiotis Demestichas, Andrey Somov, Abdur R. Biswas, and Klaus Moessner. (2013). "Enabling smart cities through a cognitive management framework for the internet of things". Communications Magazine, IEEE, 51(6), 102-111.

Chapter 6 This chapter focuses on the cloudification aspects of the Semantic Framework mechanisms. In particular, the performance and the scalability of the semantic framework, as well as the cognitive management framework functionality, as it is presented in the chapter 5, could be ideally achieved by introducing Cloud technologies. Furthermore, the data storage and management capabilities can be empowered by combining the proposed mechanisms, such as the Semantic Storage System, with Cloud storage mechanisms. Moreover the computational and processing capabilities of the framework can be extended through the deployment of the available mechanisms over distributed Cloud computing environment. The distribution, as well as the extensibility of the resources is elaborated in the context of this chapter and it is proposed an appropriate design approach for the cloudification of the framework functionality, allowing Cloud-IoT deployments, such as the Smart Cities infrastructures.

Research on the proposed solutions, as they are described in the context of the semantic framework, resulted in the following publications:

- Dimitrios Kelaidonis, Panagiotis Vlacheas, Vera Stavroulaki, Stylianos Georgoulas, Klaus Moessner, Yuichi Hashi, Kazuo Hashimoto, Yutaka Miyake, Keiji Yamada, Panagiotis Demestichas. (2016). "Cloud Internet of Things framework for enabling services in Smart Cities". Springer Book.
- Dimitrios Kelaidonis, Angelos Rouskas, Panagiotis Vlacheas, Vera Stavroulaki, Panagiotis Demestichas. (2016). "A Federated Edge Cloud-IoT Architecture – Enabling semantic-based service provisioning in Future Internet". EUCNC June, 2016, Athens Greece.
- Dimitrios Kelaidonis, Angelos Rouskas, Panagiotis Vlacheas, Vera Stavroulaki, Panagiotis Demestichas. (2016). "Federated Edge Cloud Internet of Things Architecture over 5G infrastructures". Submitted to Communications Magazine, IEEE, Feature Topic: Impact of next-generation mobile technologies on IoT-Cloud convergence, April, 2016.

Chapter 7 The last chapter discusses the main aspects introduced by this dissertation. Furthermore, on-going challenges are noted and finally the dissertation is concluded.

1.4 Chapter References

[1].Atzori L., Iera A., Morabito G. (2010). The Internet of Things: A survey. J. Computer Networks, 54, 2787-2805.

[2].Fürber, C. (2016). Semantic Technologies. In Data Quality Management with Semantic Technologies (pp. 56-68). Springer Fachmedien Wiesbaden.

[3].W3C Standards – Semantic Web. (2016). http://www.w3.org/standards/semanticweb/.

[4].Kephart, J. O., Chess, D. M. (2003). The Vision of Autonomic Computing. IEEE Computer, 36(1). 41-50.

[5].Babar, S., Mahalle, P., Stango, A., Prasad, N., & Prasad, R. (2010). Proposed security model and threat taxonomy for the internet of things (IoT). In Recent Trends in Network Security and Applications (pp. 420-429). Springer Berlin Heidelberg.

[6].Miorandi, D., Sicari, S., De Pellegrini F., Chlamtac I. (2012) Internet of things: Vision, applications and research challenges. Ad Hoc Networks, 10(7), 1497-1516.

[7].Brian, M. (2005). Semantic Web Technologies. Semantic Web Interest Group World Wide Web Consortium (W3C). Technical Report.

[8].Semantic Web Activity. (2016). [Online]: http://www.w3.org/2001/sw/.

[9].M-R. Koivunen, E. Miller. W3C Semantic Web Activity. Proceedings of the Semantic Web Kick-off Seminar in Finland. (2016). [Online]: http://www.w3.org/2001/12/semweb-fin/w3csw.

[10]. Michael Armbrust, et al. (2010). A view of cloud computing. Magazine Communications of the ACM. 53(4). 50-58.

[11]. Mcgrath, Michael P., et al. (2015). "Controlling Capacity in a Multi-Tenant Platform-as-a-Service Environment in a Cloud Computing System". U.S. Patent No. 20,150,081,916. 19.

[12]. Alcaraz Calero, J., and J. Gutierrez Aguado. (2014). "Monpaas: An adaptive monitoring platform as a service for cloud computing infrastructures and services".

[13]. Manvi, Sunilkumar S., and Gopal Krishna Shyam. "Resource management for Infrastructure as a Service (IaaS) in cloud computing: A survey". (2014). Journal of Network and Computer Applications 41: 424-440.

[14]. Serrano, Nicolas, Gorka Gallardo, and Josune Hernantes. "Infrastructure as a Service and Cloud Technologies". IEEE Software 2 (2015): 30-36.

[15]. Agrawal, Divyakant, Sudipto Das, and Amr El Abbadi. "Big data and cloud computing: current state and future opportunities". (2011) . Proceedings of the 14th International Conference on Extending Database Technology. ACM.

[16]. Chaudhuri, Surajit. (2012). "What next?: a half-dozen data management research goals for big data and the cloud". Proceedings of the 31st symposium on Principles of Database Systems. ACM.

[17]. Berners-Lee, T. (2001). "The Semantic Web". Scientific American.

[18]. Shadbolt, N., Hall, W., Berners-Lee, T. (2006). "The Semantic Web Revisited". IEEE Intelligent Systems.

[19]. OpenStack Open Source Cloud Computing Software. (2016). [Online]: https://www.openstack.org/.

[20]. Apache CloudStack: Open Source Cloud Computing. (2016). [Online]: https://cloudstack.apache.org/.

[21]. Docker - Build, Ship, and Run Any App, Anywhere. (2016). [Online]: https://www.docker.com/.

[22]. Catalogue Service. (2016). [Online]: http://www.opengeospatial.org/standards/cat.

[23]. Observations and Measurements. (2016). [Online]: http://www.opengeospatial.org/standards/om.

[24]. SensorML. (2016). [Online]: http://www.ogcnetwork.net/SensorML.

[25]. Sensor Observation Service. (2016). [Online]: http://www.opengeospatial.org/standards/sos.

[26]. Transducer Markup Language (TML). (2016). [Online]: http://www.ogcnetwork.net/infomodels/tml.

[27]. Web Processing Service. (2016). [Online]: http://www.opengeospatial.org/standards/wps.

[28]. Web Registry Service Research Document. (2016). [Online]: http://udig.refractions.net/files/docs/WRS.pdf.

[29]. De, Suparna, et al. (2011). "Service modelling for the Internet of Things". Computer Science and Information Systems (FedCSIS), 2011 Federated Conference on. IEEE.

[30]. Geography Markup Language (GML). (2016). [Online]: http://www.opengeospatial.org/standards/gml.

[31]. CityGML. (2016). [Online]: http://www.opengeospatial.org/standards/citygml.

[32]. GeoRSS :: Geographically Encoded Objects for RSS feeds. (2016). [Online]: http://www.georss.org/.

[33]. GeoSPARQL - A Geographic Query Language for RDF Data. (2016). [Online]: http://www.opengeospatial.org/standards/geosparql.

[34]. OGC® WaterML. (2016). [Online]: http://www.opengeospatial.org/standards/waterml.

[35]. EBBITS project Website. (2016). [Online]: http://www.ebbits-project.eu/.

[36]. SPITFIRE project Website. (2016). [Online]: http://spitfire-project.eu/.

[37]. SOFIA project Website. (2016). [Online]: http://www.sofia-project.eu/.

[38]. SENSEI project Website. (2016). [Online]: http://www.sensei-project.eu/.

[39]. DIEM project Website. (2016). [Online]: http://www.cs.tut.fi/ihte/projects/DIEM/index.html.

[40]. OPUTE (Open Ubiquitous Technologies) project information, http://www.tekes.fi/programmes/Ubicom/Projects?id=9822957.

[41]. Zhang L., Mitton N. (2011). "Advanced Internet of Things", Université des Sciences et Technologies de Lille, France. iThings-2011.

[42]. Lambros Sarakis, Theodore Zahariadis, Helen-Catherine Leligou, Mischa Dohler. (2012). "A Framework for Service Provisioning in Virtual Sensor Networks", Eurasip Journal on Wireless Communications and Networking.

[43]. S. Alam, Mohammad M. R. Chowdhury, J. Noll, "SenaaS:An Event-driven Sensor Virtualization approach for Internet of Things Cloud", Networked Embedded Systems for Enterprise Applications(NESEA). (2010) IEEE International Conference.

[44]. BUTLER FP7 EU Project. (2014). Duration: 2011-2014. Grant Agreement No. 287901. [Online]: http://www.iot-butler.eu/.

[45]. Internet of Things Architecture (IoT-A) EU Project Website. (2016). [Online]: http://www.iot-a.eu/.

[46]. EU/FP7 project IoT-A (The Internet-of-Things Architecture – IoT-A, 257521), Sep. 2010 – Aug. 2013, Deliverable 1.2 (D1.2), "Initial Architectural Reference Model for IoT.

[47]. EU/FP7 project IoT-i (Internet-of-Things Initiative – IoT-i, 257565), Sep. 2010 – Aug. 2012, Deliverable 1.2 (D1.2), "Final Reference Model".

[48]. Aberer, K., Hauswirth, M., Salehi, A. (2007). Infrastructure for Data Processing in Large-Scale Interconnected Sensor Networks. In: Proceedings of the International Conference on Mobile Data Management (MDM '07), 198-205.

[49]. Mattern, F. (2003). From Smart Devices to Smart Everyday Objects. In: Proceedings of the Smart Objects Conference (SOC 03), 15–16.

[50]. Beigl, M., Gellersen, H.-W. (2001). Schmidt, A.: MediaCups: Experience with Design and Use of Computer-Augmented Everyday Objects. J. Computer Networks 35(4), 401–409.

[51]. V. Stavroulaki, N. Koutsouris, Y. Kritikou, P. Demestichas, "Cognitive Management of Devices in the Wireless World", in Wireless Personal Communications, Springer, October 2013, pp: 1-34, doi: 10.1007/s11277-013-1468-2.

[52]. Melazzi N. B. (2010). "CONVERGENCE: Extending the Media Concept to Include Representations on Real World Objects", The Internet of Things: 20th Tyrrhenian Workshop on Digital Communications, 129-140.

[53]. FP7/ICT- 257123 project CONVERGENCE, Jun. 2010 - Feb. 2013, Website, http://www.ict-convergence.eu/.

[54]. Every Thing Connected: How Web Object Technology is Putting Every Physical Thing on the Web. (2012). EvryThng Ltd.

[55]. X. Liu, Y. Hui, W. Sun, and H. Liang, "Towards service composition based on mashup," in Proc. of IEEE Service Computing, 2007, pp. 332– 339.

[56]. V. Hoyer, K. Stanoesvka-Slabeva, T. Janner, C. Schroth, "Enterprise mashups: Design principles towards the long tail of user needs," in Proc. of IEEE Services Computing, vol. 2, 2008, pp. 601-602.

[57]. D. Guinard, V. Trifa, T. Pham, O. Liechti, "Towards Physical Mashups in the Web of Things". Proc. of the 6th International Conference on Networked Sensing Systems (INSS), Pittsburgh, USA, 2009.

[58]. Kourtesis, D., Alvarez-Rodríguez, J. M., & Paraskakis, I. (2014). Semantic-based QoS management in cloud systems: Current status and future challenges. Future Generation Computer Systems, 32, 307-323.

[59]. Singh, D., Tripathi, G., & Jara, A. J. (2014, March). A survey of Internet-of-Things: Future vision, architecture, challenges and services. In Internet of Things (WF-IoT), 2014 IEEE World Forum on (pp. 287-292). IEEE.

[60]. Elgazzar, K., Hassanein, H. S., & Martin, P. (2014). DaaS: Cloud-based mobile Web service discovery. Pervasive and Mobile Computing, 13, 67-84.

[61]. Husain, Mohammad Farhan, et al. "Storage and retrieval of large rdf graph using hadoop and mapreduce." Cloud Computing. Springer Berlin Heidelberg, 2009. 680-686.

[62]. Huang, Jiewen, Daniel J. Abadi, and Kun Ren. (2011). "Scalable SPARQL querying of large RDF graphs". Proceedings of the VLDB Endowment 4.11: 1123-1134.

[63]. Husain, Mohammad, et al. (2011) "Heuristics-based query processing for large rdf graphs using cloud computing". Knowledge and Data Engineering, IEEE Transactions on 23.9: 1312-1327.

[64]. Sun, Jianling, and Qiang Jin. "Scalable rdf store based on hbase and mapreduce." Advanced Computer Theory and Engineering (ICACTE). (2010). 3rd International Conference on. Vol. 1. IEEE.

[65]. Weiss, Cathrin, Panagiotis Karras, and Abraham Bernstein. "Hexastore: sextuple indexing for semantic web data management". (2008). Proceedings of the VLDB Endowment 1.1: 1008-1019.

[66]. Um, Jung-Ho, et al. (2015). "MapReduce-based Bulk-Loading Algorithm for Fast Search for Billions of Triples". Computer Science and its Applications. Springer Berlin Heidelberg, 2015. 1139-1145.

[67]. Mori, Pravinsinh, A. R. Kazi, and Sandip Chauhan. (2015). "A Survey on an Efficient Query Processing and Analysis on Big Data (RDF) Using Map

Reduce". International Journal for Scientific Research and Development 1.7: 142-146.

[68]. Park, Seong-hun, Sung-min Kim, and Young-guk Ha. (2015). "Scalable visualization for DBpedia ontology analysis using Hadoop". Software: Practice and Experience.

[69]. Entezari, M., Cavanagh Jr, E. T., & Thompson, B. E. (2015). U.S. Patent No. 9,026,865. Washington, DC: U.S. Patent and Trademark Office.

[70]. Park, J. W., & Hahm, J. (2015). Container-based Cluster Management System for User-driven Distributed Computing. KIISE Transactions on Computing Practices, 21(9), 587-595.

2 RELATED RESEARCH WORK

2.1 Chapter Outline

This chapter presents the research work, which performed in the context of the dissertation with respect to the investigation of the existing related research activities and the legacy work on the field of the IoT. The main target of the dissertation deals with the design and the development of an innovative architecture for a Semantic Framework for abstraction of things and applications in the Future Internet. Consequently, the investigation performed in the context of the dissertation focused on research projects, isolated research activities, collaboration actions and existing technological solutions that deal with the tree main dissertation's concepts and their combinations, namely semantics and virtualization, cognitive management and cloud computing. Three different main categories have been identified and they are analyzed in the next sections. Essentially, this chapter constitutes an initialization field for the research activities of the dissertation, since it summarizes a wide range of research results. These results can be used as the initial point for the evolution and the development of innovative technological solutions for the Future Internet.

2.2 Introduction

The last decade, various research activities have been performed on the "Virtualization of Objects" by applying the Semantic Technologies for the contemporary IoT environments [1]-[3]. The majority of the research activities introduced the Semantics as the enabler for the interoperability among the heterogeneous IoT entities. Moreover, various research initiatives studied and continue the work on the introduction of cognition in the IoT, whereas studied the composition of semantics, cognitive and cloud computing technologies, aiming to enable Cloud-based IoT cognitive ecosystem for the Future Internet.

The IoT vision is coming to reality, involving several billions of diverse devices inter-connected, vast amounts of quickly-emerging/versatile data, and numerous services. Connected devices can be sensors, actuators, smart phones, computers, buildings and home/work appliances, cars and road infrastructure elements, and any other device or object that can be connected, monitored or actuated. Devices are connected to the Internet, as well as with each other, via heterogeneous access networks. Services aim at leading to a smart, sustainable and inclusive society and economy. The success of the IoT services can only be achieved if they are attributed with ubiquitous accessibility, reliability, high-performance, efficiency and scalability. Such features are enabled by the introduction of cognition in the contemporary IoT environments.

Furthermore, cloud features such as on-demand service provision, ubiquitous access, resource pooling, as well as elasticity are essential for the IoT world. For instance, resource pooling enhances the reliability and efficiency of service provision, the on-demand and elasticity features are fundamental for efficient and scalable service provision (resource provision where needed, for the amount of time needed), etc. The attributes needed by IoT services and the characteristics of Cloud systems clearly motivate the merging of the Cloud and IoT worlds. Moreover, the Future Internet systems and applications will be made up of numerous sophisticated, inter-connected components that will have to process, exchange and act on data from the physical, social and cyber worlds in real time in a greatly coordinated manner.

This chapter aims to provide the analysis of the research work relates to the Cloud IoT environments, addressing the different key features and trends as they are highlighted above, categorizing the scientific literature, that relates to dissertation's work, in three different enlarged research areas: a) "Semantic Abstraction and Virtualization of Thing in the Future Internet", b) "Cognitive Management of Virtual Things and Services in the Future Internet", and c) the "Cloud internet of Thing environments". These three areas are analyzed in details in the rest of this chapter.

2.3 Semantic Abstraction and Virtualization of Things in the Future Internet

This section presents the overview of the research works that focused on the introduction of the semantic-based virtualization in the IoT field, based on the current existing literature. In particular, they are presented the semantic standards on the semantic (data) modeling, the techniques and the technologies for the semantic data management, and the semantic abstraction of virtual IoT entities. The research work described in this section, is related to the dissertation's proposed architectural solutions for the "Semantic Abstraction and Virtualization of Things" and the "Semantic Storage System", that described in the sections 3.3.1 and 3.3.2.

More specifically, the last two decades there are investigated and identified various and diverse standards for the semantic modeling (Semantic Data Modelling Standards). The Open Geospatial Consortium (OGC) [4] provides a set of different semantic web standards that some of them have already been integrated with the World Wide Web Consortium – W3C (W3C Semantic Web technological standards) [5], aiming to the enhancement of the interoperability aspects in the Semantic Web [6]. Moreover, the above composition leads to the deployment of new integrated standards for the Semantic Web and by extension for the Future Internet. Such standards include the semantic modeling, description, representation, as well as the semantic data management in the Future Internet [6][7]. This data may be associated with things, object, services, applications, locations, persons, network and Internet infrastructures, as well as with any other entity that is or may be part of the Future Internet. Specifically, in the field that includes services, applications and objects they are included the following indicative models: Catalog Service for the Web (CSW) [8], Observations and Measurements (O&M) [9], SensorML [10], Sensor Observation Service (SOS) [11], TransducerML (TML) [12], Web Processing Service (WPS) [13], Web Registry Service (WRS) [14], IoT-A Entity Model [15], IoT-A Resource Model [15], IoT-A Service Model [15]. Furthermore, various standards have been defined for the space, location and Geospatial modeling, such as the Geography Mark-up Language (GML) [16], CityGML [17], Geographically Encoded Objects for RSS feeds (GeoRSS) [18], Geographic Query Language for RDF Data (GeoSPARQL) [19], WaterML [20].

The semantic web includes a wide range of innovative technological solutions and tools that support the semantic data management in terms of the data store, query, modification (update/delete). In particular, such technological solutions and tools allow the end-user/developers to create semantic repositories, to create and deploy vocabularies, as well as enable the design of rules and principles for the semantic data management manipulation. Taking into account the W3C [21] approach, the Semantic Web technologies and tools can be classified in the following categories: a) Linked Data [22]-[24], b) Vocabularies/Ontologies [25]-[29], c) Semantic Data Reasoning and Inference [30]-[33] and d) Semantic Data Management that includes the store of data, the search and discovery of data and the data modification (update/delete) [34]-[43]. The core part of the semantic technologies that are included in the above categories are the Resource Description Framework (RDF) [28], RDF Schema (RDFS) [29], Web Ontology Language (OWL) [27], SPARQL query language [35], RDF Stores / Triple Stores [36], as well as semantic data inference languages such as the Prolog Reasoning Language [33].

There are also various research IoT projects that focus on the semantic abstraction and interoperability of real world objects and/or IoT entities. Specifically, the EBBITS platform [44] aims to provide semantic resolution to the IoT and thus present a new bridge between backend enterprise applications, people, services and the physical world. Another example is the SPITFIRE (Semantic-Service Provisioning for the Internet of Things using Future Internet Research by Experimentation) project [45] which aims to investigate unified concepts, methods, and software infrastructures that facilitate the efficient development of applications that span and integrate the Internet and the embedded world. The mission of the SOFIA project [46] is to create a semantic interoperability platform for new services which enables and maintains cross-industry interoperability. The SENSEI project [47] focused partly on semantic specification to unify the access to context information and actuation services and relies on real world objects. The DIEM (Devices and Interoperability Ecosystems) [48] project which focuses on smart environments where interoperable devices and services provide new kinds of information ecosystems. A key topic in DIEM is semantic interoperability between devices from different domains. The OPUTE (Open Ubiquitous Technologies) project [49] develops and shows semantic interoperability between embedded systems with capabilities ranging from simple passive RFID tags through active tags to complex consumer products and appliances with embedded processing and mobile personal devices. The [50] aims to introduce a particular description language that will be used for the description, as well as for the interoperability among the IoT heterogeneous objects. The work in [51] studies the concept of the "Virtual Sensor Networks" (VSN) as the enabler for the deployment of IoT systems. Specifically, the VSN is able to manage the collaboration among different virtual sensors for the deployment of collaborative computing processes over the VSN. The [52] proposes a framework for the virtualization in the IoT, having as core concept the "sensor-as-a-service". This framework presents the interconnection among heterogeneous IoT devices, by implementing them as Web Services.

2.4 Cognitive Management of Virtual Things and Services in the Future Internet

There are numerous research activities and research projects that have been performed towards the exploitation of semantics aiming in the same time to the introduction of intelligent and/or cognitive capabilities in the IoT. The research work described in this section, is related to the dissertation's proposed architectural solutions for the "Cognitive management and Composition of Virtual Things" and the "Cognitive Management of Services", that described in the sections 3.3.3 and 3.3.4.

Cognitive wireless systems emerged as a solution towards addressing the complexity in emerging and future composite radio networks [53]. Numerous research efforts in radio communication have focused on cognitive technologies for the efficient management of resources and components in future networks. The work carried out in the scope of [54], aims at overcoming the growing management complexity of future networking systems, and to reduce the barriers that complexity and ossification pose to further growth. To this end, a Unified Management Framework is proposed for the federation of different existing and emerging architectures and all the required functions to achieve self-management. The iCore project [55] worked towards the development of a cognitive IoT ecosystems composed of reconfigurable virtual objects. The main concepts of iCore project focused on the design and the development of a cognitive management framework for the IoT that would be able to allow the cognitive creation and provisioning of composite services based on end-user requirements. The BUTLER project [56] constituted one of the core IoT projects that introduced the concept of the smart objects. The BUTLER's smart objects are intelligent/cognitive modules that abstract the functional capabilities of the real world devices and allow they management for the provision of integrated functional capabilities and IoT applications. The Internet of Things Architecture (IoT-A) [57] project introduces semantic description data models for the IoT entities [58] including the IoT-A Domain Model and the IoT-A Information Model. These models define associations among objects and features/attributes and embed meta-data properties for the description of the objects. Further to that, the project introduces and combines the concepts "Object" and "Entity" in order to design and propose a well-defined meta-data structured description models for the devices and/or the available entities in the device level as it is defined in the IoT-A architecture. The IoT-I [59] introduces the concept of "IoT Device" that refers to the entity that is used for the bridging between an entity in the real-world with an entity in the virtual world. For this purpose the IoT-I presents a device-centric reference model that includes device features and properties associated with each other. The [60] presents the concept of the "virtual sensor" to hide the technological complexity from the end-user, including a wide range of heterogeneous devices, such as smart phones and sensors. Many different research activities such as the [60] focus on the "virtualization" of the real-world devices. The authors in the [61] and [62] describe their efforts towards the enhancement of the object with "smart functionalities" in order to achieve their interconnection. The researchers in [63] present a cognitive management framework for the IoT that is formed of three different levels of functionality that can be reused for various and diverse applications. More specifically, the levels under consideration are the Service Level, CVO Level and VO Level. Cognitive entities at all levels provide the means for self-management (configuration, healing, optimization, protection) and learning. In this respect, they are capable of perceiving and reasoning on context (e.g. based on event filtering, pattern recognition, machine learning), of conducting associated knowledge-based decision-making (through associated optimization algorithms and machine learning), and autonomously adapting their behaviour and their configuration according to the derived situation. The researchers in [64] aim to the achievement of the cognitive management of the available devices in the wireless world, having the user in the center of the processes. In particular, authors aim to enable of the cognitive management of the devices based on user context and related information. For the achievement of high-accuracy results and the introduction of intelligent capabilities, the authors propose the use of Bayesian statistics for learning user preferences that in turn are applied for the device management. The Versatile Digital Item (VDI) [65], a generic format for the data structuring, supports the information sharing among virtual and real entities, assisting the approach of publish-subscribe model, as it is presented in [66]. Furthermore, the work in [67] introduces the term of Active Digital Identities (ADI) in order to realize the concept of Web of Things. The ADI uniquely represents a physical item by using URL as for Web Objects. A number of initiatives and projects have addressed the concept of "mash-ups" in the scope of user generated composite applications [68]-[70]. Initially ([68][69]) the focus has been only on on-line services not looking into issues and requirements related to the integration of physical world objects and functionalities. The use of mash-ups for the integration with the physical world is addressed in [70]-[73]. In [74] the Web of Things vision is introduced by proposing a platform which tries to add, use, share and interconnect smart objects and services.

2.5 Cloud Internet of Thing environments

As it is already introduced in the two previous sections, there are many research activities that have focused on the virtualization and the cognitive management of the IoT entities and services. The research work described in this section, is related to the dissertation's proposed architectural development as a distributed Cloud-IoT system that allows the federation of functional capabilities that are provided by the proposed architectural modules, such as the semantic storage system. The deployment of the semantic framework on the Cloud is described in the section 3.3.5.

Numerous research activities have been realized towards the direction of the semantic technologies composition with Cloud Computing technologies for the design and deployment of high-performance systems. The composition of these technologies may refer to the deployment of different use cases. This dissertation studies the IoT Cloud convergence, and particularly focuses on the following core concepts: a) IoT Cloud convergence and Cloud-IoT architectures ([79]-[92]) b) Semantic-based technological solutions for the deployment of Cloud Services ([93]-[109]) and c) large-scale semantic data management ([110]-[118]).

Introducing the semantics, the virtualization and the cognition in the IoT ecosystems, empower the IoT in order to be able to ideally support challenges that require the combination of existing heterogeneous Information and Communication Technologies (ICT) solutions, so as to provide interoperable, innovative and more efficient composite services to the contemporary IoT environments. There are various fundamental technologies, such as RFID [75], NFC [76], and Wireless Sensor Networks (WSN) [77], which have been introduced and used in various domains so as to realize the IoT [78]. However, the provisioning of decentralized services in the IoT, as well as the integration of innovative IoT platforms, requires ubiquity, reliability, high-performance, efficiency, and scalability. For the accomplishment of the above requirements, the contemporary technological trends leaded to the IoT and Cloud convergence, with federated / multi-Cloud architectures. Many research activities, such as [79]-[83], focus on the provision of infrastructures with cognitive self-x (configuration, optimization, healing) capabilities, introducing in the same time cognitive communication technologies to ensure interactions and facilitate information exchange. Furthermore, numerous research projects and initiatives such as the [84]-[92], focus on the realization of innovative architectures for the Cloud-IoT, enabling innovative features such as the autonomous service provisioning and management in multi-Cloud environments [92]. Particular interest presents the introduction of cloud capabilities for the management of large-scale semantic data. The last concept is in an initiative state with continuous evolution.

The research work in [93] presents the deployment of a design model for the introduction of semantic-based services in cloud environments. The model is named Cloud-based design manufacturing (CBDM). In order to develop the CBDM, the authors initially identified the common deployment features and then selected these features that should be satisfied by the CBDM system. Then compare the model with existing models and validated its operation through an integrated application scenario. With the Cloud manufacturing (CMfg) concept, deals the work in [94] by presenting it as an innovative service-oriented model for the manufacturing in the industry. The introduction of the CMfg model changes the industrial processes, throught the orchestration of the production activities as "virtual service" that are provided to the end-users. In order to achieve the expecting result, it is required the introduction of the semantic technologies for the semantic modeling and description of the different processes. Specifically, it is designed the ontology GCMT for the semantic description of functional processes, combined with appropriate description models and semantic similarity algorithms. The [95] focuses on the Cloud-based Mobile Augmentation (CMA) approaches. The main research activities include the detailed investigation of the existing solution, as well as the composition of these solutions for the deployment of an innovative system that will support the resource-intensive mobile applications. Further to that, the CMA field introduces requirements for the use of taxonomies, semantics and augmentation concepts that re associated with the semantic web technologies field. The virtualization of the "Information Technology" (IT) services constitutes the main research concepts in the [96]. Specifically, it is performed the study of the concept for the provision of Cloud capabilities as Cloud-based IT Services on-demand. The authors study four different use cases: a) discovery, b) negotiation, c) composition and d) consumption. In the same direction is oriented the work in [97], by proposing a methodology for the deployment of Internet-based services through the application of the Service Oriented Architecture (SoA) principles. However, this approach is applied on Internet-based services and it cannot be extended to virtualized environments to allow the "on-demand" deployment of services. The authors in [98] deal with the modelling of reconfigurable services and the decision making for the dynamic creation of composite services. They introduced an advanced process for the decision making that supports the dynamic composition of services, considering the QoS indicator that characterize each available service. The [99] presents the GoodRelations ontology that has been implemented for the semantic description of the e-Commerce products. While this ontology is relevant for the description of a Cloud-based service it presents a lack of capability for the description of composite services that are provided by multiple providers. In the [100] it is proposed a technique for the composition of semantic services, whereas in the [101]-[106] research activities it is investigated the application of the Grid computing approach with respect to the addressing of requirements that relate to the "on-demand" prediction, discovery and composition of services. The research results of the studies on the Grid computing can be applied mainly for the Cloud-based services. The research work that is presented in the [107] studies the QoS concept for the SoA-based Cloud infrastructures, introducing the semantics. Specifically, the authors investigate Big Data related concepts and proposes the deployment of a Lambda Architecture that is based on Semantics and Big Data. In [108] it is presented the development of an innovative architectural models for the IoT that is based on the semantic technologies and the cloud computing. Specifically the model is named Semantic Fusion Model (SFM) and its main aim is the deployment of a framework for the WSN data processing. The system includes "semantic logic" and semantic-based information that make it intelligent. The research team in [109] investigates the different requirements in the Web-based mobile services environments that present high-complexity due to the heterogeneity of the devices and the networks. In particular, the researchers propose a Discovery-as-a-Service (DaaS) approach for the discovery of Web services. The DaaS includes in the discovery parameters, the user preferences and contextual parameters in order to achieve the best possible discovery results.

The researchers in [110] present an approach with respect to the improvement of the store and the processing of large-scale data in the semantic web. The authors describe the deployment of a framework that is based on Hadoop that uses the Hadoop Distributed File System (HDFS) data management mechanisms. In additions, they have implemented a SPARQL mechanism that uses the Hadoop MapReduce framework so as to serve the SPARQL queries. In the same direction has worked the research activity in [111] that the authors describe the problem of the rapid increase of semantic data amounts and present a management system for RDF data, as the potential solution. This system introduces three different RDF data management techniques: a) leveraging state-of-the-art single node RDF-store technology, b) partitioning the data across nodes in a manner that helps accelerate query processing through locality optimizations and c) decomposing SPARQL queries into high performance fragments that take advantage of how data is partitioned in a cluster. The [112] investigates the management of large-scale RDF Graphs, proposing a Hadoop-based framework that will support functions for the store and the retrieval of the RDF data. In [113] it is presented the Hbase application [114] for the data storage and the MapReduce techniques for the deployment of a large-scale semantic data storage system. This technique is based on the Hexastore [115] application, combined with the RDF data modeling complemented with HBase storage system capabilities. In particular, RDF triples are stored in six different HBase tables (S_PO, P_SO, O_SP, PS_O, SO_P and PO_S) that cover all the potential combination of triples storing and use as index key the column of each table. In addition, it is used the SPARQL Basic Graph Pattern (BGP) technique for the performance of the queries towards the available tables. An innovative MapReduce algorithm for the fast search and discovery of data over large-scale RDF Graphs, is presented in [116]. The authors in [117] present a detailed survey on the performance of complex queries over semantic data using MapReduce algorithms. It is presented techniques for the application of query patterns over the semantic data, as well as techniques for the prototyping of the MapReduce algorithms that will take over the execution of the queries. The [118] deals with the visualization of large-scale semantic data so as to enable the processing of data with different available tools. The authors propose the development of a Hadoop-based data processing system that is comprised by three different parts: a) a data server to analyze ontological data, b) a visualization server to visualize the result of data analysis, and c) user applications to provide users with the visualized data. Based on the research conclusions the proposed system is scalable and it can be used for the processing of large-scale ontological data.

2.6 Chapter References

[1].FIA Website. (2016). [Online]: http://www.future-internet.eu/.

[2].IERC Website. (2016). [Online]: http://www.internet-of-things-research.eu/.

[3].IoT-I Website. (2016). [Online]: http://www.iot-i.eu/.

[4].Open Geospatial Consortium (OGC). (2016). [Online]: http://www.opengeospatial.org/.

[5].World Wide Web Consortium (W3C). (2016). [Online]: http://www.w3.org/ .

[6].W3C and OGC to Collaborate to Integrate Spatial Data on the Web. (2016). [Online]: http://www.opengeospatial.org/pressroom/pressreleases/2149.

[7].Standards - W3C. (2016). [Online]: www.w3.org/standards/.

[8].Catalogue Service. (2016). [Online]: http://www.opengeospatial.org/standards/cat.

[9].Observations and Measurements. (2016). [Online]: http://www.opengeospatial.org/standards/om.

[10]. SensorML. (2016). [Online]: http://www.ogcnetwork.net/SensorML.

[11]. Sensor Observation Service. (2016). [Online]: http://www.opengeospatial.org/standards/sos.

[12]. Transducer Markup Language (TML). (2016). [Online]: http://www.ogcnetwork.net/infomodels/tml.

[13]. Web Processing Service. (2016). [Online]: http://www.opengeospatial.org/standards/wps.

[14]. Web Registry Service Research Document. (2016). [Online]: http://udig.refractions.net/files/docs/WRS.pdf.

[15]. De, Suparna, et al. (2011). "Service modelling for the Internet of Things". Computer Science and Information Systems (FedCSIS), 2011 Federated Conference on. IEEE.

[16]. Geography Markup Language (GML). (2016). [Online]: http://www.opengeospatial.org/standards/gml.

[17]. CityGML. (2016). [Online]: http://www.opengeospatial.org/standards/citygml.

[18]. GeoRSS :: Geographically Encoded Objects for RSS feeds. (2016). [Online]: http://www.georss.org/.

[19]. GeoSPARQL - A Geographic Query Language for RDF Data. (2016). [Online]: http://www.opengeospatial.org/standards/geosparql.

[20]. OGC® WaterML. (2016). [Online]: http://www.opengeospatial.org/standards/waterml.

[21]. W3C Semantic Web. (2016). [Online]: http://www.w3.org/standards/semanticweb/.

[22]. W3C Standards, Semantic Web, Linked Data. (2016). [Online]: http://www.w3.org/standards/semanticweb/data.

[23]. Linked Data - Connect Distributed Data across the Web. (2016). [Online]: http://linkeddata.org/.

[24]. The Linking Open Data cloud diagram. [Online] http://lod-cloud.net/.

[25]. W3C Standards, Semantic Web, Vocabularies. (2016). [Online]: http://www.w3.org/standards/semanticweb/ontology.

[26]. OWL Web Ontology Language Overview. (2016). [Online]: http://www.w3.org/TR/owl-features/.

[27]. OWL WEB ONTOLOGY LANGUAGE CURRENT STATUS. (2016). [Online]: http://www.w3.org/standards/techs/owl#w3c_all.

[28]. RDF Vocabulary Description Language 1.0: RDF Schema (RDFS). (2016). [Online]: http://www.w3.org/TR/rdf-schema/.

[29]. RDF Schema 1.1. (2016). [Online]: https://www.w3.org/2001/sw/wiki/RDFS.

[30]. W3C Standards, Semantic Web, Inference. (2016). [Online]: http://www.w3.org/standards/semanticweb/inference.

[31]. W3C Uncertainty Reasoning for the World Wide Web Incubator Group. (2016). [Online]: http://www.w3.org/2005/Incubator/urw3/.

[32]. RIF RULE INTERCHANGE FORMAT CURRENT STATUS. (2016). [Online]: http://www.w3.org/standards/techs/rif#w3c_all.

[33]. SWI Prolog. [Online] http://www.swi-prolog.org/.

[34]. W3C Semantic Web - Resource Description Framework (RDF). (2016). [Online]: http://www.w3.org/RDF/.

[35]. SPARQL Query Language for RDF. (2016). [Online]: http://www.w3.org/TR/rdf-sparql-query/.

[36]. W3C WiKi - LargeTripleStores. (2016). [Online]: http://www.w3.org/wiki/LargeTripleStores.

[37]. Franz Inc. AllegroGraph. (2016). [Online]: http://franz.com/agraph/allegrograph/.

[38]. OpenLink Software - Virtuoso Server. [Online] http://virtuoso.openlinksw.com/.

[39]. Information Systems Group - RDFox. (2016). [Online]: http://www.cs.ox.ac.uk/isg/tools/RDFox/.

[40]. openRDF Sesame Framework. (2016). [Online]: http://rdf4j.org/.

[41]. Apache Jena Fuseki - Fuseki: serving RDF data over HTTP. (2016). [Online]: http://jena.apache.org/documentation/serving_data/.

[42]. Systap - Blazegraph. (2016). [Online]: http://www.blazegraph.com/.

[43]. Jena Ontology API. (2016). [Online]: https://jena.apache.org/documentation/ontology/.

[44]. EBBITS project Website. (2016). [Online]: http://www.ebbits-project.eu/.

[45]. SPITFIRE project Website. (2016). [Online]: http://spitfire-project.eu/.

[46]. SOFIA project Website. (2016). [Online]: http://www.sofia-project.eu/.

[47]. SENSEI project Website. (2016). [Online]: http://www.sensei-project.eu/.

[48]. DIEM project Website. (2016). [Online]: http://www.cs.tut.fi/ihte/projects/DIEM/index.html.

[49]. OPUTE (Open Ubiquitous Technologies) project information, http://www.tekes.fi/programmes/Ubicom/Projects?id=9822957.

[50]. Zhang L., Mitton N. (2011). "Advanced Internet of Things", Université des Sciences et Technologies de Lille, France. iThings-2011.

[51]. Lambros Sarakis, Theodore Zahariadis, Helen-Catherine Leligou, Mischa Dohler. (2012). "A Framework for Service Provisioning in Virtual Sensor Networks", Eurasip Journal on Wireless Communications and Networking.

[52]. S. Alam, Mohammad M. R. Chowdhury, J. Noll, "SenaaS:An Event-driven Sensor Virtualization approach for Internet of Things Cloud", Networked Embedded Systems for Enterprise Applications(NESEA). (2010) IEEE International Conference.

[53]. J. Mitola J. (2000), "Cognitive radio: An integrated agent architecture for software defined radio", Ph.D. dissertation. Royal Institute of Technology (KTH), Stockholm, Sweden.

[54]. K. Tsagkaris, P. Vlacheas, A. Bantouna, P. Demestichas, G. Nguengang , M. Bouet , L. Ciavaglia , P. Peloso, I. Grida Ben Yahia, C. Destre (2011), "Operator-driven Framework for Establishing and Unifying Autonomic Network and Service Management Solutions", GLOBECOM Workshops (GC Wkshps).

[55]. FP7/ICT project iCore (Internet Connected Objects for Reconfigurable Eco-systems, ICT-287708), Oct. 2011 – Sept. 2014, Website: http://www.iot-icore.eu.

[56]. BUTLER FP7 EU Project. (2014). Duration: 2011-2014. Grant Agreement No. 287901. [Online]: http://www.iot-butler.eu/.

[57]. Internet of Things Architecture (IoT-A) EU Project Website. (2016). [Online]: http://www.iot-a.eu/.

[58]. EU/FP7 project IoT-A (The Internet-of-Things Architecture – IoT-A, 257521), Sep. 2010 – Aug. 2013, Deliverable 1.2 (D1.2), "Initial Architectural Reference Model for IoT.

[59]. EU/FP7 project IoT-i (Internet-of-Things Initiative – IoT-i, 257565), Sep. 2010 – Aug. 2012, Deliverable 1.2 (D1.2), "Final Reference Model".

[60]. Aberer, K., Hauswirth, M., Salehi, A. (2007). Infrastructure for Data Processing in Large-Scale Interconnected Sensor Networks. In: Proceedings of the International Conference on Mobile Data Management (MDM '07), 198-205.

[61]. Mattern, F. (2003). From Smart Devices to Smart Everyday Objects. In: Proceedings of the Smart Objects Conference (SOC 03), 15–16.

[62]. Beigl, M., Gellersen, H.-W. (2001). Schmidt, A.: MediaCups: Experience with Design and Use of Computer-Augmented Everyday Objects. J. Computer Networks 35(4), 401–409.

[63]. G. Baldini, R.R.V. P Prasad, A.R. Biswas, K. Moessner, M. Etelapera, J.P. Soininen, S.C.Nechifor, V.Stavroulaki , P. Vlacheas, "A Cognitive Management Framework to Support Exploitation Of the Future Internet Of Things", Scalable Computing: Practice and Experience (SCPE), Vol. 13(2), 2012, pp. 139–147.

[64]. V. Stavroulaki, N. Koutsouris, Y. Kritikou, P. Demestichas, "Cognitive Management of Devices in the Wireless World", in Wireless Personal Communications, Springer, October 2013, pp: 1-34, doi: 10.1007/s11277-013-1468-2.

[65]. Melazzi N. B. (2010). "CONVERGENCE: Extending the Media Concept to Include Representations on Real World Objects", The Internet of Things: 20th Tyrrhenian Workshop on Digital Communications, 129-140.

[66]. FP7/ICT- 257123 project CONVERGENCE, Jun. 2010 - Feb. 2013, Website, http://www.ict-convergence.eu/.

[67]. Every Thing Connected: How Web Object Technology is Putting Every Physical Thing on the Web. (2012). EvryThng Ltd.

[68]. X. Liu, Y. Hui, W. Sun, and H. Liang, "Towards service composition based on mashup," in Proc. of IEEE Service Computing, 2007, pp. 332– 339.

[69]. V. Hoyer, K. Stanoesvka-Slabeva, T. Janner, C. Schroth, "Enterprise mashups: Design principles towards the long tail of user needs," in Proc. of IEEE Services Computing, vol. 2, 2008, pp. 601-602.

[70]. D. Guinard, V. Trifa, T. Pham, O. Liechti, "Towards Physical Mashups in the Web of Things". Proc. of the 6th International Conference on Networked Sensing Systems (INSS), Pittsburgh, USA, 2009.

[71]. M. Marin-Perianu, N. Meratnia, P. Havinga, L. de Souza, J. Muller, P. Spiess, S. Haller, T. Riedel, C. Decker, G. Stromberg, "Decentralized enterprise systems: a multiplatform wireless sensor network approach," IEEE Wireless Communications, 2007.

[72]. L. M. S. de Souza, P. Spiess, D. Guinard, M. Koehler, S. Karnouskos, D. Savio, "Socrades: A web service based shop floor integration infrastructure," in Proc. of the Internet of Things Conference (IOT 2008), Springer, 2008.

[73]. P. Liuha, A. Lappeteläinen, J-P, Soininen, "Smart Objects for Intelligent Applications - first results made open", ARTEMIS Magazine, October 2009, No. 5, pp. 27-29..

[74]. A. Pintus, D. Carboni, A. Piras. (2012) "Paraimpu:a Platform for a Social Web of Things", WWW, Lyon, France.

[75]. Bonde, M. J., & Rane, K. P. (2014). Radio Frequency Identification (RFID) Mis-placed Objects. International Journal of Electronic and Electrical Engineering, 7(7), 657-662

[76]. Near Field Communication (NFC). [Online]: http://www.nearfieldcommunication.org/.

[77]. Yang, K. (2014). Wireless sensor networks. Principles, Design and Applications.

[78]. Want, R., Schilit, B. N., & Jenson, S. (2015). Enabling the Internet of Things. Computer, (1), 28-35.

[79]. P. Vlacheas, et al. (2013). "Enabling smart cities through a cognitive management framework for the Internet of Things". IEEE Communications Magazine, vol.51, no.6, Journal Papers.

[80]. V. Foteinos et al, (2014). "A Cognitive Management Framework for Enabling Autonomous Applications in the Internet of Things", IEEE Vehicular Technology Magazine.

[81]. Zanella, A., et al. (2014). Internet of things for smart cities. Internet of Things Journal, IEEE, 1(1), 22-32.

[82]. Jin, J., et al. (2014). An information framework for creating a smart city through Internet of things. Internet of Things Journal, IEEE, 1(2), 112-121.

[83]. Misra, P., Rajaraman et al. (2015). An Interoperable Realization of Smart Cities with Plug and Play based Device Management. arXiv preprint arXiv:1503.00923.

[84]. Cloud-of-Things - (ClouT) Project. Call: FP7-ICT-2013- EU-Japan. Type: STREP. Duration: 3 years (started on 01 April 2015). Web site: http://clout-project.eu.

[85]. MUlti-cloud Secure Applications (MUSA) Project. Call: H2020-ICT-2014-1. Topic: ICT-07-2014, Type: RIA, Duration: 3 years (started on 1st Jan, 2015), Web site: http://www.musa-project.eu.

[86]. In-network programmability for next-generation personal cloud service sup-port(INPUT) Project. Call: H2020-ICT-2014-1, Topic: ICT-07-2014, Type: RIA, Duration: 3 years (started on 01/01, 2015), Web site: http://input-project.eu.

[87]. SPECS: Secure Provisioning of Cloud Services based on SLA Management. Call: FP7-ICT-2013-1, Topic: Trustworthy ICT, Type: STREP, Duration: 2,5 years (started on 1/11/2013), Web site: http://www.specs-project.eu.

[88]. SOCIOTAL: Creating a socially aware and citizen-centric Internet of Things. Project reference: 609112. Funded under: FP7-ICT. From 2013-09-01 to 2016-08-31. Web site: http://sociotal.eu/.

[89]. COSMOS: Cultivate resilient smart objects for sustainable city applications. Project reference: 609043. Funded under: FP7-ICT. From 2013-09-01 to 2016-08-31. Web site: http://iot-cosmos.eu/.

[90]. SMARTIE: Secure and smarter cities data management. Project reference: 609062. Funded under: FP7-ICT. From 2013-09-01 to 2016-08-31. Web site: http://www.smartie-project.eu/.

[91]. FIESTA: Federated Interoperable Semantic IoT/cloud Testbeds and Applications. Project reference: 643943. Funded under: H2020-EU.2.1.1.3. From 2015-02-01 to 2018-02-01, ongoing project. Web site: http://www.fiesta-iot.eu/.

[92]. Intelligent Knowledge-as-a-Service (iKaaS) Project. Call: H2020-EUJ-2014. Topic: EUJ-1-2014. Type: R&I. Duration: 3 years (started on 1 October, 2014). Web site: http://www.ikaas.com.

[93]. Wu, D., Rosen, D. W., Wang, L., & Schaefer, D. (2015). Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation. Computer-Aided Design, 59, 1-14.

[94]. Wang, T., Guo, S., & Lee, C. G. (2014). Manufacturing task semantic modeling and description in cloud manufacturing system. The International Journal of Advanced Manufacturing Technology, 71(9-12), 2017-2031.

[95]. Abolfazli, S., Sanaei, Z., Ahmed, E., Gani, A., & Buyya, R. (2014). Cloud-based augmentation for mobile devices: motivation, taxonomies, and open challenges. Communications Surveys & Tutorials, IEEE, 16(1), 337-368.

[96]. Joshi, K. P., Yesha, Y., & Finin, T. (2014). Automating cloud services life cycle through semantic technologies. Services Computing, IEEE Transactions on, 7(1), 109-122.

[97]. Verlaine, B., Jureta, I., & Faulkner, S. (2015). Towards the Alignment of a Detailed Service-Oriented Design and Development Methodology with ITIL v. 3. In Exploring Services Science (pp. 123-138). Springer International Publishing.

[98]. Ma, H., Bastani, F., Yen, I. L., & Mei, H. (2013). QoS-driven service composition with reconfigurable services. Services Computing, IEEE Transactions on, 6(1), 20-34.

[99]. M. Hepp , GoodRelations: An Ontology for Describing Products and Services Offers on the Web, Proceedings of the 16th International Conference

on Knowledge Engineering and Knowledge Management (EKAW2008). (2008). Italy, Springer LNCS, Vol 5268, pp. 332-347

[100]. K. Ren, N. Xiao, J. Chen, "Building Quick Service Query List Using WordNet and Multiple Heterogeneous Ontologies toward More Realistic Service Composition". (2011). IEEE Transactions on Services Computing, vol. 4, no. 3, pp. 216-229.

[101]. D. De Roure et. al., The Semantic Grid: Past, Present, and Future. (2005). Proceedings of the IEEE, vol. 93, No. 3.

[102]. T Dornemann, E Juhnke, B Freisleben. (2009). On-Demand Resource Provisioning for BPEL Workflows Using Amazon's Elastic Compute Cloud, proc. of CCGrid.

[103]. Quan Z. Sheng, et al, , Configurable Composition and Adaptive

[104]. Provisioning of Web Services. (2009). IEEE Transactions on Services Computing, Vol. 2, No. 1.

[105]. Mike Boniface, et al. (2007). Dynamic Service Provisioning Using GRIA SLAs Service-Oriented Computing - ICSOC.

[106]. Ana Juan Ferrer, et al, (2011). OPTIMIS: A holistic approach to cloud service provisioning, FGCS.

[107]. Kourtesis, D., Alvarez-Rodríguez, J. M., & Paraskakis, I. (2014). Semantic-based QoS management in cloud systems: Current status and future challenges. Future Generation Computer Systems, 32, 307-323.

[108]. Singh, D., Tripathi, G., & Jara, A. J. (2014, March). A survey of Internet-of-Things: Future vision, architecture, challenges and services. In Internet of Things (WF-IoT), 2014 IEEE World Forum on (pp. 287-292). IEEE.

[109]. Elgazzar, K., Hassanein, H. S., & Martin, P. (2014). DaaS: Cloud-based mobile Web service discovery. Pervasive and Mobile Computing, 13, 67-84.

[110]. Husain, Mohammad Farhan, et al. "Storage and retrieval of large rdf graph using hadoop and mapreduce." Cloud Computing. Springer Berlin Heidelberg, 2009. 680-686.

[111]. Huang, Jiewen, Daniel J. Abadi, and Kun Ren. (2011). "Scalable SPARQL querying of large RDF graphs". Proceedings of the VLDB Endowment 4.11: 1123-1134.

[112]. Husain, Mohammad, et al. (2011) "Heuristics-based query processing for large rdf graphs using cloud computing". Knowledge and Data Engineering, IEEE Transactions on 23.9: 1312-1327.

[113]. Sun, Jianling, and Qiang Jin. "Scalable rdf store based on hbase and mapreduce." Advanced Computer Theory and Engineering (ICACTE). (2010). 3rd International Conference on. Vol. 1. IEEE.

[114]. Apache Hbase. (2016) [Online]: http://hbase.apache.org/.

[115]. Weiss, Cathrin, Panagiotis Karras, and Abraham Bernstein. "Hexastore: sextuple indexing for semantic web data management". (2008). Proceedings of the VLDB Endowment 1.1: 1008-1019.

[116]. Um, Jung-Ho, et al. (2015). "MapReduce-based Bulk-Loading Algorithm for Fast Search for Billions of Triples". Computer Science and its Applications. Springer Berlin Heidelberg, 2015. 1139-1145.

[117]. Mori, Pravinsinh, A. R. Kazi, and Sandip Chauhan. (2015). "A Survey on an Efficient Query Processing and Analysis on Big Data (RDF) Using Map Reduce". International Journal for Scientific Research and Development 1.7: 142-146.

[118]. Park, Seong-hun, Sung-min Kim, and Young-guk Ha. (2015). "Scalable visualization for DBpedia ontology analysis using Hadoop". Software: Practice and Experience.

3 SEMANTIC FRAMEWORK FOR THE FUTURE INTERNET

3.1 Chapter Outline

The technological heterogeneity, of the wide variety of the things (aka ICT and non-ICT objects) and the applications, requires the abstraction of the processes through the design and the deployment of innovative technological solutions for the virtualization of the hardware and software infrastructures. The introduction of Semantic Web Technologies in collaboration with virtualization techniques and Cloud technologies constitutes a promising vision that will ensure the interconnectivity and the seamless interoperability of heterogeneous IoT entities for the provision of reliable complex services and applications for the IoT. Towards this direction, this chapter presents the main aim of this dissertation that deals with the design and the development of a Semantic Framework for the abstraction of things and application for the Future Internet. The framework will combine semantic, virtualization and Cloud technologies for the deployment of high-performance and scalable technological solutions that will allow the realization of the things and applications abstraction in different and diverse IoT application domains.

3.2 Introduction

One of the main targets of this dissertation lies on the design and the development of a Semantic Framework for the Future Internet, with particular focus on the IoT. Furthermore, the exploitation of the Cloud technologies will enable the deployment of a high-performance, scalable cloud-based semantic infrastructure, considering the low-energy cost of the framework processes.

During the preparation of the dissertation were performed advanced studies and research activities, including the design, the implementation and the validation of different mechanisms of the Semantic Framework. In these research works it was considered the introduction and the (re-)use of different Semantic Data Models in various use cases, such as the research works in [1]-[8]. Moreover, the research activities, in the context of the dissertation, focused on the composition between the research results from the semantics, virtualization and cognition with technologies and evaluated research results from the Cloud Computing field ([9]-[19]). Considering the above studies and the research work, this dissertation proposes the deployment of the semantic framework architecture for the Cloud-IoT that is depicted in Figure 1.

The next sections present in details the proposed architecture, focusing on each particular architectural building block. The different architectural building blocks deal with a particular range of processes that are combined in a collaborative context, by providing the set of the semantic framework operations.

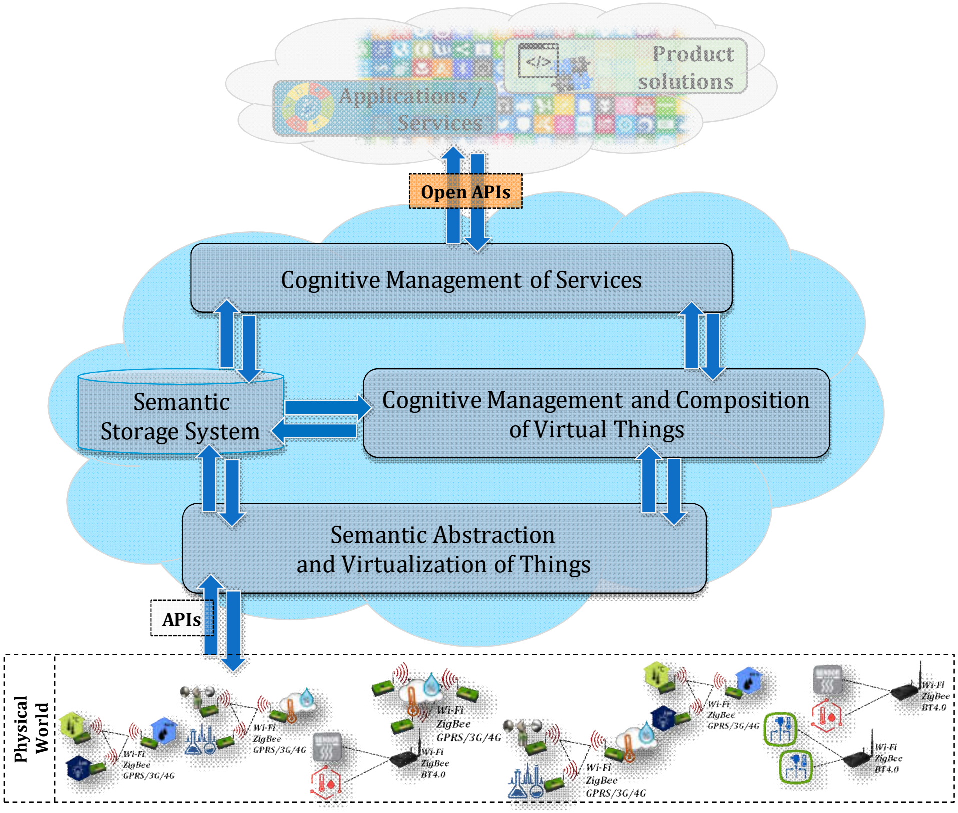


Figure 1: High-level overview of the Semantic Framework Cloud-based architecture for the Future Internet [10]

3.3 Semantic Framework Architecture Overview

The proposed architecture for the Semantic Framework (Figure 1) is comprised by the following architectural building blocks: a) "Semantic Abstraction and Virtualization of Things", b) "Semantic Storage System", c) "Cognitive Management and Composition of Virtual Things" and d) "Cognitive Management of Services". The Semantic Framework has been designed so as to allow the distribution and the scalability of its mechanisms, by adopting the architectural principles of the Cloud Computing. Consequently, the dissertation proposes a Cloud-based Semantic Framework the functionality of which will be based cloud technologies, such as the OpenStack [20] and Docker [21].

Further to the above, Open Application Programming Interfaces (APIs) will be provided to the end-users of the Semantic Framework, in order to allow the interaction with it. As the end-users of the framework may be considered the heterogeneous applications and services, as well as integrated experimentation testbeds. In the next sub-sections it is presented the detailed description of the framework features, as well as of the technological and the functional features of the architectural blocks.

3.3.1 Semantic Abstraction and Virtualization of Things

The "semantic abstraction and virtualization of thing" architectural building block aims to face the challenges that arise with respect to the technological heterogeneity of the real world objects, the devices and the applications of the Future Internet. Specifically, it is studied the combination of the semantic technologies with the virtualization technologies for the provision of an innovative, integrated solution. To that respect, they are designed and implemented two key concepts: a) the "semantic model" for the real world objects and b) the "abstract software module". The combination of these two parts, structures the Virtual Thing.

In particular the "semantic model" constitutes a generic graph-based model that represents in an abstract way the features and the properties of the real world things. The model is structured in a way so as to allow the description of any specific feature of any different object from the real word, by supporting the external reference to existing system/domain/concept specific ontologies. The model includes a set of different meta-data containers that some of them are used for the description of standard, common information, such as the unique identifier, the type of the thing, the location where it exists, etc. Further to that, there are meta-data containers that include meta-data properties (e.g. type & value), which allow the external reference to third-party properties that are described into independent ontologies that may be deployed in the context of a particular domain, system, etc. Thus, the "semantic model" is introduced so as to structure integrated modeled data with respect to the real world things, combining a set of common information complemented with particular information by existing external ontologies.

The "abstract software module" corresponds to generic software component(s) that are implemented following particular specifications and architectural principles (e.g. REST architecture principles) and constitute the software implementation of the functional capabilities of the real world things. These modules composed by two functional parts: a) the Front-End and b) the Back-End. The Front-End implements the North-bound interface of the software module and the Back-End constitutes the South-bound interface of the module. Essentially, each part constitutes interfacing the software module with the third-party entities in a corresponding environment. More specifically, the Back-End takes the role of the device driver for the real world device, including particular functional capabilities, implemented in particular programming language, even using specific libraries and system binaries. Actually, the Back-End part is a device and/or system/platform specific software that creates the bridge among the real world and the virtual world. The Front-End correspond to the common communication interface among the external/third-party entities and the real world device. The Front-End is built as a REST Endpoint that provide a common communication scheme among the external entities with the different available devices, hiding in this way the technological heterogeneity and the complexity of the technological processes. Actually, the Front-End works as an abstract communication interface. This communication interface is used, always in the same way, in order to interconnect the external entities, such as the IoT applications, with any heterogeneous device. For the dynamic deployment of the Virtual Things, there are appropriate templates (Virtual Thing Templates) that include information with respect to the execution of the Virtual Thing as a software module into an appropriate hosting environment that is called Virtual Thing Container. For instance, a Virtual Thing Container may be built as a Web Server that hosts the RESTful web services that implement the Front-End and the Back-End functionalities.

As already introduced above, the combination of the "semantic model" and the "abstract software module" comprise the Virtual Thing that represents a real world thing, such as a device. The Virtual Thing supports, through appropriate software, the control and the manipulation of the device functionality. Furthermore, through their semantic description it is possible the discovery and the re-use in different use cases. The Virtual Thing is introduced in the Semantic Framework in two phases: a) the phase of the semantic description creation based on the semantic model, and b) the installation and execution phase into the Virtual Thing Container, using the appropriate Virtual Thing Template. The first phase includes the creation of the semantic description in order the information to be registered, accessible, and manageable through the semantic storage system. The second phase include the introduction of appropriate data into the Virtual Thing Template so as to create an executable template instance that will be hosted into the Virtual Thing Container as a unique software entity, such as a RESTful web service. The template instances will be also called Virtual Thing Deployment Files, since they include all appropriate information that describe how a Virtual Thing can be deployed in the hosting environment.

Consequently, taking into account the above, the "Semantic Abstraction and Virtualization of Things" architectural block implements the bridge among the real and the virtual world.

3.3.2 Semantic Storage System

The "Semantic Storage System" architectural block constitutes a core architectural part of the Semantic Framework that aims to solve scalability and performance issues with respect to the semantic data storage management. It includes semantic data (e.g. RDF/XML) that corresponds to Virtual Things descriptions, as well as on Composite Virtual Things and Services that are based on the compositions of the Virtual Things. Moreover, the storage system may include data from the templates and the deployment files of the Virtual Things that can be formed in different formats such as YAML, JSON, etc. The semantic storage system combines the Semantic Repositories, from the semantic technologies field, and the Object Storage System, from the Cloud technological field. This combination introduces the flexibility of the deployment of a hybrid, scalable, high-capacity and high-performance storage system for the support of the Semantic Framework requirements.

This architectural block supports the functionality of the rest of the architectural blocks for the real world devices virtualization, the (Composite) Virtual Thing creation and management, as well as for the management of the services. In particular, the semantic repositories store semantic data that describes the (composite) virtual things and the services and they are complemented with appropriate REST endpoints for the performance of queries and modification requests. The different building blocks include mechanisms that require the use of the semantic data so as to perform different operations. These mechanisms perform queries and requests towards the semantic data in form of SPARQL requests and fetch appropriate information and/or update the overall data structure in accordance the requirements. Further to that the Object Storage System that complements the Semantic Storage System is based on OpenStack Swift [22] and the management of the Virtual Things templates and their instantiations is being based on their distribution in different containers. Each Object Storage container stores the Virtual Thing templates and the Deployment files based on their format (e.g. a container for YAML files). In this way it is achieved the speed-up of the templates and deployment files discovery process, supporting high-performance and high-accuracy results. On the other hand, the distributed semantic repositories are implemented by using the OpenRDF Sesame Repository API [23], as well as they can be federated in the "Federated Semantic Storage System" using the OpenRDF Sesame API [24]. The communication interface and the corresponding REST Endpoints for the interaction among the components are based on a Jetty Server [25] web-based implementation.

Consequently, the "Semantic Storage System" allows the semantic data storage and management of the available entities in the Semantic Framework, including (Composite) Virtual Things and services, as well as supports the manipulation of the templates and deployment files of the software entities the abstract the real world things in the virtual/digital world.

3.3.3 Cognitive Management and Composition of Virtual Things

The "Cognitive Management and Composition of Virtual Things" architectural building block provide appropriate functionality with respect to the composition of existing isolated Virtual Things in more complex deployments for the support of new, innovative and advanced functional capacities that are able to support a particular Service. The existing Virtual Things by their own support the bridging among the real and virtual world, by taking over the implementation of abstract functionality for the control and management of the real things, such as sensing and actuation devices. The combination of the functional capabilities of such devices may allow the provision of integrated capabilities to the systems, the applications and the end-users. Indicatively, it is considered that there are distributed sensors for the environmental conditions monitoring, such as temperature, humidity and luminosity sensors. Through the composition of the functional capabilities of these sensors it will be possible to provide composite virtual thing functionality for the environmental conditions monitoring in a particular environment that the sensors are deployed.

The composition and the management of the (Composite) Virtual Things, is realized by custom algorithms that base their functionality on the semantics. Specifically, it is supported the semantic-based Decision Making for the creation of the composite virtual things based on particular requests that refer to the satisfaction of specific requirements (e.g. create a composite virtual thing for the environmental conditions monitoring). Such requests are in form of JSON data that are interpreted by the Decision Making algorithm, isolating the requested functionalities that should be discovered and combined for the delivery of a more complex functionality. The Decision Making mechanism perform appropriate SPARQL requests to the "Semantic Storage System" so as to create and deploy dynamically the composite virtual thing based on the semantic data description. Such data may refer to the functional capabilities of the virtual things, to non-functional features and properties, as well as to access information with respect to the communication interfaces of the virtualized things (e.g. which is the online address of a REST endpoint so as to access a virtual thing software entity). The compositions of the virtualized things are also described by particular meta-data that compose the semantic description of the composite virtual things. This semantic description is also stored and accessible on the "Semantic Storage System". In this way the existing composition of virtual things may be reused in the context of future related requests that may refer on similar needs. Similarly, the Virtual Things descriptions may allow the exploitation and the re-use of the abstract virtual representations of the virtual things even outside of their initial concept. Indicatively, an actuation device, such as the controller of an air-conditioning system, could be re-used so as to control the air-conditioning system in an automated way based on the particular user preferences, combined with the current environmental conditions in the place where it exists.

Consequently, the "Cognitive Management and Composition of Virtual Things" building block supports the dynamic management of the (Composite) Virtual Things, as well as the semantic-based composition of existing Virtual Thing in the scope of particular requirements addressing/satisfaction.

3.3.4 Cognitive Management of Services

The "Cognitive Management of Services" building block deals with the dynamic creation and management of services for the end-user and the IoT applications of the Semantic Framework. Through the provision of open APIs the framework's third-party entities will be able to interact with the services that will be created on-demand and based on particular requirements.

The services will use the existing Composite Virtual Things in order to support complex IoT applications for the end-users and the systems in the Future Internet.

For the dynamic creation of the services it is applied a cognitive semantic-based mechanism that exploit the semantic data for the deployment of the services that either use directly the existing Composite Virtual Things or trigger the framework processes for the creation of new compositions. Thus, it is possible the dynamic creation and deployment of services based on the current requirements, ensuring the reusability of existing functionalities in different application concepts.

For the description of the created services are used semantic models that provide information about the features of them, such as the involved virtual things in the composition that supports the service. The semantic data of the services is stored in the "Semantic Storage System" and it is used for the execution access and use of services by third-party entities, as well as by framework's mechanisms. Such mechanism may be the Decision Making mechanism for the dynamic composition and management of services, using the existing data.

The service management in the context of the Semantic Framework focuses on two main aspects: a) the dynamic reuse of services by different IoT applications and b) the dynamic service reconfiguration allowing a type of service migration among heterogeneous environments. The implementation of the last aspect is being realized through the reconfiguration of the software parameters with respect to the access on the available (Composite) Virtual Things that may be distributed in different environments. Specifically, this capability supports the reconfiguration of the services in terms of the virtual things they used so as to interact with the available real world devices. This situation may arise in case the IoT application is migrated across different systems, and it should be supported its seamless interoperability from one system to another.

Consequently the "Cognitive Management of Services" building block supports the dynamic creation, management and reconfiguration of the services that can be supported in the Semantic Framework for the IoT applications. Furthermore, it allows the distribution of the functional capabilities of the services and the software modules that support the IoT applications for the seamless migration of them among distributed heterogeneous environments.

3.3.5 Semantic Framework Cloud Deployment

The Semantic Framework has been design with particular specifications that allow its deployment over Cloud Computing infrastructures that can take over the hosting and the execution of particular functionalities of the framework architectural blocks. The proposed deployment includes two core aspects: a) the Edge Clouds and b) the Federated Cloud. The Edge Clouds correspond to small and/or medium deployments that instantiate the framework in the context of a particular prototype, such as smart home and smart cities deployments. Each Edge Cloud includes its own virtualized real world things, supports particular services for IoT applications and includes specific semantic data for their entities. Moreover, each local cloud is complemented with publicly accessible endpoints so as to allow the interaction with external third-party entities. For the integration of the distributed Edge Cloud environments it is proposed the deployment of a large-scale Cloud deployment that is called "Federated Cloud". The Federated cloud include data processing and service management mechanisms for the seamless integration of the distributed Edge Cloud environments, whereas it supports the federation of the semantic data included in the Edge Cloud, through the performance of federated queries and requests on the available data.

The deployment of the Edge Cloud infrastructures may be based on the container based virtualization using the Docker container that can be hosted over the Docker engine. The Docker engine may be hosted on small scale systems such as embedded computers. To this direction it is possible the deployment of low-cost, energy efficient and high-performance "cloud-in-the-box" environments for the instantiation of the Edge Clouds. Indicatively, such implementation may be based on the embedded systems of Raspberry Pi 2 [26] and/or Odroid XU4 [27].

The deployment of the Federated Cloud environment can be performed over a hypervisor-based implementation with capabilities for the provision of more processing power. Such implementation could be based on OpenStack Cloud, with the deployment of guest Virtual Machines (VMs) for the hosting of the distributed mechanisms, such as the "Federated Semantic Storage System". The VMs may interconnect with the distributed Edge Cloud components over the Software Defined Network (SDN) and Network Function Virtualization (NFV) OpenStack Neutron controller [28].

Consequently, the Semantic Framework can be deployed as a distributed cloud-based infrastructure with multiple instances hosted on the different cloud environments and interconnected among each other over SDN infrastructures for high-performance and reliable deployments.

3.4 Chapter References

[1].Kelaidonis, Dimitris, et al. (2012, November). "Virtualization and cognitive management of real world objects in the internet of things". In Green Computing and Communications (GreenCom), 2012 IEEE International Conference on (pp. 187-194). IEEE.

[2].Tilanus, Paul, Ran, Bob, Faeth, Matthias, Kelaidonis, Dimitris, & Stavroulaki, Vera. (2013, June). "Virtual object access rights to enable multi-party use of sensors". In World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2013 IEEE 14th International Symposium and Workshops on a (pp. 1-7). IEEE.

[3].V. Foteinos, D. Kelaidonis, G. Poulios, V, Stavroulaki, P. Vlacheas, P. Demestichas, R. Giaffreda, A. R. Biswas, S. Menoret, G. Nguengang, M. Etelapera, N. Septimiu-Cosmin, M. Roelands, F. Visintainer, and K. Moessner, "A Cognitive Management Framework for Empowering the Internet of Things", Future Internet Assembly 2013: Validated Results and New Horizons, A. Galis and A. Gavras (Eds.): FIA 2013, LNCS 7858, pp. 187-199, 2013, Book Chapters.

[4].Foteinos, V., Kelaidonis, D., Poulios, G., Vlacheas, P., Stavroulaki, V., & Demestichas, P. (2013). "A Cognitive Management Framework for Service Provisioning in the Internet of Things". Future Networks and Mobile Summit 2013, Portugal, Lisbon.

[5].Vassilis Foteinos, Dimitris Kelaidonis, George Poulios, Panagiotis Vlacheas, Vera Stavroulaki, and Panagiotis Demestichas. (2013). "Cognitive management for the Internet of things: A framework for enabling autonomous applications". Vehicular Technology Magazine, IEEE, 8(4), 90-99.

[6].Panagiotis Vlacheas, Raffaele Giaffreda, Vera Stavroulaki, Dimitris Kelaidonis, Vassilis Foteinos, George Poulios, Panagiotis Demestichas, Andrey Somov, Abdur R. Biswas, and Klaus Moessner. (2013). Enabling smart cities through a cognitive management framework for the internet of things. Communications Magazine, IEEE, 51(6), 102-111.

[7].FP7/ICT-287708 iCore Project. Deliverable Document 3.1 "Virtual Object Requirements and Dependencies".

[8]. Kelaidonis, Dimitris, et al. (2014, August). "Smart energy management of wireless technologies and mobile applications". In Wireless Communications Systems (ISWCS), 2014 11th International Symposium on (pp. 848-852). IEEE.

[9]. Dimitrios Kelaidonis, Panagiotis Vlacheas, Vera Stavroulaki, Stylianos Georgoulas, Klaus Moessner, Yuichi Hashi, Kazuo Hashimoto, Yutaka Miyake, Keiji Yamada, Panagiotis Demestichas. (2016). "Cloud Internet of Things framework for enabling services in Smart Cities". Springer Book.

[10]. Dimitrios Kelaidonis, Angelos Rouskas, Panagiotis Vlacheas, Vera Stavroulaki, Panagiotis Demestichas. (2016). "A Federated Edge Cloud-IoT Architecture – Enabling semantic-based service provisioning in Future Internet". Accepted. EUCNC June, 2016, Athens Greece.

[11]. Dimitrios Kelaidonis, Angelos Rouskas, Panagiotis Vlacheas, Vera Stavroulaki, Panagiotis Demestichas. (2016). "Federated Edge Cloud Internet of Things Architecture over 5G infrastructures". Submitted to Communications Magazine, IEEE, Feature Topic: Impact of next-generation mobile technologies on IoT-Cloud convergence, April, 2016.

[12]. P. Vlacheas, V. Stavroulaki, A. Georgakopoulos, D. Kelaidonis, K. Moessner, A. Rahim, Y. Miyake, S. Kiyomoto, K. Yamada, K. Hashimoto. "An overview and main benefits of an Intelligent Knowledge-as-a-Service Platform". (2015). Accepted. 34th WWRF meeting. Santa Clara, California, US.

[13]. P. Vlacheas, V. Stavroulaki, A. Georgakopoulos, D. Kelaidonis, K. Moessner, A. Rahim, Y. Miyake, S. Kiyomoto, K. Yamada, K. Hashimoto. "An overview and main benefits of an Intelligent Knowledge-as-a-Service Platform". (2015). Submitted to IEEE VTM Journal 2015.

[14]. K. Hashimoto, K. Yamada, K. Tabata, M. Oda, T. Suganuma, A. Rahim, P. Vlacheas, V. Stavroulaki, D. Kelaidonis, A. Georgakopoulos. "iKaaS Data Modeling: A Data Model for Community Services and Environment Monitoring in Smart City". (2015). Accepted. 3rd International Workshop On Self-Aware Internet-of-Things 2015 (Self-IoT 2015). Grenoble, France.

[15]. K. Hashimoto, K. Yamada, K. Tabata, M. Oda, T. Suganuma, A R. Biswas, P. Vlacheas, V. Stavroulaki, D. Kelaidonis, A. Georgakopoulos. (2015).

"3D Geospatial Definition of Smart City and its Data Model for Community Services", submitted to IEEE BIOT 2015.

[16]. Dimitris Kelaidonis, Kostas Tsagkaris, Panagiotis Demestichas. (December, 2014). "Enabling experimentation on building and traffic management through the XiFi node of the University of Piraeus". Available online at: https://blog.fi-xifi.eu/wp-content/uploads/2014/09/TNS_XiFi_Node.pdf.

[17]. P. Demestichas, K. Tsagkaris, D. Kelaidonis, A. Georgakopoulos. (2015). "Leveraging XIFI for conducting experimentally-driven research on 5G". Newsletter. Available online at: https://blog.fi-xifi.eu/wp-content/uploads/2015/01/XIFI-Newsletter-UPRC-20150112a.pdf.

[18]. Dimitris Kelaidonis, Aristi Galani, Marios Logothetis, Panagiotis Demestichas. (2015). Presentation. Title: "Towards a Cognitive Internet of Things: From lab experiments to small scale pilots; Experience from the iCore and XiFi projects". Event: "Telecommunication Networks & integrated Services (TNS) Node in Piraeus: Capabilities & Prospects". University of Piraeus. Event Programme: http://tns.ds.unipi.gr/tns/multi/ProgrammeXIFIevent_eng.pdf.

[19]. Dimitris Kelaidonis. (2015). "Towards a Cognitive Internet of Things: From lab experiments to small scale pilots; Experience from the iCore and XiFi projects". Event: «RFID και Internet of Things - Παραδείγματα και Επιχειρηματική Αξιοποίησης». Organized by: Εργαστήριο Ηλεκτρονικού Επιχειρείν και Εμπορίου (ELTRUN) – Οικονομικό Πανεπιστήμιο Αθηνών. Event Programme: http://www.eltrun.gr/wp-content/uploads/2015/03/%CE%95%CE%BA%CE%B4%CE%AE%CE%BB%CF%89%CF%83%CE%B7-RFID-IOT-31-March-2015-Final-Program-2.pdf.

[20]. OpenStack Open Source Cloud Computing Software. (2016). [Online]: https://www.openstack.org/.

[21]. Docker - Build, Ship, and Run Any App, Anywhere. (2016). [Online]: https://www.docker.com/.

[22]. Swift-OpenStack. (2016). [Online]: http://docs.openstack.org/developer/swift/.

[23]. OpenRDF Sesame API. "The Repository API". (2016). [Online]: http://rdf4j.org/sesame/2.7/docs/users.docbook?view#The_Repository_API.

[24]. OpenRDF Sesame API. "Create Federation Store". (2016). [Online]: http://rdf4j.org/sesame/2.7/docs/users.docbook?view#Create_a_Federation.

[25]. Eclipse Jetty Web Server. (2016). [Online]: http://www.eclipse.org/jetty/.

[26]. RASPBERRY PI 2 MODEL B. (2016). [Online]: https://www.raspberrypi.org/products/raspberry-pi-2-model-b/.

[27]. Hardkernel Odroid. (2016). [Online]: http://www.hardkernel.com/.

[28]. OpenStack Neutron. (2016). [Online]: https://wiki.openstack.org/wiki/Neutron.

4 SEMANTIC MODELLING FOR THE DEPLOYMENT OF VIRTUAL THINGS IN THE FUTURE INTERNET

4.1 Chapter Outline

This chapter deals with the virtualization of real world objects and the management of their virtual counterparts in the IoT environments. A framework that provides appropriate mechanisms for the semantic-based virtualization is presented. The framework consists of three levels of functionality and each level comprises cognitive entities that provide the means for self-management and the deployment of smart, flexible applications and objects. Moreover, the framework enables the abstraction of the heterogeneity that derives from the vast amount of diverse objects/devices, while enhancing reliability and facilitates the consideration of the views of various users/stakeholders (owners of objects & communication means) for ensuring proper application provision, business integrity and, therefore, maximization of exploitation opportunities. The framework is applied for the enhancement of contemporary IoT environments, aiming to ensure the interoperability among heterogeneous object and application, introduce security and accessibility control on virtualized resources and it is applied in the field of the energy management for wireless enabled IoT infrastructures.

4.2 Introduction

The virtualization of things and applications constitutes the key enabler for the provision of advanced, effective IT solutions that hide the technological heterogeneity and minimize the complexity of the integration and interoperability processes among heterogeneous hardware and software entities. The virtualization techniques that are based on the semantic modeling include the design and the development of abstract virtual representations, comprised by two different parts: a) the Semantic Description and b) the abstract software module. Combining the semantics with abstract software modules it is achieved the deployment of Virtual Objects that bridge the abstract representations of the Real World Objects with the Virtual World of the Future Internet infrastructures.

Essentially, the Virtual Objects (VOs) constitute the implementation of the Virtual Thing (VT) entity that is included in the "Semantic Abstraction and Virtualization of Things" building block of the Semantic Framework. The form of the Virtual Objects as abstract entities, allows the reuse of the VOs in different operation concepts and application domains, even outside of the domain in which they were initially developed. This practically means that a VO that was initially deployed in the IoT ecosystem as a virtual abstract representation of a Smart Home real world device, it can be reused outside of the Smart Home context, such as in a Smart City environment.

Consequently, the Semantic Framework for the Future Internet enhances the above processes, through the provision of appropriate mechanisms and software modules from the "Semantic Abstraction and Virtualization of Things" and the "Semantic Storage System" architectural blocks. Specifically, the Semantic Framework includes functional features that satisfy the requirements that are related to the semantic modeling and the semantic data management of the VOs semantic descriptions. Furthermore, the Semantic Framework contributes to the virtualization processes by introducing the Virtual Thing (VT) concept that as it will be presented in the next subsections of this chapter, it is adapted in the different research concepts and it is presented in various forms, such as Virtual Objects (VOs).

The evaluation and the validation of the dissertation contribution through the Semantic Framework entities (mechanisms and/or software modules), as well as the added value of these mechanism in the IoT, it is presented through the results of different scientific publications. The most important publications that constitute research work of this dissertation are presented in the rest of this chapter. In particular, the section 4.3 is based on the publications [1][2][3] by studding and presenting the overall concept of the semantic-based virtualization for the creation of virtual abstract representations, called VOs, in heterogeneous the IoT environments. Furthermore, the published software prototype in [4] constitutes the dissertation contribution in terms of software implementation concepts that have been designed in the context of the Semantic Framework.

4.3 Virtualization of Real World Objects in the Internet of Things

The term 'Internet of Things' (IoT), exists for more than 10 years [5]. However, a reader can find various definitions in the literature [6]. The common understanding of the IoT is associated with the future where all physical and digital objects or things could be interconnected by appropriate Information and Communication Technologies (ICT) to enable new applications and services [7].

The first attempts towards the virtualization of Real World Objects (RWO) were connected with Radio Frequency Identifiers (RFID) [8] which could capture only 'raw' data. Next steps were done in the contextualization of captured data [9]. Nowadays, Virtual Objects (VOs), i.e. virtual representations of objects/things, tend to be 'smarter' by enriching their models with cognitive management functions and user information [10]. Although much research has been done in terms of virtualization in the IoT domain, much more research is required to understand how things and their corresponding VOs can be connected and interact in a smart way, or how the concepts can be exploited and implemented.

In this direction, this chapter focuses on the virtualization of real world things, exploiting semantic technologies. The virtualization of RWOs in this context is realized through the creation of VOs which are semantically enriched with context related information. Additionally, VOs of different types can be combined in a more sophisticated way by forming compositions of VOs, which provide services to high-level applications and end-users. For the realization of the dynamic VOs composition and management, it is required the introduction of Cognitive Management mechanisms. The cognitive management of VOs and the CVO concepts are described and they are being elaborated in the chapter 5.

The rest of this work is structured as follows. Background on the IoT and Web of Things key concepts, virtualization of RWO in the IoT, and fire detection using WSN technology is presented in Section 4.3.1. The semantic data modeling and the virtualization concepts are described in the sections 4.3.2 and 4.3.3 respectively. The implementation details are provided in Section 4.3.4. Finally, the chapter concludes with a summary of the main outcomes as well as targets for future extensions and/or applications of this work.

4.3.1 Related Work

One the main aspects in the IoT, refers to the Virtualization of RWOs. Many different research activities have been performed focusing on this field. In [11], the objects are identified with RFID, while the authors use the ontologies for the description of the objects. In [12] there is the categorization of the objects into three groups: resources, entities, and resource users to address a high number of distributed sensor and actuator networks. Furthermore, the virtual sensor abstraction is used in [13] to hide the implementation complexity of large scale sensor networks. One of the main aims in [14] was to make the physical world information available to smart services, bridging the physical with the virtual world, using abstract representation models. The work in [15] aims to provide a standardization scheme for a new paradigm that is based on a specific description language and allows the identification and interconnection of every object and event with a standard format. The work in [16] considers concept of Virtual Sensor Network (VSN) as a crucial technology for the realization of the IoT vision. The VSN manages the dynamic collaboration of sensor nodes subsets, aiming to fulfill high computation tasks. Moreover, the work in [17] proposes an IoT virtualization framework which uses the notion of sensor-as-a-service. This framework represents connected objects in an IoT cloud in the form of web services. The Versatile Digital Item (VDI) [18], a very general data format holding information related to any virtual or physical item, is used as the main concept in [19] for the enhancement of a publish-subscribe model. The VDI has been designed to provide broad support to references to RWOs. Furthermore, the work in [20] introduces the term of Active Digital Identities (ADI) in order to realize the concept of Web of Things. The ADI uniquely represents a physical item by using URL as for Web Objects. A number of initiatives and projects have addressed the concept of "mash-ups" in the scope of user generated composite applications [21]-[23]. Initially ([21][22]) the focus has been only on on-line services not looking into issues and requirements related to the integration of physical world objects and functionalities. The use of mash-ups for the integration with the physical world is addressed in [23]-[26]. In [27] the Web of Things vision is introduced by proposing a platform which tries to add, use, share and interconnect smart objects and services. In particular, these artifacts are represented as "virtual" things. It elaborates abstractions to create "mash-ups" of heterogeneous things. These approaches focus on enabling users to create mash-ups from a combination of available real world objects/devices and services. Our approach introduces the CVO as a collection of information and services from partial digital images of the world and their VOs, building on previous work but also introducing additional intelligence for increased autonomicity and dynamicity. The CVO concept leads to intelligent services, fulfilling requirements (also from hidden stakeholders), while details and complexity are hidden from end users. CVOs are self-managed, self-configurable components, which exploit cognitive mechanisms to enable the mash-up and re-use of existing VOs and CVOs by various applications, also outside the context and domain for which they were originally developed. CVOs are created dynamically in an autonomous manner taking into account requirements deriving from the user and objects levels, without requiring any particular user expertise. In this direction, this chapter describes appropriate mechanisms and specifications for the deployment of software solutions that will allow the semantic-based virtualization or real world things.

4.3.2 Semantic Model for the real world things abstraction

The Figure 2 depicts the semantic model that is used for the semantic description of the virtual abstract representations such as the Virtual Objects (VO). A VO represents an ICT Object and is owned by one VO owner who essentially is the end-user. The VO may have one or more VO Parameters that refer on specific information regarding the VO. Each VO Parameter, depending on its type, may have specific Access Rights as well as specific Billing Costs. Furthermore, a VO represents the Functionality that is offered by ICT object. In particular the VO is associated with VO Functions that, in turn, have specific Input and Output parameters, whilst are described in terms of VO Function Features, such Utilities (add positive meaning on the function) and Costs (add negative meaning on the function) as well as it has Access Rights and Billing Costs. Moreover, the virtual abstract representation includes information for the further description of ICT and non-ICT Objects. Such information is classified in ICT Parameters and Geo Location parameters of objects. An ICT Parameter can include information about the specifications of ICT object and other necessary data regarding the ICT. The parameters that are associated with an ICT object describe essentially the specific features that characterize the ICT Object. For instance, in case where we have as an ICT Object, a sensor, a potential ICT Parameter could be the range or the accuracy of sensor. On the other hand, the objects, which belong in the real world, have a physical location that is described in terms of geographical coordinates through the Geo Location parameters. At this point it should be highlighted that an ICT and non-ICT can have the same or different Geo Location. A typical example for this situation arises when we have as ICT Object, a camera that observes a building that is some meter far away of it. In this case the [ICT_Object = Camera] hasICTLocation "X" and the [non-ICT_Object = Building] hasNonICTLocation "Y".

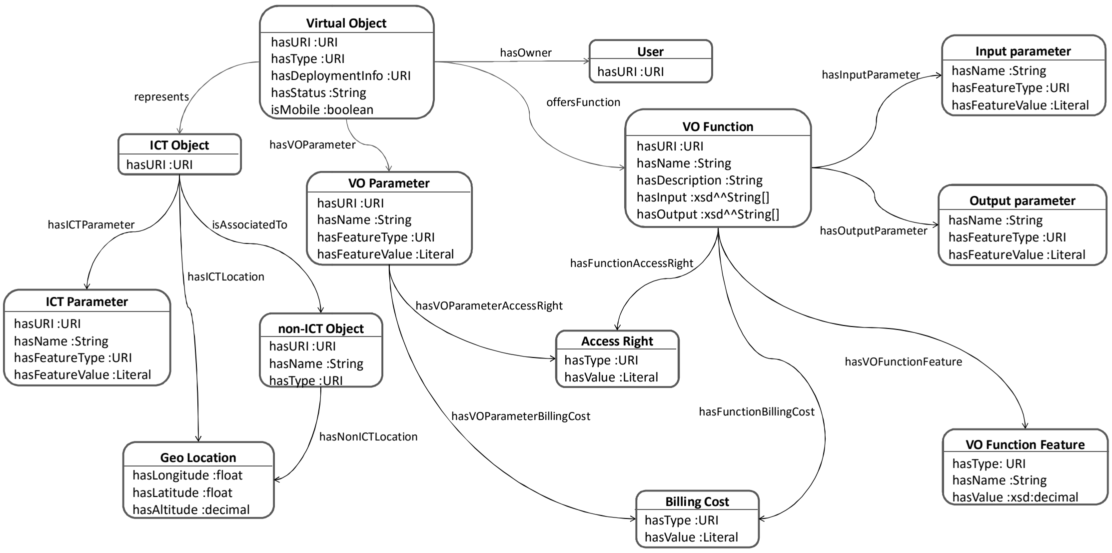


Figure 2: Abstract Virtual Representation Semantic Model

The information that is described above can be clearly readable and understandable by humans (human readable and understandable data) [28] but it is quite difficult to be readable and understandable by machines (machine readable and understandable data) [28]. In order to allow the machines to be able to understand the meaning of data and consequently to infer conclusions on them, should be carried out the semantic enrichment of data. In addition through the semantic enrichment of data, it is allowed the semantic interoperability between heterogeneous entities in the IoT system. A possible and an efficient way to achieve this, is the use of ontologies that belong to semantic web technologies [29][30][31]. The visualization of the Semantic Model concepts is presented in the Figure 3.

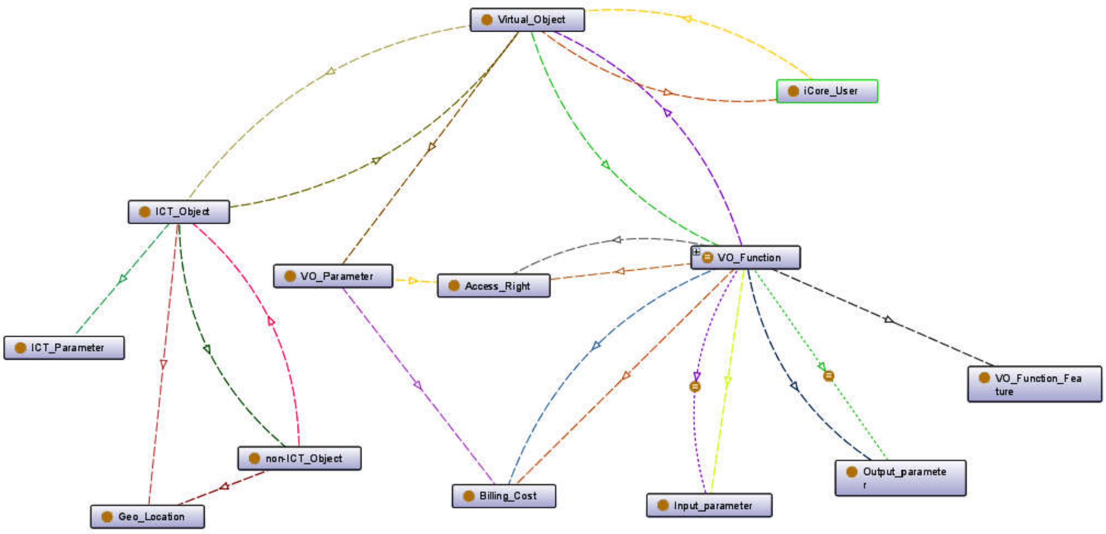


Figure 3: Semantic Model Ontology Concepts

4.3.3 Specifications of semantic-based virtual abstract representations

The vast amount of everyday objects that are comprised in the IoT generates technological heterogeneity that should be addressed in order to achieve the integration between different types of hardware and software infrastructures. The abstraction of technology-specific details will enable the development of applications and interoperability of software entities that handle or use the managed devices. Additionally, one equally important issue is the different views and goals that derive from users and stakeholders of IoT systems. In order to address these issues, it is proposed the introduction of the Virtual Objects that essentially constitute the instantiation of the Virtual Things concept that is proposed in the context of this dissertation.

4.3.3.1 Virtual Object (VO)

The virtual representations can be structured as virtual objects, as well as the composition of the virtualized objects so as to provide a more complex functionality to the end-users. Specifically, a Virtual Object (VO) is the dynamic virtual representation of a RWO that contains information for the description of the RWO, while it is implemented as computer software that is used to link the RWO with the virtual world. Any object, whether it embeds ICT capabilities (e.g. sensors, webcams, smartphones, etc) or not (e.g. persons, furniture, buildings, etc) is considered to be a RWO. An ICT object can be associated to a non-ICT object (e.g.: a temperature sensor that is associated to a room and measures the room temperature) and can be described in such a manner that it enables its exploitation and accessibility in the virtual world. Additionally, a non-ICT object can be implicitly described in the virtual world, through the association with the ICT object. Essentially, a VO provides an abstract representation of the features and capabilities, of both ICTs and non-ICTs in the virtual world. The VO is comprised by two parts; (a) the semantically enriched information for the description of the VO and (b) a software agent, developed as a RESTful Web Service (WS) [32], that implements a set of functions (e.g.: retrieval of measurements on environmental conditions, etc) related to the features/capabilities of the RWO. The Resource Description Framework (RDF) [33], W3C standard model for data interchange on the Web, has been used for the representation and storing of the VO information in machine readable/understandable data. The VO information is stored as RDF Triples [33] in the form Subject – Predicate – Object (SPO), in the VO registry and constitutes the description of VO.

4.3.3.2 Virtualization (VO) Templates and VO Container

The Virtualization templates are description templates of software entities that allow the dynamic instantiation of the virtual representations, through the exploitation of the semantic data of a VO. Essentially the VO Templates are filled with semantic data that corresponds to functional features of the real world objects, and then are deployed into the VO Container so as to be executed. Different VO Templates are available, with each VO Template to correspond to a different real-world device type (e.g. sensor, actuator, etc). Each template should be available, accessible and downloadable over the Internet (e.g. through a URL) and it may be provided in various formats, such as RDF/XML, YAML and JSON. The VO Templates constitute the deployment description of the REST WS that actually implements the VO, and it is parameterized using the semantic data, that is included in the VO Semantic Description, based on the Semantic Model. The VO Container imports a new VO as a new software package that implements the standard structure of a RESTful WS that follows the CRUD principles and it uses the VO Template so as to deploy the final structured and configured RESTful WS that will constitute the virtualization of the real-world device.

4.3.3.3 VO Security Aspects

The VOs support a basic type of access control by exploiting the capabilities of the semantic data enrichment of their descriptions. Specifically, as it is observed the Semantic Model (Figure 2) includes the "Access Rights" node that can include meta-data with respect to the access rights descriptions for the end-users and the third-party entities that may be able to interact with the particular VO. These descriptive data are stored into the VO Registries and using a Role Based Access Control (RBAC) algorithm based on the semantic query language SPARQL [34], it is possible to create a basic security aspect for the VO. The Access Rights can be represented as RDF triples in the VO Registry. Every registered VO function or VO parameter goes along with a set of Access Rights. These Access Rights define whether a function or parameter can be read or manipulated by a specific user or a specific user role. The advantage of this implementation is that it provides the possibility to individually assign read/write Access Rights to every VO function or VO parameter. The disadvantage is that it can increase the size of the VO Registry by orders of magnitude when lots of users or user roles must have access to a VO. This can potentially result in scalability issues.

4.3.3.4 VO Registry

Information regarding the available VOs is stored in distributed VO registries. An information model consisting of the appropriate attributes for the description of VOs has been designed and is depicted in Figure 2. It includes information regarding the ICT object being virtualized, its location in the real world expressed in geographic coordinates, its associations with any non-ICT object(s), information on how the VO can be accessed and used, as well as details regarding the functions that it offers. Regarding the latter, details on their inputs, outputs as well as various associated costs and utilities arising from their usage, are also stored in the VO registries. Such information on function costs and function utilities are taken into account when selecting the most appropriate VOs based on the application requirements and policies, i.e. during the decision making process, which will be described in more detail in the following paragraphs. Uniform Resource Identifiers (URIs) [35] have been used for the identification of VOs, ICT objects, and their offered functions.

4.3.4 Concepts Implementation

4.3.4.1 Real World Objects: Hardware and Communication

In this implementation we use three embedded platforms (in our case RWOs): WaspMote [36], a gas sensor node [37][38] for fire detection and Arduino [39] for the management of actuators. A laptop serves as a gateway and the Internet as the communication infrastructure among sensors, actuators and the cognitive management framework. The platforms and their interconnection are described in more details in the following sub-sections.

Sensing: For fire sensing two platforms are used: WaspMote and gas sensor node. WaspMote (see Figure 4a) is a commercial wireless sensor platform designed by Libelium. The platform advantages include its extensibility and ease of use. Extensibility is provided by a number of extension boards (with various sensors on board) for various applications: smart city, smart parking, agriculture just to list a few. One extension board can be connected to the main sensor board at a time. The main sensor board contains the necessary components for sensing: microcontroller

Atmega1281 by Atmel, wireless communication unit XBee-802.15.4 (ZigBee, 2.4 GHz), temperature sensor and accelerometer, power supply provided by Li-ion batteries. For our scenario the 'Smart City' extension board with humidity sensor has been used. In total the temperature and humidity sensors for fire detection have been used. In fact, to detect the fire using these sensors the increase of temperature and decrease of humidity need to be checked at the same time. The sensors' power consumption is less than 1 mW in active mode.

The gas sensor node (see Figure 4b) is a custom design platform for the detection of hazardous gases. The platform supports semiconductor and catalytic sensors. In this work we use a semiconductor one. The principle of fire detection is based on the sensing of pyrolisys in the environment. Pyrolisys is a gas which contains hydrogen (H2) and carbon oxide (CO). This gas appears due to smoldering or overheating of materials that help to predict possible fire in advance. The sensor node is built on Atmega168p microcontroller by Atmel, wireless modem ETRX2 (ZigBee, 2.4 GHz) by Telegesis. Power consumption of the node is, however, around 150 mW which results in approximately 1.5 years of autonomous operation. More details on the design and operation of the node can be found in [40]. Both sensor platforms exploit wireless communication for connection with the laptop.

Actuation: To alarm a user about the potential dangerous situation we use three actuators (associated with the WaspMote sensors) connected to Arduino (see Figure 4c): red Light Emitting Diode (LED), colored lamp, and fan. The colored lamp alarms a user when humidity drops below a threshold, fan turns on when the

a) b) c)

Figure 4: Sensing and actuation devices used (a) WaspMote wireless sensor platform, (b) wireless gas sensor node, and (c) Arduino platform with connected actuators (LED, lamp, fan).

temperature increases, and red LED starts to blink when potential fire is detected by the framework. We would like to note that the gas sensor node has a buzzer on board. This buzzer serves as an actuator (alarm) when the framework detects a potentially dangerous situation.

Arduino is connected directly to the internet using Ethernet. The next sub-section provides a description on how the devices and framework are interconnected.

Communication: The internet provides the sensors, actuators and framework with the communication infrastructure. The sensor nodes are connected to it through the gateway (laptop), while the framework and Arduino with the actuators are connected directly. In order to enable the framework cognitive mechanisms to interact with the Xively (former Cosm) platform [41] is utilized. This platform allows the online, real-time submission, storage and access of sensor measurements. In this respect sensing and actuation feeds have been created. The sensing feed registers the measured values from the temperature, humidity and gas sensors. The cognitive mechanisms of the framework access this data through the Cosm platform and perform an analysis to determined the behavior of the CVO and consequently of the VOs and corresponding sensors/actuators. In case an action is deemed necessary as result of this analysis simple binary commands are submitted through the actuation Cosm feed. Arduino with three actuators on board and the gas sensor node with the buzzer read the commands and react on the event by turning the actuators on/off.

4.3.4.2 Implementation of VO: Virtualization of Real World Objects

The Virtual Object (VO) is the result of the Virtualization Techniques application on the real-world things. The VO is comprised by two different parts (Figure 5): a) the Front-End (FE) and b) the Back-End (BE). The Front-End works as the contact point between any third-party entity (e.g. applications, services, developers, etc) and the VO. It is implemented as an integrated HTTP-REST Endpoint that implements a set of different CRUD-based calls for the management of the VO. The Back-End is the software module that works as the virtualized device driver (system driver) for the virtual infrastructure. It can be installed either inside the device, since it supports hosting capabilities for software (e.g. Memory, Processing Power, etc) or outside in a third-party hosting entity that interconnects with the device directly over some communication interface, such as a serial port. Independent of the host for the BE module, it communicates with the VO FE through an abstract software module that is named Back-End (BE) Connector. The BE Connector is adapted based on the Semantic Model for the virtual representations that describes the real-world device. Essentially, the information that is provided by the Semantic Model structure, is exploited for the dynamic deployment of the BE Connector functionality.

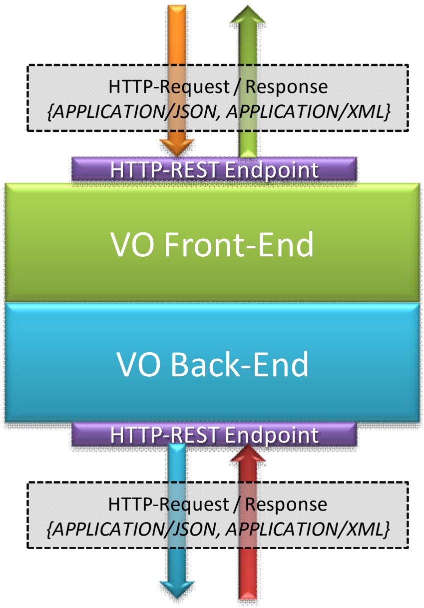


Figure 5: High-level overview of VO Software module structure

The main idea lies on the approach that the deployment information for the VO is fetched by the corresponding Semantic Repository (VO Registry), and the BE Connector is appropriately parameterized so as to adapt its functionality based on the VO semantic description. The REST-based design approach of the VOs facilitates the above approach, since it is possible to deploy on-the-fly RESTful WS that are dynamically configured based on the semantic data. Thus the BE Connector is always configured by using data from the corresponding VO description, allowing the actual implementation of the dynamic / on-demand deployment of things, application and/or services in the contemporary IoT environments. As its main responsibility, the BE Connector takes over the realization of the communication between the device and the software module that virtualizes the device functionality in the virtual-world.

4.3.4.3 Implementation of VO Templates and VO Container

The available Virtual Objects are hosted and executed on the VO Container (Figure 6). The VO Container constitutes the implementation of a web server that supports the execution of RESTful WS. The VOs are implemented as REST WS and provide the Hardware capabilities through the software. For the deployment and the execution of the VOs, the VO Container provide a set of different capabilities that allow the deployment of the REST WS, allowing in the same time the monitoring of the VO execution. These capabilities are known as Information & Deployment Ops. The deployment of the VOs is performed by using appropriate VO Templates. Each VO Template (Figure 7) may correspond to a different device type and it can be designed so as to present a specific set of functions that are provided by the device (e.g. temperature monitoring, video streaming, body pulses, etc.). The VO Templates are configured based on the information that is provided by the semantic data that describe the VO, using the Semantic Model. A parameterized VO instance of a VO Template constitutes the virtual abstract representation of the real-world device and consequently the core operational abstraction part of the VO.

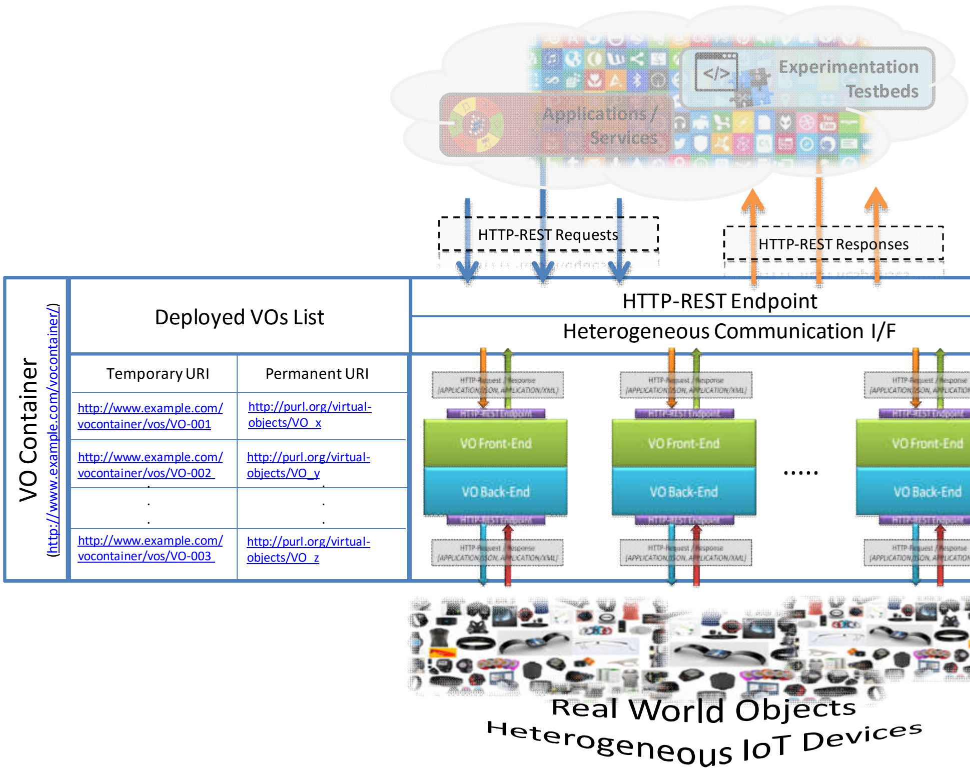


Figure 6: High-level overview of the VO Container structure and its communication interfaces

The VOs as RESTful WS are executed on the Web Server and forms the Execution Environment of the VO Container. Each new instantiated VO Template is deployed on the Execution Environment as REST WS, configured based on the data fetched from the Semantic Data Management layer and specifically by the corresponding Semantic Repository. The VO Container functionalities are accessible through an appropriate HTTP-REST Endpoint that is able to serve particular requests for the management of the VOs, such as the deployment, the start/stop execution, etc. A REST API is offered to the end-user (e.g. VO Developers) so as to allow the interaction with the VO Container, as well as to enable the development of advance distributed VO Container clients, management modules and monitoring modules for the available VOs.

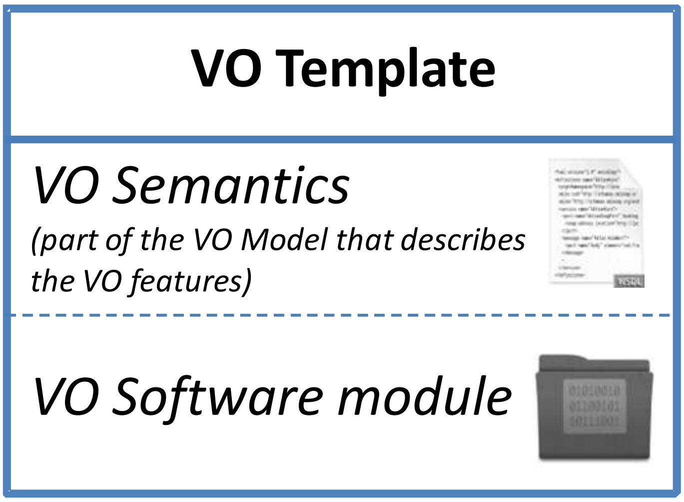


Figure 7: High-level Overview of VO Template structure

4.3.4.4 Implementation of VO Security Aspects

Adding access rights properties as RDF triples to the VO Registry makes it is possible to use the SPARQL query language for finding a certain feature of a VO as well as use it to directly check whether a VO function or parameter is accessible for the querying user. To do so a query parser is written. This parser makes use of the Apache Jena [42] query decomposition abilities to detect which parameters are requested by the user. Afterwards the parser manipulates the query by adding the access rights constraints on its structure. An example is of this functionality is given in the following two figures.

```
PREFIX vo: <http://IoT.com/virtualobject/>
PREFIX location: <http://IoT.com/locations/>

SELECT ?VO

WHERE {
 ?VO vo:Function ”getTemperature”.
 ?VO location:City ”Amsterdam”.
}
```

Figure 8: Query before parsing

A user is looking for a VO that has the function getTemperature and is located in the city of Amsterdam. This query is written as a SPARQL query in Figure 8. The user sends this query to the VO Registry by making use of RESTful web service. In order to identify him/her, the user adds his username (UserB) as an additional field to the http header.

The VO Registry receives the users query together with its username. Thereafter it checks which variables are requested by the user, in this case there is only one variable requested namely VO (line 5). In order to check whether the UserB has rights to read that variable from the DB the VODB adds this as constrain to the query. This is being done by adding the access rights prefix to the query (line 1) and adding constrains to the 'WHERE' clause (line 10).

```
1. PREFIX rights: <http://IoT.com/accesrights/>
2. PREFIX vo: <http://IoT.com/virtualobject/>
3. PREFIX location: <http://IoT.com/locations/>
4.
5. SELECT ?VO
6.
7. WHERE
8.  ?VO vo:Function "getTemperature".
9.  ?VO location:City "Amsterdam".
10. ?VO rights:Read "UserB".
11. }
```

Figure 9: Query after parsing

After parsing the query (Figure 9), the query now asks from the VO Registry something like "Is there a VO which has a function getTemperature, is located in the city of Amsterdam and where UserB has read access rights". The VO Registry will answer that query with a list of VOs that satisfy these conditions. Similar parsing concepts can be used to check on write access of VOs.

4.3.4.5 Implementation of VO Registry API

The VO Registry is implemented as an RDF Semantic Repository that stores RDF data. This data corresponds to the instances of the Semantic Model for the virtual representations. The implementation of the Back-End part of the VO Registry has been performed based on the RDF4j API [42] that constitutes an extensible Java framework that supports the management of RDF data. The RDF4j allow the implementation of multiple repository instances for the RDF data store, whereas it supports the SPARQL query language for the execution of queries on the stored data. For the interaction with the VO Registry, as well as for the implementation of the data management functionalities and the accessibility endpoints, it has been implemented as a Java reference implementation the VO Registry API. The Figure 10 presents an overview of the VO Registry design.

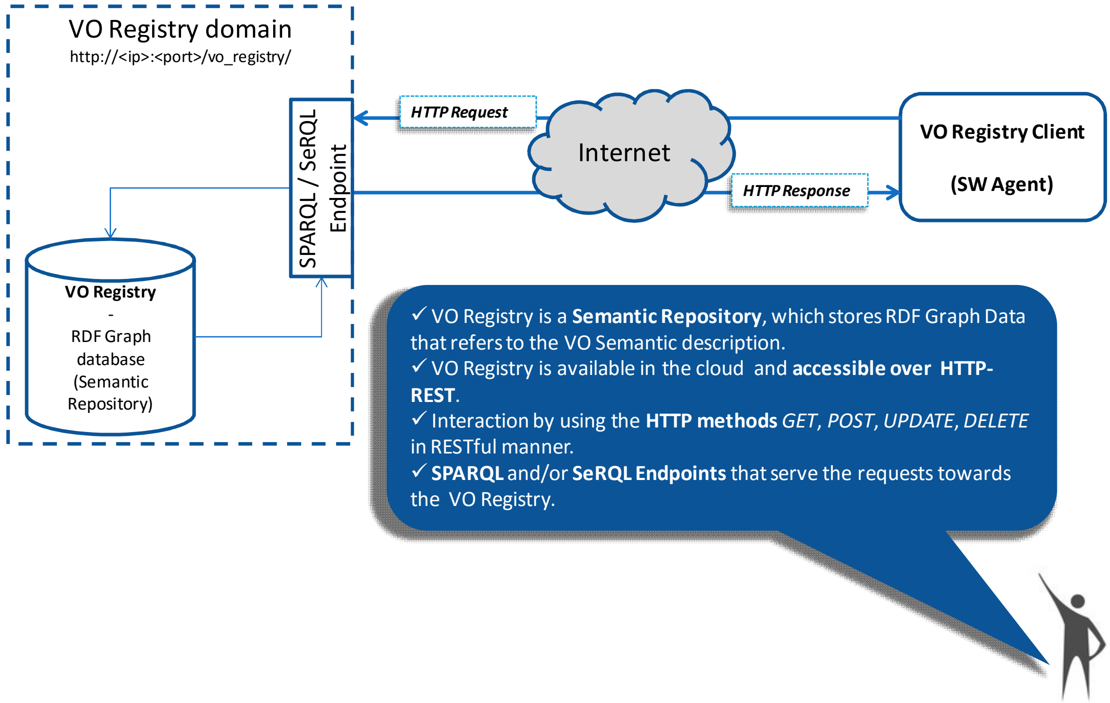


Figure 10: VO Registry design overview

4.3.4.5.1 Java API – reference implementation

The VO Registry API has a set of different specifications that allows the building of different functional parts related to VO Registry, by third-party entities (e.g. developers, end-users, stakeholders, etc.). By using this API it is possible to implement various processes that are summarized as follow: a) dynamic creation of the semantic description of the VOs and dynamic registration of the VO in the VO Registry, b) dynamic loading of the VO Description Templates contents in form of XML, JSON, RDF/XML, RDF/JSON and dynamic registration of the VO in the VO Registry, c) dynamic generation of SPARQL Requests by using the Java API Classes, d) dynamic discovery of VOs by using specific search criteria. For the implementation of the discovery process it is used the SPARQL Language and by using the API it is able to generate SPARQL code, just by calling the corresponding java classes, e) dynamic modification of VOs and their properties by using SPARUL (aka SPARQL 1.1 Update) [44] for the performance of Update & Delete requests toward the VO

Registry. The corresponding SPARQL Update code is automatically generated by using the corresponding java classes, f) dynamic construction of VO Registry Requests based on the corresponding specifications and g) communication interface between the VO Registry and its clients, by using HTTP-REST [45], with the data to be exchanged in usual popular forms such as XML and JSON. The VO Registry API is supported by a Java reference implementation that is distributed as a Java single library API. The Java API is comprised by 3 different parts: a) the VO Model, b) the VO Registry Client and c) the VO Registry Server.

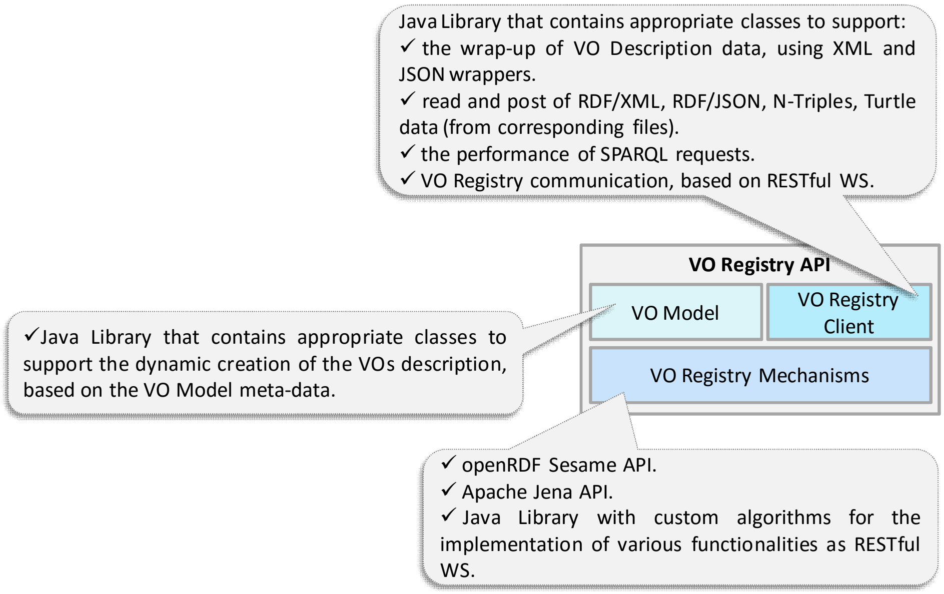


Figure 11: VO Registry Java API overview

The API library includes the required modules for the modelling of the VOs, using the Semantic Model (aka VO Model), the modules for the Client development, as well as the VO Registry Server module that can used only by the VO Registry owners, not by the end-users. This happens because the end-user requirements / needs are fully covered by the VO Model and the VO Registry Client modules and the end-user either human or software agent has the absolute freedom to perform requests and get response from the VO Registry server side. Moreover, the VO Registry offers a structure communication interface that allows the interaction with different REST Clients implementations. The VO Registry interface includes two (2) types of data type: a) the VO Registry Request (Figure 12) and b) the VO Registry Response (Figure 13). In addition, the Table 1 and the Table 2 present the description of the structure for the VO Registry Request and VO Registry Response, respectively.

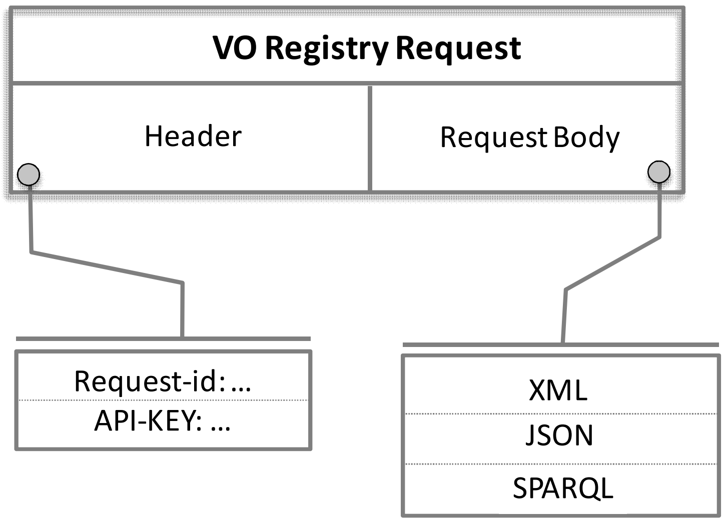


Figure 12: VO Registry Request Structure overview

Table 1: VO Registry Request - Description of contents

Data type	**Description**
Request Header(Request-id, API-KEY)	The Request head includes some data that are filled automatically by the system, such the Request id, Request Type, while it includes the API-KEY. The API-KEY is a string that corresponds to a unique identifier for the end-user entity which uses the VO Registry API.
Request Body	String that corresponds to the data of the VORegistryRequest payload. Depending on the situation, it may include XML, JSON, SPARQL data types.

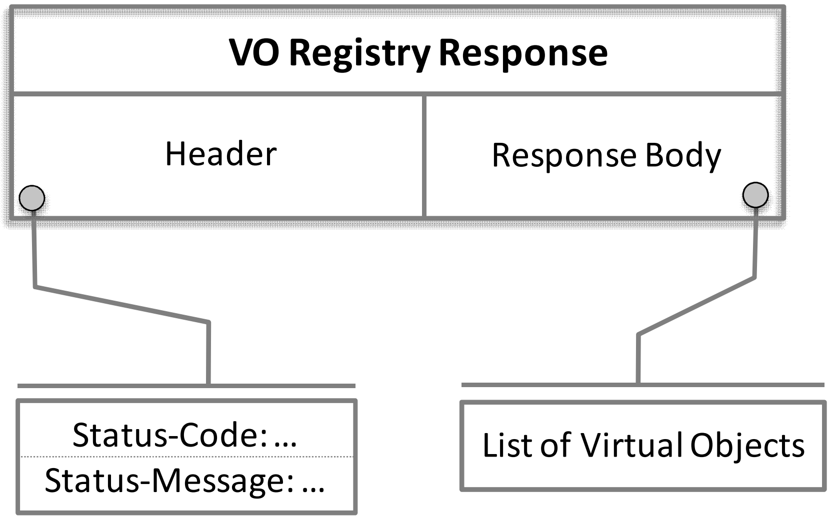


Figure 13: VO Registry Response Structure overview

Table 2: VO Registry Response - Description of contents

Data type	Description
Status-Code	Integer that presents the code of the response status, (e.g. 200).
Status-Message	String that presents the message of the response, (e.g. "Success").
List of Virtual Objects	A List of URIs that corresponds to the VOs, which match the VORegistryRequest. It is null in case the status code is 404, namely in case there are no available VOs that match the request.

4.3.4.5.2 cURL API

Since the VO Registry communication interface is based on the HTTP-REST, it has been designed and developed a cURL API for the interaction with the VO Registry, by aiming, in the same time, to enhancement of the interoperability aspects since the cURL functional aspects are supported by several programming languages such C++, php, etc. In order to use the cURL API, it is assumed that you have obtained an API-KEY, as well as that you have installed cURL (comes with Mac OS X and most Linux and BSD distributions).

For the support of the cURL API they have been developed the structure of the VO Registry Response and Request in form of XML and JSON. Thus, a cURL user can perform specific cURL commands either through its console or via appropriate code in any programming language, which supports cURL, The Table 3 and Table 4 below presents the cURL commands that should be executed in order to perform the corresponding interactions with the VO Registry.

Table 3: cURL Commands - Write Request data directly into the terminal

Interaction Type	**Data Format**	**cURL Command**
Discovery Request	TEXT/XML APPLICATION/XML	curl -X POST --data "voregistryrequest=<XML_DATA>" http://<IP>:<PORT>/vo_registry/discovery.xml
	APPLICATION/JSON	curl -X POST --data "voregistryrequest=<JSON_DATA>" http://<IP>:<PORT>/vo_registry/discovery.json
Registration Request	TEXT/XML APPLICATION/XML	curl -X POST --data "voregistryrequest=<XML_DATA>" http://<IP>:<PORT>/vo_registry/registration.xml
	APPLICATION/JSON	curl -X POST --data "voregistryrequest=<JSON_DATA>" http://<IP>:<PORT>/vo_registry/registration.json
Update Request	TEXT/XML APPLICATION/XML	curl -X POST --data "voregistryrequest=<XML_DATA>" http://<IP>:<PORT>/vo_registry/update.xml
	APPLICATION/JSON	curl -X POST --data "voregistryrequest=<JSON_DATA>" http://<IP>:<PORT>/vo_registry/update.json
Delete Request	TEXT/XML APPLICATION/XML	curl -X POST --data "voregistryrequest=<XML_DATA>" http://<IP>:<PORT>/vo_registry/delete.xml
	APPLICATION/JSON	curl -X POST --data "voregistryrequest=<JSON_DATA>" http://<IP>:<PORT>/vo_registry/delet

		e.json

Table 4: cURL Commands - Read Request data from file

Interaction Type	Data Format	cURL Command
Discovery Request	TEXT/XML APPLICATION/XML	curl -X POST --data-urlencode voregistryrequest@filename.xml http://<IP>:<PORT>/vo_registry/discovery.xml
	APPLICATION/JSON	curl -X POST --data-urlencode voregistryrequest@filename.json http://<IP>:<PORT>/vo_registry/discovery.json
Registration Request	TEXT/XML APPLICATION/XML	curl -X POST --data-urlencode voregistryrequest@filename.xml http://<IP>:<PORT>/vo_registry/registration.xml
	APPLICATION/JSON	curl -X POST --data-urlencode voregistryrequest@filename.json http://<IP>:<PORT>/vo_registry/registration.json
Update Request	TEXT/XML APPLICATION/XML	curl -X POST --data-urlencode voregistryrequest@filename.xml http://<IP>:<PORT>/vo_registry/update.xml
	APPLICATION/JSON	curl -X POST --data-urlencode voregistryrequest@filename.json http://<IP>:<PORT>/vo_registry/update.json
Delete Request	TEXT/XML APPLICATION/XML	curl -X POST --data-urlencode voregistryrequest@filename.xml http://<IP>:<PORT>/vo_registry/delete.xml
	APPLICATION/JSON	curl -X POST --data-urlencode voregistryrequest@filename.json http://<IP>:<PORT>/vo_registry/delete.json

4.3.5 Conclusions and future work

This chapter focused on the semantic-based virtualization conceptual aspects for the dynamic creation and composition of virtual abstract representations of real world things. The concept of VOs has been introduced with the aim of bridging the virtual world with the physical world. In addition the concept of mash-ups of semantically interoperable VOs has been introduced, namely CVOs enabling the dynamic creation of smart applications that can be reused outside of the context and the domain for which they were originally developed. An indicative smart home scenario was adopted in order to implement and validate the proposed concepts.

The planning for future work involves the introduction of the proposed concepts and their specifications into a Cognitive Management Framework for the design and the deployment of a dynamic self-managed framework for the IoT that will base its operational capabilities on the semantic-based (C)VOs concepts. Indicatively, such framework will include various types of cognitive mechanisms for the management of the information regarding the users, mechanisms for the translation of application requirements, decision making algorithms, etc. In addition, it is planned to apply the cognitive management framework in further application scenarios, such as the smart city application domain.

4.4 Chapter References

[1]. Kelaidonis, Dimitris, et al. (2012, November). “Virtualization and cognitive management of real world objects in the internet of things”. In Green Computing and Communications (GreenCom), 2012 IEEE International Conference on the Internet of Things (pp. 187-194). IEEE.

[2]. Tilanus, Paul, Ran, Bob, Faeth, Matthias, Kelaidonis, Dimitris, & Stavroulaki, Vera. (2013, June). “Virtual object access rights to enable multi-party use of sensors”. In World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2013 IEEE 14th International Symposium and Workshops on a (pp. 1-7). IEEE.

[3]. Kelaidonis, Dimitris, et al. (2014, August). “Smart energy management of wireless technologies and mobile applications”. In Wireless Communications Systems (ISWCS), 2014 11th International Symposium on (pp. 848-852). IEEE.

[4]. Dimitris Kelaidonis, Vera Stavroulaki, Panagiotis Vlacheas. (2014, November). Software Prototype. IoT Open Platforms. iCore – Virtual Object Registry API.

[Online]: http://open-platforms.eu/standard_protocol/icore-virtual-object-registry-api/.

[5].M. Zorzi, A. Gluhak, S. Lange, and A. Bassi, "From Today's Intranet of Things to a Future Internet of Things: A Wireless- and Mobility-Related View," Wireless Communications, vol. 17, no. 6, Dec 2010, pp. 44-51.[Online]. Available: ACM Digital Library, doi: 10.1109/MWC.2010.5675777.

[6].L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A Survey," Computer Networks, vol. 54, no. 15, Oct 2010, pp. 2787-2805. [Online]. Available: ACM Digital Library, doi: 10.1016/j.comnet.2010.05.010.

[7].D. Miorandi, S. Sicari, F, De Pellegrini, and I. Chlamtach, "Internet of Things: Vision, Applications and Research Challenges", Ad Hoc Networks, vol. 10, no. 7, Sept 2012, pp. 1497-1516. [Online]. Available: ACM Digital Library, doi: 10.1016/j.adhoc.2012.02.016.

[8].R. Weinstein, "RFID: a technical overview and its application to the enterprise," IT Professional, vol.7, no.3, May-June 2005, pp. 27- 33. [Online]. Available: IEEE Xplore Digital Library, doi: 10.1109/MITP.2005.69.

[9].K. Aberer, M. Hauswirth, and A. Salehi, "Infrastructure for Data Processing in Large-Scale Interconnected Sensor Networks", Proc. of the International Conference on Mobile Data Management (MDM 07). Washington, DC, USA, May 2007, pp. 198-205. [Online]. Available: ACM Digital Library, doi: 10.1109/MDM.2007.36.

[10]. V. Stavroulaki, Y. Kritikou, and P. Demestichas, "Acquiring and Learning User Information in the Context of Cognitive Device Management", Proc. of International Conference on Communications (ICC 09), 2009, pp. 1–5. [Online]. Available: IEEE Xplore Digital Library, doi:10.1109/ICCW.2009.5208053.

[11]. FP7/ICT Coordination and Support Action (CSA) for Global RFID-related Activities and Standardization (CASAGRAS2). http://www.iot-casagras.org/. Accessed: January 2014.

[12]. Villalonga C., Bauer M., Aguilar F., Huang V.,Strohbach M. (2010), "A Resource Model for the Real World Internet", Springer, Lecture Notes in Computer Science, vol. 6446, pp 163-176, November, 2010.

[13]. Aberer, K., Hauswirth, M., Salehi, A. (2007). Infrastructure for Data Processing in Large-Scale Interconnected Sensor Networks. Proceedings of

the International Conference on Mobile Data Management (MDM '07), 198-205.

[14]. ARTEMIS project SOFIA (Smart Objects for Intelligent Applications) Jan. 2009 - Jan.2012, http://www.sofia-community.org/. Accessed Jan 2014.

[15]. Zhang L., Mitton N. (2011). "Advanced Internet of Things", Université des Sciences et Technologies de Lille, France. iThings-2011.

[16]. Lambros Sarakis, Theodore Zahariadis, Helen-Catherine Leligou, Mischa Dohler, "A Framework for Service Provisioning in Virtual Sensor Networks", Eurasip Journal on Wireless Communications and Networking, 2012.

[17]. S. Alam, Mohammad M. R. Chowdhury, J. Noll, "SenaaS: An Event-driven Sensor Virtualization approach for Internet of Things Cloud", Networked Embedded Systems for Enterprise Applications (NESEA), 2010 IEEE International Conference, November 2010.

[18]. Melazzi N. B. (2010). "CONVERGENCE: Extending the Media Concept to Include Representations on Real World Objects", The Internet of Things: 20th Tyrrhenian Workshop on Digital Communications, 129-140.

[19]. FP7/ICT- 257123 project CONVERGENCE, Jun. 2010 - Feb. 2013, Website, http://www.ict-convergence.eu/. Accessed May 2013

[20]. Every Thing Connected: How Web Object Technology is Putting Every Physical Thing on the Web, EvryThng Ltd., 2012.

[21]. X. Liu, Y. Hui, W. Sun, and H. Liang, "Towards service composition based on mashup," in Proc. of IEEE Service Computing, 2007, pp. 332– 339.

[22]. V. Hoyer, K. Stanoesvka-Slabeva, T. Janner, C. Schroth, "Enterprise mashups: Design principles towards the long tail of user needs," in Proc. of IEEE Services Computing, vol. 2, 2008, pp. 601-602.

[23]. D. Guinard, V. Trifa, T. Pham, O. Liechti, "Towards Physical Mashups in the Web of Things". Proc. of the 6th International Conference on Networked Sensing Systems (INSS), Pittsburgh, USA, 2009.

[24]. M. Marin-Perianu, N. Meratnia, P. Havinga, L. de Souza, J. Muller, P. Spiess, S. Haller, T. Riedel, C. Decker, G. Stromberg, "Decentralized enterprise systems: a multiplatform wireless sensor network approach," IEEE Wireless Communications, 2007.

[25]. L. M. S. de Souza, P. Spiess, D. Guinard, M. Koehler, S. Karnouskos, D. Savio, "Socrades: A web service based shop floor integration

infrastructure," in Proc. of the Internet of Things Conference (IOT 2008), Springer, 2008.

[26]. P. Liuha, A. Lappeteläinen, J-P, Soininen, "Smart Objects for Intelligent Applications - first results made open", ARTEMIS Magazine, October 2009, No. 5, pp. 27-29.

[27]. A. Pintus, D. Carboni, A. Piras, "Paraimpu:a Platform for a Social Web of Things", WWW, Lyon, France, 2012.

[28]. Taye, M. (2010). Understanding Semantic Web and Ontologies: Theory and Applications. Journal of Computing 2(6). ISSN 2151-9617. HTTPS://SITES.GOOGLE.COM/SITE/JOURNALOFCOMPUTING/. WWW.JOURNALOFCOMPUTING.ORG.

[29]. Matthews, B. (2005). Semantic Web Technologies. JISC Technology and Standard Watch.

[30]. W3C Standards – Semantic Web. http://www.w3.org/standards/semanticweb/.

[31]. OWL Web Ontology Language Overview. http://www.w3.org/TR/owl-features/.

[32]. Alex Rodriguez, RESTful Web Services: The basics, Nov. 2008, Available:http://www.ibm.com/developerworks/webservices/library/ws-restful/.

[33]. Resource Description Framework (RDF): Concepts and Abstract Syntax, W3C Recommendation, February 2004, Available: http://www.w3.org/TR/rdf-concepts/.

[34]. SPARQL Query Language for RDF, W3C Recommendation, Jan. 2008. Available: http://www.w3.org/TR/rdf-sparql-query/.

[35]. W3C Naming and Addressing: URIs, URLs Available: http://www.w3.org/Addressing.

[36]. Libelium, WaspMote sensor platform. Available: http://www.libelium.com/products/waspmote.

[37]. A. Somov, D. Spirjakin, M. Ivanov, I. Khromushin, R. Passerone, A. Baranov, and A. Savkin, "Combustible Gases and Early Fire Detection: An Autonomous System for Wireless Sensor Networks", Proc. of the First International Conference on Energy-Efficient Computing and Networking (e-Energy 10), Passau, Germany, April 13–15, 2010, pp. 85–93.

[38]. A. Somov, A. Baranov, A. Savkin, D. Spirjakin, A. Spirjakin, and R. Passerone, "Development of Wireless Sensor Network for Combustible Gas Monitoring", Sensors and Actuators A: Physical, vol. 171, no. 2, Nov 2011, pp. 398-405. [Online]. Available: National Library of Australia, doi:10.1016/j.sna.2011.07.016.

[39]. Arduino platform, Available: http://arduino.cc.

[40]. A. Somov, A. Baranov, A. Savkin, M. Ivanov, L. Calliari, R. Passerone, E. Karpov, and A. Suchkov, "Energy-aware Gas Sensing Using Wireless Sensor Networks", Proc. of the 9th European Conference on Wireless Sensor Networks (EWSN 12), Trento, Italy, February 15-17, 2012, LNCS vol.7158, pp. 245-260.

[41]. Cosm Connect your world. Available: https://xively.com/.

[42]. Apache Jena - A free and open source Java framework for building Semantic Web and Linked Data applications. [Online]: https://jena.apache.org/.

[43]. RDF4j API. [Online]: http://rdf4j.org/about/.

[44]. SPARQL Update. [Online]: https://www.w3.org/Submission/SPARQL-Update/.

[45]. "Are REST and HTTP the same thing?". [Online]: http://restcookbook.com/Miscellaneous/rest-and-http/.

5 COGNITIVE MANAGEMENT OF (COMPOSITE) VIRTUAL THINGS AND SERVICES IN THE FUTURE INTERNET

5.1 Chapter Outline

The IoT paradigm is expected to be a key communication platform between real world objects and the virtual realm. Nevertheless, the growing number of heterogeneous physical objects (ICT and non-ICT ones) restricts their application in the IoT. At the same time the great number of virtualized real world objects along with the respective services requires significant efforts in the IoT platform maintenance and management. In this chapter it is proposed the design and the development of a cognitive management framework for the IoT. In particular, the framework includes three levels of functionality: virtual object (virtual representation of real object enriched with context information), composite virtual object (cognitive mash-up of semantically interoperable virtual objects), and user/stakeholder levels. Cognitive entities at all levels provide the means for self-management (configuration, healing, optimization, protection) and learning. The framework is applied to enable autonomous application in the IoT through the cognitive management, as well as it is evaluated and validated on the Future Smart Cities that will be enabled by advanced IoT ecosystems.

5.2 Introduction

The dynamic/on-demand creation of complex services that will be provided to the end-users, constitute one of the most challenging topics in the context of the IoT and the Future Internet. The complex services will be created based on end-user requirements and preferences and they will be resulted as the composition of different Virtual Objects (VOs) that will be called Composite VOs (CVOs). The main challenge in this application field lies on the hiding of the processes' complexity and their automation, addressing in the same time the technological heterogeneity for the processes' integration. The introduction of the Cognitive Technologies combined with Semantic Technologies, constitutes the key factor for the support of the requirements that relate to the above challenges, and can work as key enabler for the Cognitive Management for the IoT ecosystem.

Specifically, the Cognitive Management of the IoT deals with two basic concepts: a) the realization of the abstraction of the technological heterogeneity that arise from the vast amount of things/objects and b) the user preferences involvement on the creation and the provision of complex services, maximizing the reuse capabilities of the object and the available application in the IoT ecosystems. The proposed solution to ensure the satisfaction of the above requirements lies on the design and the deployment of a Cognitive Management Framework that among others includes technologies from the Semantic and Virtualization fields. Specifically, the framework is comprised by three different functional levels: a) Virtual Object (VO) level, b) Composite VO (CVO) level and c) Application/Service level.

The exploitation of the Semantic Framework mechanisms that are proposed in this dissertation, for the enhancement of the Cognitive Management Framework and their distribution on the three available levels will enable innovative capabilities and functional features that will realize a wide set of functionalities. Indicatively, key features with added value for the Cognitive Management Framework can be considered the application of the Semantic Models, for the description of the available entities (VOs, CVOs, Services, etc.), the semantic data management, in terms of store, query and modification, as well as the management of templates and deployment files with respect to the deployment of semantically enriched virtualized things of the real world (Virtual Thing).

The evaluation and the validation of the Semantic Framework entities (mechanisms from the "Semantic Storage System" and the "Semantic Abstraction and Virtualization of Things" building blocks), as well as their added value in the Cognitive Management Framework, it is presented through a set of different scientific publications, with the most important of them to be presented in the rest of this chapter. In particular, the section 5.3 is based on the merging of the research work performed in the publications [1] and [2]. The [1] presents a cognitive management framework providing the means to enable autonomous applications in the IoT, whereas the [2] describes the application of the cognitive management framework in the context of Smart Cities IoT ecosystems. As it is described in detail in the next subsections, various Semantic Framework mechanisms work as enablers for the provision of the cognitive functionalities of the applied framework.

5.3 Cognitive Management for the Internet of Things: A Framework for Enabling Autonomous Applications

It is estimated that there will be 50 billion mobile wireless devices connected to the Internet by 2020, while the total number of devices connected to the Internet could reach 500 billion [3]. These devices include sensors, actuators, smart phones, cars, computers, home appliances, buildings and city infrastructure, etc., that will be connected to the Internet as well as with each other via heterogeneous wireless and wired access networks, with the aim of providing smart, personalized applications and services anytime, anywhere. A vast variety of Internet of Things (IoT) applications is envisaged that will assist in addressing societal challenges but will also provide solutions for automating and improving processes in the business sector, by reducing costs and increasing productivity. However current developments have mainly focused on specific applications, leading to domain-centric silos that lack flexibility and interoperability. Given the size and functional needs of the true IoT vision and especially, large scale IoT applications such as Smart Cities, several challenges need to be solved to achieve autonomicity, ubiquity, scalability, dependability and sustainability of IoT service provision. These key challenges include: (i) Increased integration of heterogeneous networks, technologies and IoT applications; (ii) Efficient addressing of the complexity of the IoT infrastructure; (iii) Increased usability of diverse "things" and applications; (iv) Support for smart, self-adaptive, autonomous applications and objects; (v) On-demand and flexible IoT service provision [4][5].

This paper presents a Cognitive Management framework targeted to overcoming these key challenges. This Cognitive Management framework has the ability to dynamically select its behaviour, through self-management functionality, taking into account information and knowledge (obtained through machine learning) on the situation/context of operation (e.g., internal status and status of environment), as well as policies (designating objectives, constraints, rules, etc.). The framework comprises three main levels of enablers, namely the Virtual Object (VO), Composite Virtual Object (CVO) and Service levels, which are reusable for the realization of diverse applications [4]-[6]. Three main processes of this framework, enabling autonomous IoT application are presented in this paper: the Dynamic CVO creation, the Knowledge-based CVO Instantiation and the Self-healing of a CVO. The remainder of this paper is organized as follows. First, an overview of related work is given and the innovation of the work addressed in this paper is highlighted. An overview of the aforementioned Cognitive Management framework is provided, and some indicative operation processes are presented. Finally, the paper presents a first prototype implementation of this framework as well as corresponding derived results that demonstrate high potential towards the self-reconfigurable IoT.

5.3.1 Related Work and Contribution

This section provides an overview of selected related work on IoT architecture, VOs, CVOs and cognitive management and aims to highlight the added value of this work with respect to existing work.

A key challenge for the realization of the IoT, as already introduced, will be to overcome the heterogeneity of diverse objects, in terms of their features as well as the network technologies exploited for their interconnection. This can be achieved through the virtualization of these objects [7]. In [8], the complexity of large scale sensor networks is addressed through the virtual abstraction of sensors. Identification of objects is another important issue that needs to be tackled efficiently. Radio-frequency identification (RFID) can be exploited for this purpose [9][10]. The authors in [9] follow the representation strategy, while the authors in [10] exploit ontologies. In addition, there are a number of European projects addressing some of the issues related to the IoT and especially, the management of Real World Objects (RWOs). In the SENSEI project approach [11] the digital world has been divided into three abstractions, resources, entities and resource users for addressing a large number of globally distributed wireless sensor and actuator networks. In the EBBITS project [12] every subsystem or device is virtualized through a web service with semantic resolution. Abstract representation models for integrating the physical with the virtual world, in the SOFIA project [13]. In [14] the authors present a description language that allows the identification and interconnection of objects and events utilizing a standard format. The CONVERGENCE project [15] introduced a common container for any kind of digital data, including representations of services, people and RWOs. The IoT-A project [16] has specified an architectural reference model that comprises a set of building blocks that provide appropriate functions to allow the interoperability and connection between IoT entities.

A number of initiatives have also addressed the concept of "mash-ups" in the scope of user generated composite applications and for the integration of the physical and virtual worlds [17]-[20]. These approaches focus on enabling users to create mash-ups from a combination of available real world objects/devices and services.

Cognitive wireless systems emerged as a solution towards addressing the complexity in emerging and future composite radio networks [21]. Numerous research efforts in radio communication have focused on cognitive technologies for the efficient management of resources and components in future networks. In particular, the E3 project [22] following the "cognitive radio" and "cognitive network" paradigms, suggested a distributed architecture over different network elements in order to introduce cognitive and self-x functionalities into different communication components in future networks. The OneFit project [23] realized the vision of opportunistic networks, which are managed and coordinated with the infrastructure, by advanced cognitive systems, introducing a set of cognitive mechanisms that can support the management of opportunistic networks and their coordination with infrastructure networks. The UniverSelf project [24] aims at overcoming the growing management complexity of future networking systems, and to reduce the barriers that complexity and ossification pose to further growth.

The cognitive management framework presented in this paper capitalizes on these efforts, applying cognitive technologies for the management of objects and applications in the IoT. As already introduced, this paper presents cognitive management mechanisms so as to enable autonomous IoT applications through the dynamic creation, deployment, self-configuration and self-management of VOs and CVOs and reuse of existing RWOs outside the context and domain for which these were developed. In this framework, any type of RWOs can be represented in various ways, independent of a particular single technology, as in [9] and [10]. The VO concept is introduced as a dynamic virtual representation of RWOs and the CVO concept further enhances this dynamic representation capability. The intention is not to create new digital representations/objects, but to use the concepts that already exist in the domain (representing IoT resources as services, e.g. [25]), and merge them into advanced, intelligent representations, which are exploitable by existing and new applications. A VO can be dynamically created and destructed, may consist of information and services and is a dynamic object since it has to represent dynamically changing RWOs. A CVO, which can also be dynamically created and destructed, represents a collection of information and services from partial digital images of the world and their virtual objects. CVOs are created in an autonomous manner given: (i) the requirements coming from the service/stakeholder level and (ii) the capabilities offered by available VOs. The CVO concept leads to autonomous, intelligent services/applications, fulfilling requirements (also from hidden stakeholders), while details and complexity are hidden from end users. In this sense, this work is closely related to the concepts presented in [19], [26], but also combined with cognitive management concepts. Furthermore, self-managed and self-configurable CVOs represent a collection/"mash-up" of information and services from VOs, contrary to [12] where a single service or application is provided from each object.

5.3.2 Cognitive Management Framework Overview

This section provides a high-level view of the Cognitive Management framework (Figure 14) [5][6] for enabling autonomous applications and efficient service provisioning in the Internet of Things. This framework comprises three levels of functionality. From a bottom-up perspective these are the VO level, the CVO level and the Service/stakeholder level. Cognitive entities at all levels provide the means for self-management (configuration, healing, optimization, protection) and learning. In this respect, they are capable of perceiving and reasoning on context (e.g. based on event filtering, pattern recognition, machine learning), of conducting associated knowledge-based decision-making (through associated optimization algorithms and machine learning), and autonomously adapting their behaviour and the configuration according to the derived situation. The aim of the proposed Cognitive Management framework is to enhance context-awareness by providing the means to exploit more objects, render high reliability through the ability to use heterogeneous objects in a complementary manner for reliable service/application provision, and improve energy-efficiency through the selection of the most efficient and suitable objects from the set of heterogeneous ones, and, in general, through the optimal management of a large population of resource constrained devices.

5.3.2.1 VO Level

The VO level comprises VOs that represent RWOs. RWOs can be distinguished in Information and Communication Technology (ICT) enabled objects and objects that are not ICT-enabled (hereafter termed non-ICT objects). Sensors and actuators can be identified as ICT enabled objects. In particular, sensors can be exploited for acquiring various types of data, while actuators enable the enforcement of appropriate actions. The state of non-ICT objects can be retrieved, influenced or controlled through one or more ICT enabled objects attached to them. VOs are linked to one RWO, which may provide one or more than one functions. The aim of VOs is to allow for the introduction of new objects/devices and the removal or replacement of existing elements in a "plug ‛n play" fashion. VOs provide a high-level (generic) interface to devices/objects abstracting the complexity of the underlying

IoT infrastructure (in terms of devices/objects and networking technologies used for their interconnection). VOs allow for the description, discovery and exploitation of objects/devices. Information regarding each VO is stored in the VO Registries of this level. In this manner, the type of a VO, the object that is connected to, the functions that it can provide, its features and other related data can be acquired by querying these registries.

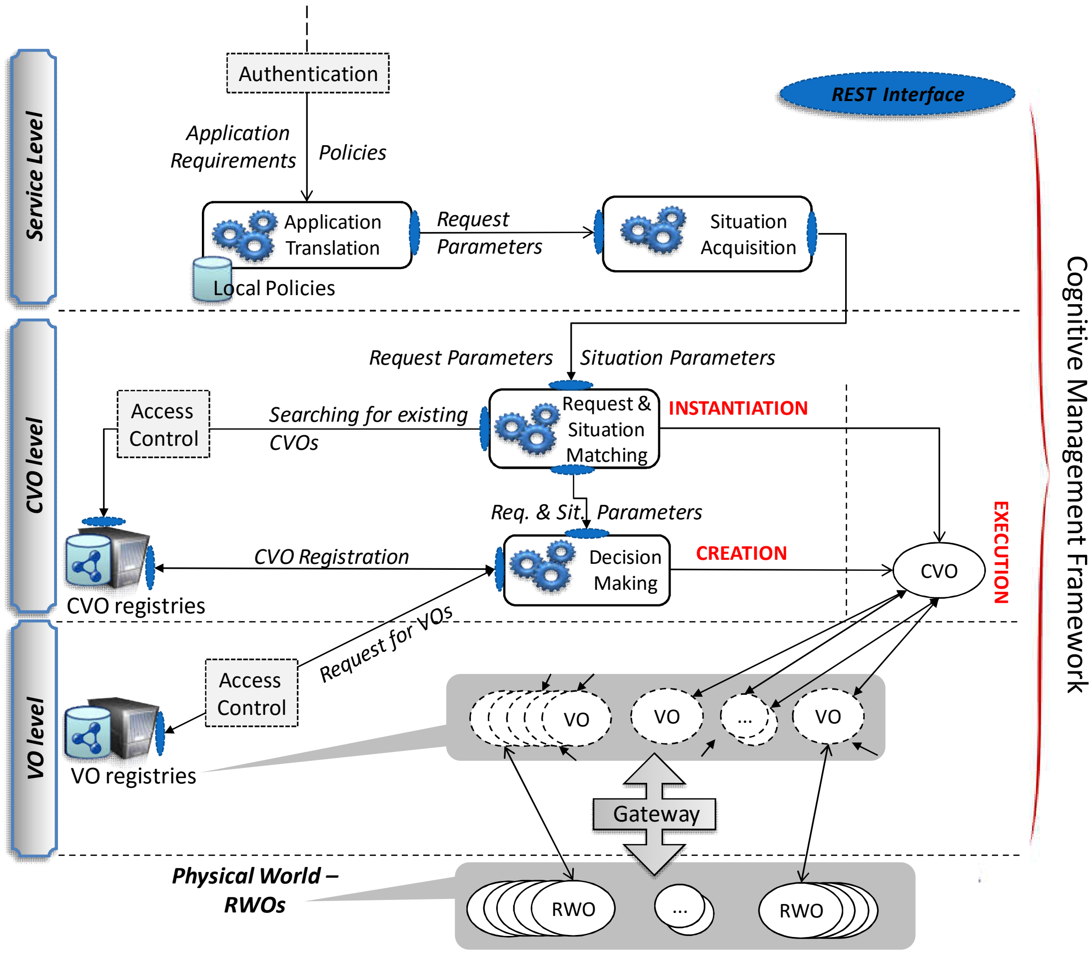


Figure 14: Cognitive Management Framework Overview [2]

5.3.2.2 CVO Level

A service can be realized through the composition of functions of one or more VOs and/or CVOs. CVOs can be dynamically created, in order to offer a particular service/application. Information regarding these CVOs can be found in the CVO Registries of this level. This information includes features of the CVOs and data regarding the conditions under which they were created, as well as information on the VOs comprised in a particular CVO. Moreover, at this level, there are two further key components of the Cognitive Management framework, i.e. Request and Situation

Matching and Decision Making. The Request and Situation Matching component comprises functionality for building knowledge and experience related to CVOs created in the past. The derived knowledge is then exploited in order to enable reaching reliable decisions faster. In other words, this component is responsible for searching for already existing CVOs that can fulfill the requested service requirements, thus enabling the reuse of already existing CVOs, in order to increase efficiency in terms of time, computation and resource savings. More specifically, information/knowledge stored in the CVO Registries is exploited and a similarity metric-based matching algorithm searches and finds an adequate match (if available) based on a specific threshold. In case this component cannot succeed in this target (because no suitable CVO is yet available), it triggers the Decision Making component for the optimal composition of VOs, which will dynamically create a CVO according to the requested functions and policies. To this end, an objective function is utilized, with the goal of maximizing the value of the CVO that will be created (in terms of encompassed features such as performance, energy efficiency, cost, etc).

5.3.2.3 Service Level

The Service level allows users/stakeholders to define features of a required service/application through appropriate interfaces and provides functionalities for autonomously deriving the requirements for the requested service. These requirements consist of the functions required for fulfilling a certain service, the policies for various functions features (e.g. performance, energy efficiency, etc) and in addition a number of situation parameters (e.g. time, location, desired level of luminosity, etc). At this level, there are two more components of the Cognitive Management framework: Situation Acquisition and Application Translation. The Situation Acquisition component evaluates the conditions under which a service/application was requested and provides the corresponding situation parameters (e.g. time, location). The Application Translation component infers the functions and the policies from the user's request, which is received from a dedicated User Interface. Moreover, learning mechanisms are exploited for obtaining and learning information on user preferences. All this information is then forwarded to the CVO level for the dynamic composition of VOs and the instantiation of the corresponding CVOs.

5.3.2.4 Cognitive Features

Cognitive features can be identified in all three levels of this framework, exploiting optimization, machine learning and pattern recognition techniques. In particular, in the VO level, optimization and learning techniques are used in order to select the optimal links between VOs and RWOs and additionally, to forecast problematic links and propose alternative ones. In the CVO level, learning techniques are used for acquiring situation information and exploiting this information for the instantiation and re-use of CVOs. More specifically, pattern recognition techniques are exploited for this purpose to propose CVOs that can be reused for a certain requested service/application. Optimization techniques are exploited for evaluating candidate VOs and creating optimal CVOs. Finally, at the service level, semantic reasoning is used for the translation of the request and the derivation of the application requirements, while learning techniques are used for obtaining information on user/stakeholder preferences.

5.3.3 Framework Operation

This section presents aspects of the operation of the proposed Cognitive Management framework through three main processes it enables, namely Dynamic CVO creation, Knowledge-based CVO Instantiation and Self-healing of a CVO. The first process is targeted to the creation of a CVO "from scratch" and offers the requested service/application to the users, the second process offers a service/application, achieving time and resource savings through the reuse of an already existing CVO and the third process sustains the functionality of this service/application, in case of faults and misbehaviors. To this end, the dynamic CVO creation evaluates VOs and creates a CVO, the knowledge-based CVO instantiation evaluates already existing CVOs to propose one to be reused and the self-healing of a CVO evaluates VOs to replace a malfunctioning one in a composed, running CVO.

5.3.3.1 Dynamic CVO Creation

A user requests a service and declares the importance of service/application function features, denoted as policies, which should be respected by the system. This request is captured through the User Interface at the Service level and is forwarded to the Application Translation, which derives, from the overall issued service request, the requested functions and defined policies. This information is forwarded to the Situation Acquisition component that examines the situation parameters and forwards these, as well as the requested functions and defined policies to the Request and Situation Matching component. Moreover, learning mechanisms provide information regarding the user preferences. The Request and Situation Matching component searches for an already existing CVO that can fulfill the request, in the CVO Registry. If this reuse of a CVO is not possible, then it forwards the relevant information to the Decision Making component, in order to create an optimal composition of VOs, according to requested functions and policies. For this purpose, information on available VO features and provided functions (VO descriptions) are retrieved from the VO Registry. Once a CVO is created, the request, associated situation parameters and CVO composition (e.g. comprised VOs) are recorded in the CVO Registry, in order to ensure that if a similar contextual situation occurs again, the solution may be retrieved directly. Finally, the created CVO provides the requested service/application to the user.

5.3.3.2 Knowledge-based CVO Instantiation

This process enables the reuse of an already existing CVO. The steps of the previous operation are repeated until the request is received by the Request and Situation Matching component. At this point the service request and situation information can be compared with records in the CVO Registry for an adequate match. Past records corresponding to CVO components (VOs) with functions that are unavailable in the current situation (either exact or approximate ones) are filtered out, as they definitely cannot fulfil the service goals. The remaining records are ranked based on a satisfaction-rate similarity metric and the highest ranked one is tested against a pre-defined similarity threshold. The satisfaction-rate depends on the amount of total requested functions being available as well as their correlations and it is calculated as a score (i.e. a sum) of these correlations between the set of the requested and the required CVO functions. Apart from the functions, for the calculation of the overall similarity metric also the rest of the situation and request parameters (requested policies, time of request, area of interest, available VOs) are taken into account. The similarity threshold is derived from the user preferences and from learning mechanisms that exploit user feedback/ratings for past CVOs. If the overall similarity metric for an existing CVO equals or exceeds this threshold, then this existing CVO can be considered as suitable for a newly issued request. In this way the CVO level components can apply known solutions as a response to a service/application request, thus, reducing the time needed for handling of requests from the Service level.

5.3.3.3 Self-healing of a CVO

The self-healing process enables the detection of a problem in the operation of a used RWO/VO and dynamic reconfiguration of the corresponding CVO (and consequently application) to overcome the problem. This process is triggered when a VO failure is identified due to an RWO becoming unreachable (e.g. due to loss of connectivity of the VO with RWO, RWO hardware failures, etc). A Reconfiguration request is issued from the Request and Situation Matching to the Decision Making component. The Decision Making component then selects the most appropriate VO (and consequently RWO) for replacing the problematic VO. Information on the reconfiguration of the CVO is stored in the CVO Registry, to be exploited for future similar CVO creations/instantiations.

5.3.4 Case study validation

This section intends to demonstrate the use of the proposed IoT cognitive management framework and the cross-application nature of objects in one smart city scenario. The smart city scenario connects horizontally several application domains and more specifically the smart health / smart home / smart living, the smart transport and the public safety. Smart Cities are actually a real driver for connecting application domains. Furthemore, it is presented the perfrormance assessment of the framework operations, including detailed results of the mechanisms execution, complemented with their evaluation.

5.3.4.1 Storyline summary

This scenario refers to how the proposed framework may be exploited to protect and facilitate the daily life in the smart city. Sarah, an elderly woman, has opted for an assisted living service that is provided by a medical centre. A doctor, who monitors Sarah's health remotely from the medical centre, receives an alarm that Sarah has fainted. An ambulance is informed to run for assistance of Sarah. A smart driving application is used by the ambulance, so as to reach Sarah's home as faster as possible.

5.3.4.2 Proof Of Concept description

The storyline introduces three different smart city applications domains (smart health, public safety, smart transport). The situation in each domain requires a respective CVO, namely (a) the CVO in the medical centre for the monitoring of Sarah's health and of the environmental conditions in the smart home, (b) the CVO in the police department for the traffic jam monitoring and (c) the CVO in the smart vehicle for the smart driving in the city roads.

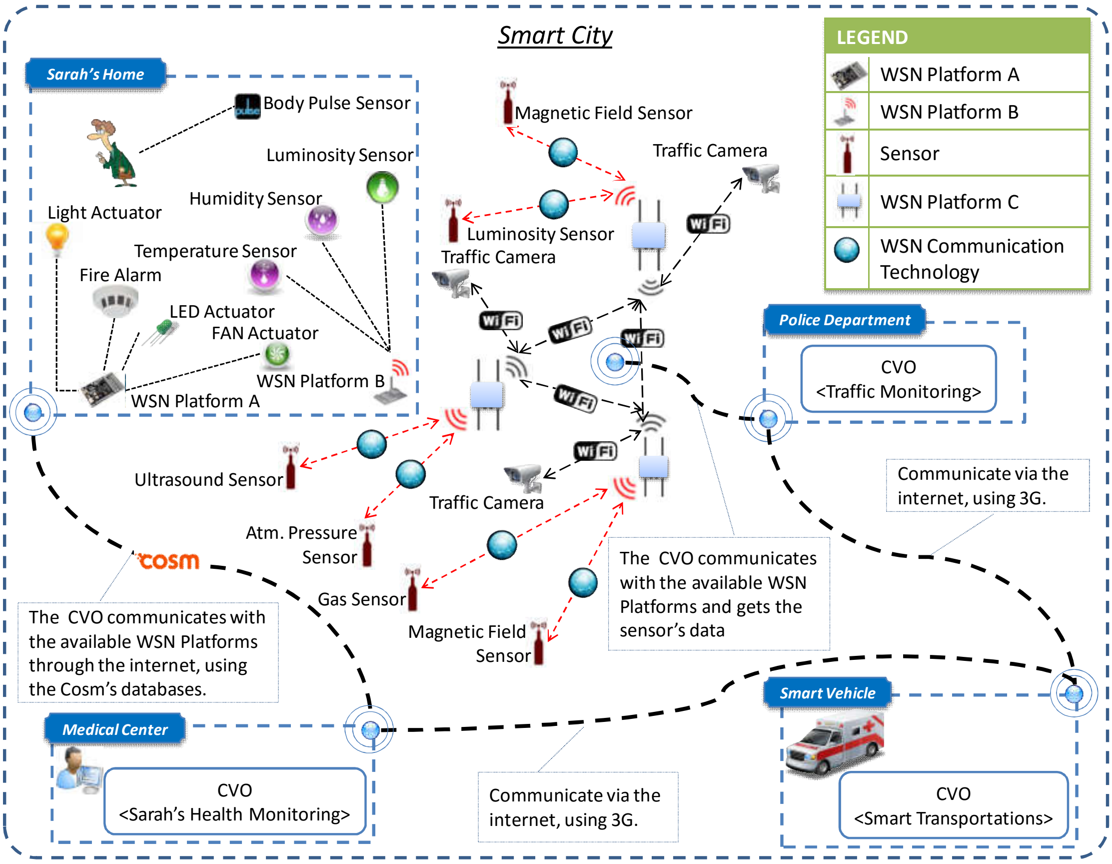


Figure 15: Smart City scenario implementation aspects [2]

The use case workflow is depicted in that is associated with the scenario description in section 5.3.4.1 would be presented as follow. Initially, the request parameters (e.g. Sarah's Pulse, Room Temperature, Alarm (in the medical centre and in the smart home) etc.) and the situation parameters (e.g. Sarah's location, time, available VOs representing a body pulse sensor, a temperature sensor, a fire alarm etc.) are extracted by Application Translation and Situation Acquisition to be used for deriving the CVO in the medical centre. The scenario assumes that an appropriate existing CVO cannot be found by RSM, so that DM selects the appropriate VOs and triggers the creation of a new CVO. The fire alarm is selected to play the role of the alarm in the smart home based on proximity. This selection of an object to deliver an application requirement ("raise an alarm") in an approximate way ("can make noise") enhances the resilience of the offered by the CVO service in absence of other more appropriate objects. The CVO is then executed.

When Sarah faints, the CVO becomes aware of the accident, since it receives periodic measurements from the body pulse VO and compares them with a predefined threshold. An alarm is raised by the CVO in both the smart home (fire alarm) and the medical centre, the last one being automatically transmitted to an ambulance, potentially with some policies about the seriousness of incident. The ambulance requests a CVO for the smart driving, so as to find the best itinerary to Sarah's home and save valuable time. The RSM mechanism finds and instantiates an existing CVO that matches the incoming request. This CVO receives input data from the 'Traffic Monitoring' CVO in the police department, which combines real-time data from different types of sensors (e.g. cameras, Gas Sensors, Magnetic Field Sensors (MFSs)) and infers about the traffic status in the city's streets. For instance, if the MFSs detect many cars and the Carbon Dioxide levels are higher than a value, it can infer that there is a traffic jam in the specific area.

The implementation aspects are depicted in Figure 15. The emulated smart city includes the smart home of Sarah that is equipped with actuators and sensors hosted by Wireless Sensor Network (WSN) Platforms A and B respectively. The CVO in the medical centre uses the Cosm on-line database service, in order to get the sensor measurements from WSN Platform B as well as to send the actuator commands to WSN Platform A. In the smart city, there are various types of sensors, which are connected with the type of WSN Platform C using various access technologies and/or communication protocols (e.g. ZigBee, Bluetooth, Wi-Fi, etc) sharing their data. The CVO in the police department receives data from the distributed platforms of type C in order to infer about the traffic status in the city streets.

5.3.4.3 Performance evaluation

A number of experiments have been performed on the implemented prototype platform in order to assess its performance and validate the efficiency of the proposed Cognitive Management framework, in terms of execution time and amount of bytes required for the various components of the framework to accomplish their task. In addition, the value of the CVO and the overall time needed for its instantiation have been explored for the three processes. In the following figures, results for eight different cases are presented, which vary in the number of considered available VOs that could possibly be exploited, thus also showing some aspects of the scalability of the proposed mechanisms. Each experiment has been repeated five times. The outcomes were quite similar in each repetition, however in the results presented in the following the corresponding mean times are depicted, for the sake of accuracy. In all cases, the requested CVO was instantiated successfully. The related experimentation results, as well as the conclutions and the evaluation of them, is described in the rest of this section.

Initially, the Figure 16 presents the evolution of the execution time required for the Request and Situation Matching component operation as the number of considered available VOs increases. As can be observed, this execution time remains relatively constant, around 9 msec. Thus, it can be concluded that this process is not affected by the number of available VOs in the area of interest.

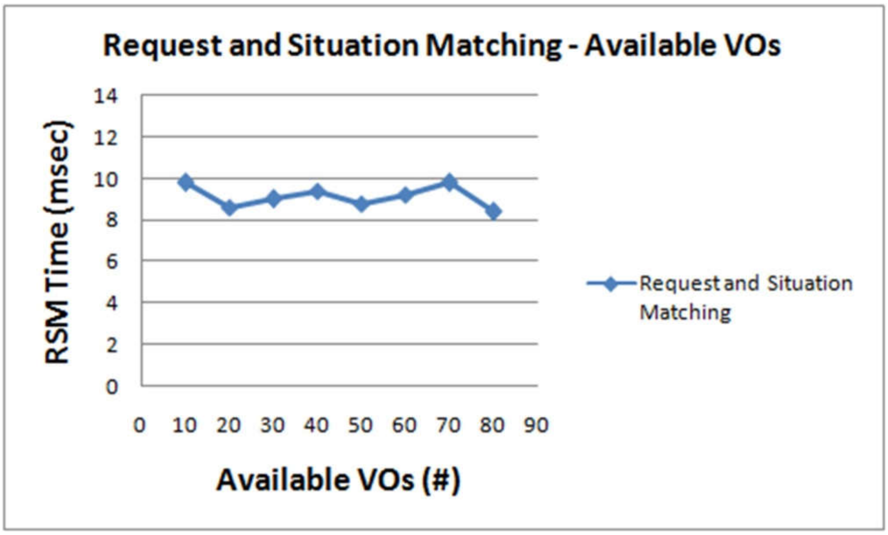


Figure 16: Request and Situation Matching Execution Time

The Figure 17 shows the evolution of the execution time for the Decision Making component as the number of considered available VOs increases. This duration corresponds to the optimization process of selecting the appropriate VOs for the creation of the optimal CVO. In particular, two algorithms have been utilized for the implementation of this mechanism; the CPLEX [28] algorithm for finding the optimal composition of functions of VOs or the Decision Making Heuristic Algorithm (DMHA) that finds the optimal solution for each requested function separately and combines them in order to compose the optimal CVO. The DMHA algorithm is more time efficient than the CPLEX. Moreover, the time required for both algorithms increases, as the number of the available VOs in the area increases. Nevertheless, this duration can be considered as short.

Figure 17: Decision Making Execution Time

The Figure 18 depicts the evolution of the time required for discovering available VOs and retrieving corresponding information from the VO Registry as the number of relevant available VOs increases. As can be observed this process is affected by the increase in the number of considered VOs. However, it should be noted that due to the fact that this time mainly influences the set-up/creation time of a CVO (prior to its execution) it does not influence the efficiency of running CVOs (IoT applications).

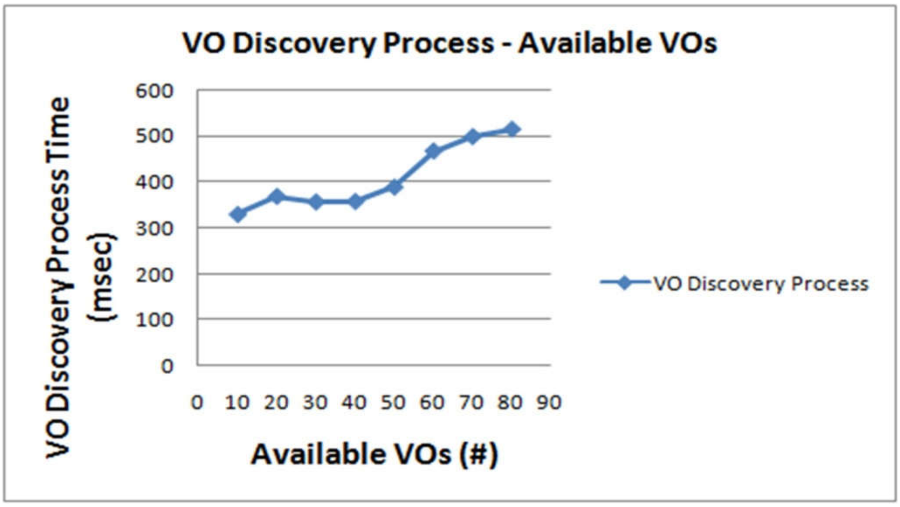


Figure 18: VO Discovery Process Execution Time

The Figure 19 depicts the value of the composed CVO, in terms of comprised features such as performance, energy efficiency, etc. As the number of VOs increases, it is possible that the CVO value increases due to the existence of more suitable VOs, in terms of offered functions and features of these functions (e.g. VOs that correspond to RWOs that exhibit improved performance).

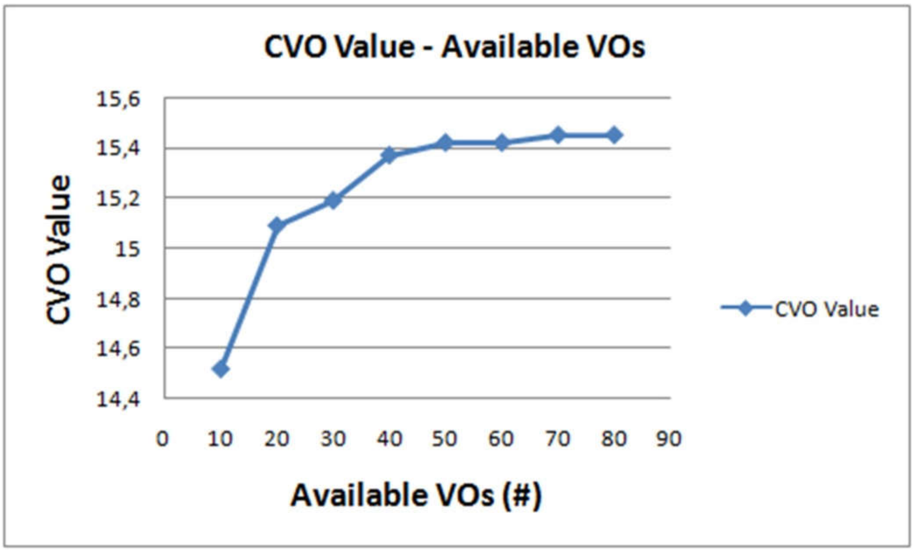


Figure 19: CVO Value

The amount of bytes that were received from each functional component has been recorded and depicted in Figure 20. As can be observed, the number of received bytes is similar for the Request and Situation Matching and the Decision Making components. This is anticipated as the major portion of this data corresponds to the information that is received from the VO Registry for the requested VOs. Both of the aforementioned components acquire information on VOs from the VO Registry. Furthermore, as expected this amount of bytes increases as the number of considered available VOs increases.

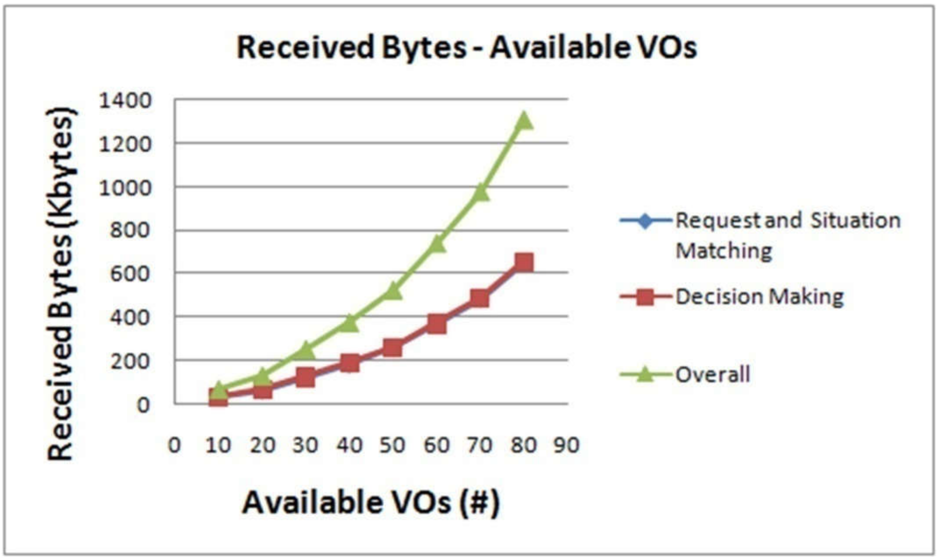


Figure 20: Received bytes vs. Number of available VOs

Finally, the Figure 21 presents the overall picture of the framework performance, including the three different supported operations. Specifically, the diagram presents the overall time that is required for the three processes to accomplish their task. As can be observed, the creation of a CVO from scratch demands more time, as it depends on the evaluation of the available VOs according to the requested functions and policies. The processes for Knowledge-based instantiation of a CVO and Self-healing of a CVO demand much less time in comparison with the CVO creation. The Knowledge-based instantiation mainly depends on the Request and Situation Matching execution time, while the CVO Self-healing essentially involves the Decision Making for selecting a particular VO. Both of these components, as also presented in the previous figures, are quite time efficient.

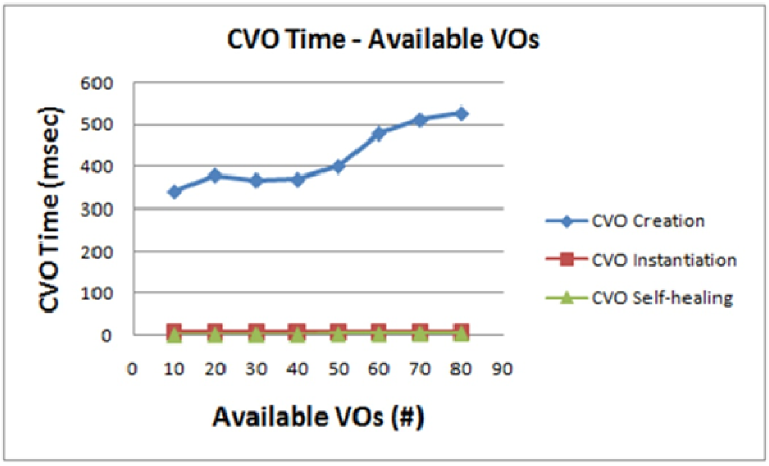


Figure 21: CVO Execution overal time for the three different operations

Throught the result observation, as well as aiming to provide the evaluation of the framework application in the described PoC, a set of benefits have been highlighted. Specifically, the benefits of the framework can be summarized to the following: (a) easy creation and delivery of added-value services from business actors allowing them to increase profits and market share, (b) service provision dynamically tailored to the needs of end users, even being able to act on behalf of them, (c) decrease on Capital Expenditures for telecom and service providers due to a gradual replacement of legacy technology enabled by VO abstraction without disrupting the currently delivered services, (d) development of innovative cross-domain applications due to CVO abstraction, (e) support of large-scale networking through cognition, (f) reduced OPEX in terms of time, maintenance, energy consumption via cognition / proximity, (g) decrease on time-to-market by reusing available VOs and (h) new business roles as (C)VOs may be owned by different stakeholders.

5.3.5 Concepts Implementation

The proposed Cognitive Management framework has been implemented in the context of the Smart City PoC, described in the section 5.3.4.2. The current corresponding implementation comprises, apart from software components for the various functional components presented in the previous, as well as of a number of real world object that corresponds to actual sensors and actuators. In particular, Arduino and WaspMote platforms have been combined with a variety of sensors (such as luminosity, temperature, humidity, and location), actuators, a (Zigbee-enabled) Gateway, as well as various software technologies such as RESTful Web Services, JSON, RDF, SPARQL, Sesame API, etc. An OWL ontology has been developed which includes all appropriate metadata (e.g. offered functionalities, access rights and features [6][27]) for the description of VOs, CVOs and Services. The semantic data that describe the instantiated CVOs is stored in Semantic Repositories implemented with RDF4j API.

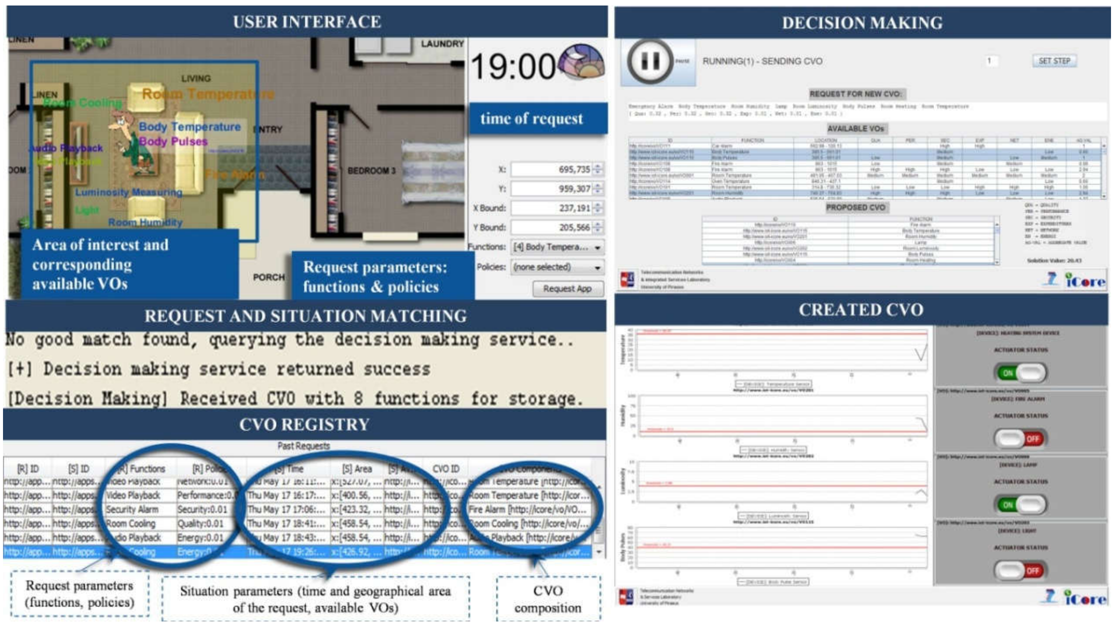


Figure 22: Overview of the Cognitive Management Framework implemented components involved in Dynamic CVO Creation

Specifically, the CVO Registry stores and provides semantically enriched data on the existing CVOs. This information can be utilized for the re-usability of CVOs and includes information on the context in which CVOs have been created and/or activated. Such context information may comprise the requirements coming from the service level, the time of day, the creation/activation domain, etc. It should be noted that there may be various, CVO registries which may be distributed across several domains, while the information can be exploited by machine learning and knowledge functionality to link the current requirements for a CVO, with previously encountered requirements and consequentially other, existing, VOs and CVOs.

At this point it should be highlighted that the exploitation of the VO Level semantics as well as of the CVO Lovel semantics, constitute a critical process for the realization of the framework operations as they have described in the section 5.3.3. Specifically, the VO semantics, that is stored in the VO Registry, is used by the decision making mechanism allowing the dynamic creation of decisions with respect to the composition of virtualized objects that will compose the CVO. Additionally, the semantic data that is stored in the CVO Registry and essentially constitute the description of the corresponding CVO, enable the dynamic instantiation of existing CVOs and their reusability into different application/services contexts.

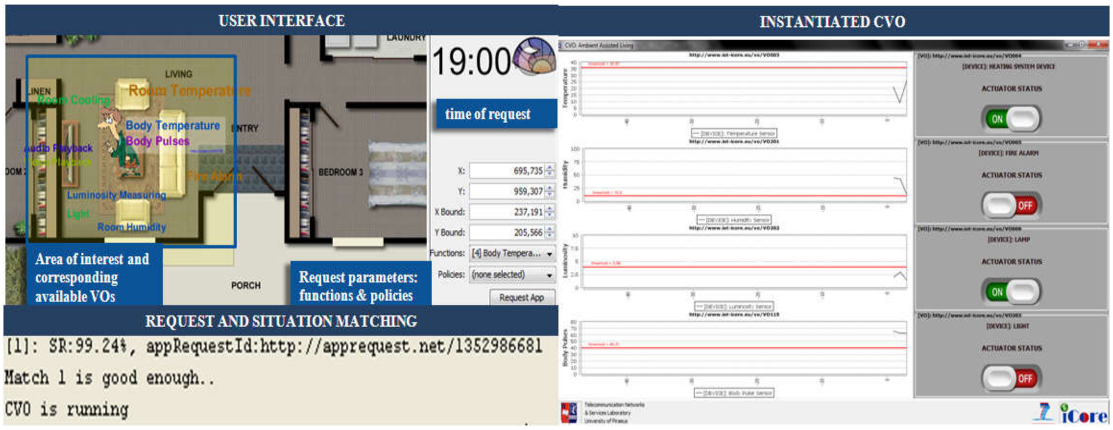


Figure 23: Overview of Cognitive Management Framework implemented components involved in Knowledge-based CVO Instantiation

Finally, the VO Level interactions among the software modules and the real world objects, such as the ICT devices, include the sensing and actuation streams, that essentially realize the interaction of RWOs with the Cognitive Management framework. The implementation approaches followed for the realization of the streams, lie on two different ways: a) using TCP/IP sockets and direct connections to the WSN gateways and b) with the use of VO Container that includes the implemented VOs as RESTful web services. Indicative views of the framework components user interfaces for its operation in the context of the smart city scenario are presented in the figures: Figure 22 to Figure 24.

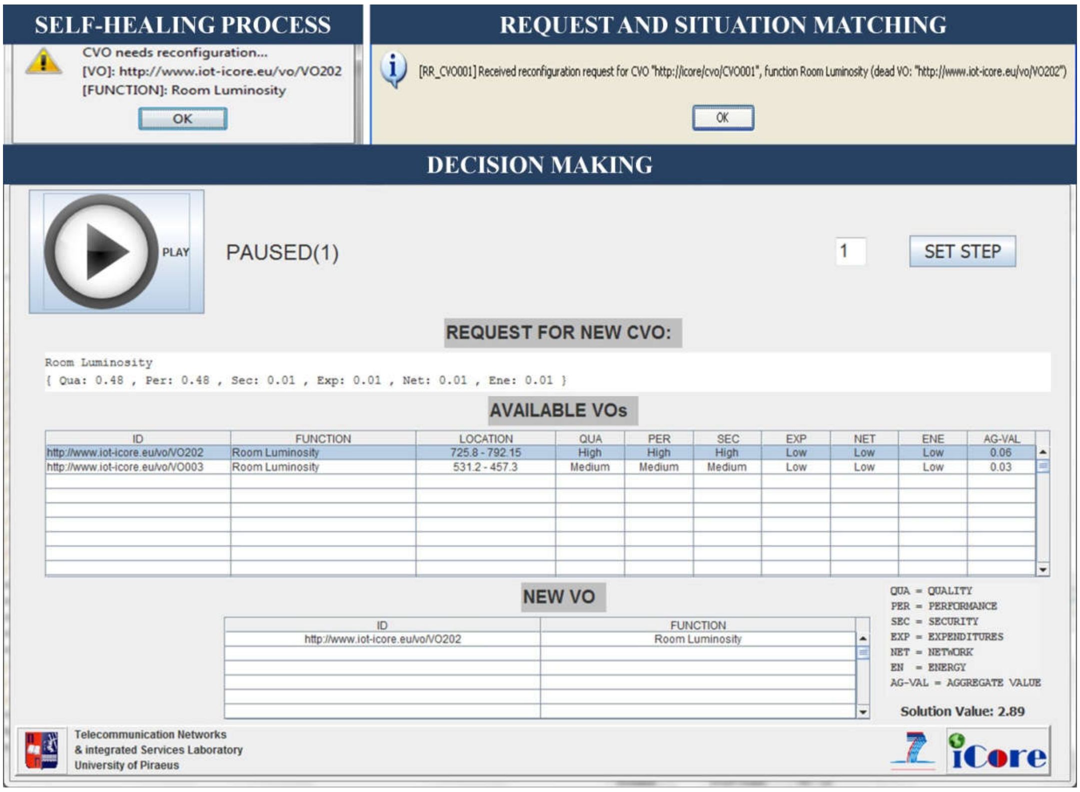


Figure 24: Overview of Cognitive Management framework components involved in Self-healing of a CVO

5.3.6 Conclusions

This work presented a Cognitive Management framework for addressing the complexity and technological heterogeneity of the envisaged IoT infrastructure and facilitating the development of new IoT applications and the re-use of objects/devices across various domains. The exploitation of such a platform will enable the faster development of more and better IoT services and applications, taking into account requirements from various stakeholders and will also allow for greater flexibility, reliability and efficiency of the IoT infrastructure. The reusability of objects (equipment/software) can reduce the CAPital EXpenditures (CAPEX) for the service provider/manufacturer. Furthermore, the reusability of already utilized resources, the optimum resource utilization as well as the support of policies (e.g. energy efficiency) can increase OPeration EXpenditures (OPEX) savings. Also, autonomic reconfiguration of CVOs (self-healing process) can reduce the OPEX for the service provider. Consideration of user preferences and the provided user friendliness can increase the satisfaction for end users and consequently increase the funds for the service provider. The paper started from an overview of the proposed Cognitive Management framework, highlighting the features of its main components. The operation and the corresponding interactions among the Cognitive Management framework components were described. The key features of the corresponding Cognitive Management framework implementation were presented as well as indicative performance results, showcasing the efficiency of the proposed framework components.

5.4 Chapter References

[1]. Vassilis Foteinos, Dimitris Kelaidonis, George Poulios, Panagiotis Vlacheas, Vera Stavroulaki, and Panagiotis Demestichas. (2013). "Cognitive management for the Internet of things: A framework for enabling autonomous applications". Vehicular Technology Magazine, IEEE, 8(4), 90-99.

[2]. Panagiotis Vlacheas, Raffaele Giaffreda, Vera Stavroulaki, Dimitris Kelaidonis, Vassilis Foteinos, George Poulios, Panagiotis Demestichas, Andrey Somov, Abdur R. Biswas, and Klaus Moessner. (2013). "Enabling smart cities through a cognitive management framework for the internet of things". Communications Magazine, IEEE, 51(6), 102-111.

[3]. OECD (2012), "Machine-to-Machine Communications: Connecting Billions of Devices", OECD Digital Economy Papers, No. 192, OECD Publishing http://dx.doi.org/10.1787/5k9gsh2gp043-en.

[4]. FP7/ICT-287708 project iCore (Internet Connected Objects for Reconfigurable Eco-systems) Website, http://www.iot-icore.eu, accessed Aug. 2013.

[5]. V. Foteinos, D. Kelaidonis, G. Poulios, P. Vlacheas, V. Stavroulaki, P. Demestichas, "A Cognitive Management Framework for Service Provisioning in the Internet of things", in Proc. of Future Network & Mobile Summit 2013, Lisbon, Portugal, 3-5 July 2013.

[6]. D. Kelaidonis, A. Somov, V. Foteinos, G. Poulios, V. Stavroulaki, P. Vlacheas, P. Demestichas, A. Baranov, A. Rahim Biswas, R. Giaffreda, "Virtualization and Cognitive Management of Real World Objects in the Internet of Things" in Proc. of The IEEE International Conference on Internet of Things, iThings 2012, Besancon, France, 20-23 November 2012.

[7]. E. De Poorter, I. Moerman, P. Demeester, (2011). Enabling direct connectivity between heterogeneous objects in the internet of things through a network-service-oriented architecture. EURASIP Wireless Communications and Networking, 1, 1-14.

[8].K. Aberer, M. Hauswirth, A. Salehi, (2007). Infrastructure for Data Processing in Large-Scale Interconnected Sensor Networks. Proceedings of the International Conference on Mobile Data Management (MDM '07), 198-205.

[9].K. Romer, T. Schoch, F. Mattern, T. Dubendorfer, (2004). Smart Identification Frameworks for Ubiquitous Computing Applications. J. Wireless Networks 10(6), 689-700.

[10]. CSA for Global RFID-related Activities and Standardisation (CASAGRAS2), http://www.iot-casagras.org/. Accessed Aug. 2013.

[11]. FP7-ICT-215923 project SENSEI (Integrating the Physical with the Digital World of the Network of the Future), Jan. 2008 - Dec. 2010, Website, http://www.sensei-project.eu/, Accessed Aug. 2013.

[12]. FP7/ICT- 257852 project EBBITS (Enabling the Business-Based Internet of Things and Services), http://www.ebbits-project.eu/. Accessed Aug. 2013.

[13]. ARTEMIS project SOFIA (Smart Objects for Intelligent Applications) Jan. 2009 - Jan.2012, http://www.sofia-community.org/ Accessed Aug. 2013.

[14]. L. Zhang., N. Mitton (2011). Advanced Internet of Things, Universite des Sciences et Technologies de Lille, France. iThings-2011.

[15]. FP7/ICT- 257123 project CONVERGENCE, Jun. 2010 - Feb. 2013, Website, http://www.ict-convergence.eu/. Accessed Aug. 2013.

[16]. FP7/ICT-257521 project IoT-A (Internet of Things Architecture), Sep. 2010 - Aug. 2013, Website http://www.iot-a.eu/. Accessed Aug. 2013.

[17]. X. Liu, Y. Hui, W. Sun, and H. Liang, "Towards service composition based on mashup," in Proc. of IEEE Service Computing, 2007, pp. 332– 339.

[18]. V. Hoyer, K. Stanoesvka-Slabeva, T. Janner, C. Schroth, "Enterprise mashups: Design principles towards the long tail of user needs," in Proc. of IEEE Services Computing, vol. 2, 2008, pp. 601-602.

[19]. D. Guinard, V. Trifa, T. Pham, O. Liechti "Towards Physical Mashups in the Web of Things". Proc. of the 6th International Conference on Networked Sensing Systems (INSS), Pittsburgh, USA, 2009.

[20]. P. Liuha, A. Lappeteläinen, J-P. Soininen, "Smart Objects for Intelligent Applications - first results made open", ARTEMIS Magazine, October 2009, No. 5, pp. 27-29.

[21]. J. Mitola,. Cognitive radio: An integrated agent architecture for software defined radio. Ph.D. dissertation. Royal Institute of Technology (KTH), Stockholm, Sweden, 2000.

[22]. FP7/ICT-216248 project E3 (End-to-End Efficiency), Jan. 2008 - Jan. 2010, Website: http://www.ict-e3.eu. Accessed Aug. 2013.

[23]. FP7/ICT-257385 project OneFIT (Opportunistic networks and Cognitive Management Systems for Efficient Application Provision in the Future InterneT, ICT-2009-), Jul. 2010 – Dec. 2012, Website: http://www.ict-onefit.eu. Accessed Aug. 2013.

[24]. FP7/ICT-257513 project UniverSelf (Universal Self-Management) Sep. 2010 - Aug. 2013, Website. http://www.univerself-project.eu/. Accessed Aug. 2013.

[25]. S. De, P. Barnaghi, M. Bauer, S. Meissner, "Service modelling for the internet of things," in Computer Science and Information Systems (FedCSIS), 2011 Federated Conference on, Sept. 2011, pp. 949 –955.

[26]. D. Guinard, V. Trifa, F. Mattern, E. Wilde, "From the Internet of Things to the Web of Things: Resource Oriented Architecture and Best Practices.", Architecting the Internet of Things, pp. 97-129, Springer, Jan. 2011.

[27]. P. Tilanus, B. Ran, M. Faeth, D. Kelaidonis, V. Stavroulaki, "Virtual Object Access Rights to Enable Multi-Party Use of Sensors", accepted for publication to IEEE IoT-SoS, Madrid, Spain 2013.

[28]. IBM ILOG CPLEX Optimizer. Available Online: http://www-01.ibm.com/software/integration/ optimization/cplex-optimizer/, accessed Aug. 2013.

6 CLOUD INTERNET OF THINGS INFRASTRUCTURES FOR THE FUTURE INTERNET

6.1 Chapter Outline

In the future internet era, the Internet of Things (IoT) has consolidated its presence in the contemporary IoT environments, such as the Smart Cities, with a variety of innovative IoT platforms for the provisioning of relevant services. The provisioning of such services requires ubiquity, reliability, high-performance, efficiency, scalability. For the accomplishment of the addressing of the challenges and the requirements, a popular trend is to merge IoT and Cloud concepts by combining multi-Cloud IoT architectures. The introduction of cognition was the first step for the IoT success, as it brought essential self-management and awareness capabilities combined with knowledge-generation functionality. The Cloud-IoT architectural vision is paving the way to the next/vital step for the IoT success and for new business value propositions for the IoT world leveraging cloud principles. Towards this direction, this chapter presents a set of challenges that have been identified, with a set of different research initiatives that aim to address them. Moreover, it is elaborated the deployment of innovative Cloud-IoT architectures, enabled by the Semantic Technologies, for the Future Internet environments, such as the 5G Wireless Networking ecosystems. This chapter presents a promising approach for the design of Cloud-based architectures for enabling Cloud-IoT services over multi-Cloud smart environments. Furthermore, it is analyzed how the proposed architecture, empowered by the Semantic Framework mechanisms, could enable the deployment of Federated Edge Cloud-IoT environments over 5G wireless communication technologies.

6.2 Introduction

The last decade the IoT field introduced new visions and trends with respect to the communication capabilities between heterogeneous devices, whereas enabled contemporary application and services that improve and facilitate the daily life of the humans in our world. This fact has introduces new technological challenges and requirements in the various fields, such as the data management, communication and access management, IT services delivery, etc. At the same time, Cloud Computing came into play to offer enormous storage, computing facilities and data sharing opportunities. It is obvious that the convergence of IoT and Cloud can provide new opportunities for both technologies. The use of cloud computing is considered as a viable approach for alleviating the burden of limited resources on smart devices. However there is no particular solution that could be applied to all different situations, taking into account the wide range of applications, the corresponding use of the cloud resources, such as offloading computation, edge content delivery, distributed data processing, etc, and their respective requirements, such as the mobility support, real-time interaction needs, etc. Combining the two different technological fields, Cloud-IoT platforms can be deployed by introducing a new horizon of ubiquitous sensing and data monitoring, devices interoperability, services distribution and on-demand delivery, as well as plethora of other applications. Moreover, the Cloud-IoT solutions will enable powerful processing and storage facilities in the Big IoT-data worlds, and it will be realized the real-time automated decision making for various challenging processes. Consequently, the convergence of the IoT and the Cloud can enable the development of new innovative applications in various emerging areas such as smart cities, smart healthcare, smart energy management and others to improve all aspects of life.

Particular interest it is positioned to the next generation mobile and wireless networking technologies such as 5G wireless networks and software-defined networking (SDN). While there are many different research activities that focused on the study of IoT and cloud convergence, there is a limited effort with respect to the combination of the Cloud-IoT solutions with the 5G communication technologies. The 5G technologies could constitute the success factor for realizing the IoT-Cloud convergence since they will allow the acceleration of the communication among heterogeneous devices, allowing in the same time the boost-up of data generation and processing. Furthermore, the 5G technologies can lead to a new form of interaction between IoT and Cloud by supporting better spectral efficiency, network capacity, mobility and coverage.

The combination of the Semantic Framework concepts with the Cloud-IoT, are presented and evaluated in the next subsections. In particular, the next sections are comprised by research work that was performed in the context of the publications [1][2][3] that study the Cloud-IoT concepts, as well as the design and the deployment of innovative 5G enabled Cloud-IoT architectures that support the efficient service provisioning and management.

6.3 A Federated Edge Cloud-IoT Architecture – Enabling semantic-based service provisioning in Future Internet

The contemporary era of the future internet has already been deployed, in the form of innovative Internet of Things (IoT) infrastructures, in different application domains that range from Smart Health and Smart Buildings to Smart Cities. Focusing on the Smart Cities domain, by 2030 it is anticipated that more than twenty seven large cities with more than ten million population will exist, while sixty percent (60%) of the world population will live in an urban environment [4]. Major challenges will be presented due to the increase of cities' population and some of the most important of them will refer to energy and waste management, citizens' health status monitoring, traffic management and air pollution monitoring and control. Such challenges will require the combination of existing heterogeneous Information and Communication Technologies (ICT) solutions, so as to provide innovative and more efficient composite services to the people that will live in these cities[5][6].

The application of the IoT paradigm in the context of Smart Cities implies a wide range of heterogeneous devices such as sensors, actuators, smart phones, cars, computers, home appliances, buildings, smart city infrastructure elements, that will be connected to the internet, as well as with each other via heterogeneous access networks, with the aim of providing smart, personalized applications and services any-time, anywhere [7]. A vast variety of IoT applications is envisaged; however most current developments have mainly focused on specific applications, leading to domain-centric silos that lack flexibility and interoperability. Given the size and functional needs of the true IoT vision and especially, of large scale IoT applications such as those deployed/required in Smart Cities, there are key challenges to be solved to achieve ubiquity, scalability, dependability and sustainability of real-time IoT service provision. The vast amount of objects and devices that have to be handled and the variety of networking and communication technologies, as well as the administrative boundaries, that have to be supported, require a different management approach. The added value of IoT consideration consists not only in providing the objects with the infrastructure for physical communication, but also in exchanging derived data and knowledge, which can be (re-)used by other objects and applications and, therefore, making possible the development of totally new or already existing applications but with more enhanced features/functionalities [8][9].

The last decade, various fundamental technologies have been introduced and used in various domains so as to realize the IoT [10], including technologies such as the

Radio Frequency Identification (RFID) [11][12] and Near Field Communications (NFC) [13][14], Wireless Sensor Networks (WSN) [15], etc. As it has been highlighted in previous research activities [16]-[20], the IoT paradigm of the "7 trillion devices for 7 billion people" requires cognitive self-x (configuration, optimization, healing) solutions that will effectively contribute to the overcoming of the various issues that arise. Moreover, whereas various research efforts, such as [20]-[30] have significantly contributed to the definition of IoT architectures and cognitive communication technologies to ensure interactions and facilitate information exchange, there has been less focus on the distribution of the solutions that will enable greater scalability and extensibility of the capabilities of IoT infra-structures and relevant data processing. Furthermore, there is a lack of distributed management functionality to overcome the technological heterogeneity of the capillary networks, to enhance the context awareness, as aspects that can be resolved though the design and the deployment of cloud-based applications from the IoT field.

This work focuses on the current trends in the context of cloud infrastructure services combined with IoT integrated systems/platforms and/or frameworks towards the provision of large scale cloud-based distributed IoT services in the context of the Smart Cities of the future. These trends include [31] the integration of special devices in the whole computing continuum, from high performance computing ones to mobile devices, and the design of decentralized service-oriented systems. Moreover, the main contemporary trends include the improvement of the virtualization technologies, the achievement of portability and interoperability requirements, or the automation of the organization and management of the backend resources. Consequently, cloud-based applications from the fields of the IoT and Big Data are expected to guide the new services.

The next sections present the evaluation and the validation of the Semantic Framework entities (mechanisms and/or software modules), as well as their added value in the Cloud-IoT field. In particular, the rest of this chapter is structured as follows: section 6.3.1 presents the identified challenges for the cloud-based IoT architectures, and section 6.3.2 presents an overview of the work in progress in this field. Furthermore, section 6.3.3 presents a promising multi-Cloud IoT architectural solution, and the section 6.3.5 presents our proposed architecture. Moreover, the section 6.3.6 presents a case study evaluation of the proposed architecture, focusing on the "Semantic Storage System" performance evaluation. Finally, the work concludes with the section 6.3.8 that summarizes the findings and paving the way forward.

6.3.1 Challenges

The IoT realized the vision of an interconnected world with emerging volume of data and numerous services that are delivered via heterogeneous access networks. At the same time, the Cloud Computing participating the technological innovation board, by offering enormous storage, computing facilities and data sharing opportunities. The convergence of IoT and Cloud can provide new opportunities for both technologies as well as bring new challenges on the forefront. Indicatively, Cloud-IoT realizes ubiquitous sensing, allows the interconnection of devices [32], enables the service sharing and provisioning, and provides automated decision making in real time [33]. However, there are various critical challenges that should be taken into account, whereas the contemporary trends in the application provisioning require capabilities for services migration [34], data aggregation close to the end-users/consumers/applications [35], interworking of infrastructures in a peer-to-peer way, namely cloud peering [36], distributed data processing over small and medium scale mobile cloud environments (aka Edge Clouds) [37].

The heterogeneity of the entities that are involved in the context of the smart cities, including devices, services and applications, requires the deployment of innovative mechanisms that will enable the production, the discovery, the mix and the re-use of different service components and the creation of new added value public services through pooling and sharing of resources, data, content and tools, even across national borders. In this way, they will facilitate the collaboration between different stakeholders, end-users and public administrations. The "automated discovery and composition of services" [27][38][39] will enable the establishment of federated environments that will support publicly available cloud services. The last requires interoperable, reusable modules for public service functionalities, which ideally address the smart cities requirements.

The "federated environments" concept [40] is one of the core concepts for the design, the deployment and the management of decentralized cloud infrastructures. Such a concept may be applicable to "software-defined data centers" (SDDC) [41][42], "software-defined networks" (SDN) [43][44] and additional appropriate cloud-based mechanisms to enable incorporation of resources and services independent of their location across distributed computing and data storage infrastructures.

Through the federation of distributed environments, different approaches to-wards the design and the development of standards should be elaborated. These approaches will lead to increased interoperability between cloud services and infrastructure providers. The "interoperability and standardization" [45][46] aspects, in turn, will enable efficient migration of services, applications and data. Having overcome potential borders with respect to interoperability aspects, the design and the development of distributed, federated and heterogeneous cloud computing architectural models [47][48] will ensure the harmonization of the heterogeneous cloud-based systems interworking in an efficient and high-performance way.

In this direction, "services deployment and management" [49][50] in a decentralized and autonomous way should be supported. This will be achieved through the introduction of tools for automatic and dynamic deployment, configuration and management of services to enhance availability, flexibility, and elasticity to meet targeted performance constraints (e.g. resources management based on "minimum requirements vs. available resources"). In addition, the introduction of innovative software and hardware solutions should be elaborated, so as to facilitate the coherent deployment of distributed applications over heterogeneous infrastructures and platforms from multiple providers, as well as the design and the deployment of mechanisms to off-load computation and storage tasks from mobile devices onto the cloud at both design and execution time.

"Security and privacy" [51][52] constitute challenging aspects for cloud systems by including mechanisms, tools and techniques ensuring the security and transparency of cloud infrastructures and services, including data integrity, localization and confidentiality, also when using third party cloud resources.

The "trust" [53] aspect focuses on data and services from different cloud providers that refers to the collaborative development, adaptation and testing of open-source software for innovative and trusted cloud-based services. In this way, "trust" will allow the collaboration across different platforms and different technical environments for the deployment of integrated systems.

Table 5 summarizes the identified topics and challenges in the context of the research field that focuses on the design and the development of Cloud-IoT architectures for smart cities environments. Bearing in mind the identified challenges, the next section presents the latest research activities towards the realization of the Cloud-IoT architectures.

Table 5: Identified topics & challenges for Cloud-IoT Environments

Challenge	**Description**
Development of distributed, federated and heterogeneous cloud computing models	This challenge refers to the design and the development of multi-Cloud architectural models that will allow the distribution of the resources, the services and applications in multi-IaaS (Infrastructure-as-a-Service) environments.
Deployment and management of resources: in a decentralized, autonomous way	This challenge is related to the issues with respect to the introduction of tools for autonomic and dynamic deployment, configuration and management of services to enhance availability, flexibility, and elasticity to meet targeted performance constraints (e.g. resources management based on "minimum requirements vs. available resources").
Security, privacy	Cloud systems with built-in security mechanisms and tools that will exploit techniques ensuring the security and transparency of cloud infrastructures and services, including data integrity, localization and confidentiality.
Trust: data and services from different cloud providers	Definition of specification and standards for the provision of Cloud mechanisms that will address multi-cloud concerns with respect to data manipulation and exploitation, as well as will take into account the trust issues to define the suitability of data generating devices.
Federated environments	The federated cloud environments deal with the deployment and the management of cloud-based mechanisms to enable incorporation of resources and services independent of their location across distributed

	computing and data storage infrastructures. It can be ideally combined with the outcomes of the modeling activities with respect to the design and the development of multi-Cloud architectures, as they are investigated in the context of the "development of distributed, federated and heterogeneous cloud computing model" challenge.

6.3.2 Cloud Internet of Things architectures

An important number of research initiatives in the context of the identified challenges for the Cloud-IoT architectures have been kicked off from different European Research and Innovation projects. The outcomes of these research activities will contribute to advanced, innovative architectural solutions to enable Cloud-IoT capabilities in the context of diverse application domains, with particular focus on large-scale experimentation environments in smart cities. In the following sub-sections some indicative research projects that are currently being performed are introduced and reviewed.

ClouT: Cloud-of-Things

ClouT [54], which stands for "cloud of things", is providing infrastructure, services, tools and applications that will be used in the context of smart cities (e.g. by municipalities, citizens, service developers, etc.) integrating advances from the IoT and Cloud domains. The main features of the proposed architecture include: a) the support of the capability for acquisition of Smart City data leveraging IoT and Internet of People, b) the functionality for the city data provision so as to allow the easy development of scalable, dependable, and semantic services, and c) the deployment of innovative Smart City applications in pilot cities. ClouT projects proposed reference architecture for the integration of IoT enabled Cities deployments with the Cloud computing. The architecture includes IoT related technologies in terms of devices (e.g. sensors, actuators, etc.) and appropriate software for the device management, data gathering and management (Sensorisation and Actuatorisation, IoT Kernel and Interoperability & City Resource Virtualization building blocks). Moreover, the architecture includes components from the Cloud field, for the provision of computing and storage capabilities (Computing and Storage building block). The Cloud-IoT integration is realized through the ClouT architecture that is structured in the City Platform-as-a-Service (CPaaS) and the City Infrastructure-as-a-Service (CIaaS) view, complemented with security aspects in a cross architecture view.

MUSA: Multi-cloud secure applications

In the context of heterogeneous cloud ecosystems a key factor refers to the deployment of applications that are able to maximize the benefits of the combination of the cloud resources in use in the involved clouds, therefore to the creation of multi-cloud applications. The MUSA project [55][56] aims to the design and the development of a framework that will include security-by-design mechanisms to allow application's self-protection at runtime, as well as methods and tools for the integrated security assurance in both the engineering and operation of multi-cloud applications. Aiming to the deployment and the support of a multi-Cloud environment (that among other integrates IoT deployments) the proposed framework is composed by four different architectural building blocks. First introduces an integrated development environment (IDE) for creating the multi-cloud application taking into account its security requirements together with functional and business requirements. Advanced security mechanisms designed and embedded in the application components so as to allow the self-protection, ensuring in the same time the dynamic, automated and secure collaboration among different applications, such as distributed IoT deployments. In large-scale IoT deployment and Cloud applications, framework's intelligent decision support system will realize an automated deployment environment that will allow the dynamic distribution of the components according to security needs. Finally, a security assurance platform in form of Software-as-a-Service (SaaS) that will support multi-cloud application's runtime security control and transparency to increase user trust, that constitutes a critical factor for the integration of distributed Cloud-based IoT environments.

RAPID: Heterogeneous secure multi-level remote acceleration service for low-power integrated systems and devices

The RAPID project [57] focuses on the development of efficient and powerful computing infrastructures that among others will be exploited so as to accelerate cloud-based applications for the IoT, by improving significantly their perfor-mance. In particular, the project focus on the introduction of innovative Cloud computing processing capabilities, enable by an efficient heterogeneous CPU-GPU (Central

Processing Unit – Graphics Processing Unit) cloud computing in-frastructure. Such infrastructure can be used to seamlessly offload CPU-based and GPU-based (using CUDA API [58]) tasks of applications running on low-power devices such as Wireless Sensor Networks (WSN) nodes, wearable devices, etc., to more powerful devices over a heterogeneous network (HetNet). This will benefit the existing IoT infrastructures in terms of energy management, distributed processing and load balancing on IoT deployments. The proposed solution by the project, consists of three different core modules: a) the accelerator client that take over the decision making with respect to the execution host of particular tasks either locally or remotely on accelerator servers, b) the accelerator server that takes over the execution of particular tasks and returns the results and c) the directory server that keeps status and resource information of the RAPID accelerators. Throught the introduction of RAPID enablers complemented with appropriate APIs it will be achieved the realization of evolved Cloud-based IoT deployments and software solutions that require high-performance and resource availability so as to achieve the best possible re-sult.

INPUT: In-network programmability for next-generation per-sonal cloud service support

The INPUT project [59] aims realize a distributed Cloud-IoT architecture for the deployment of Cloud-based IoT environments, through the virtualization of physical infrastructures in the smart infrastructures, including smart city concepts such as Smart Homes. In particular, through the replacement of the Smart Devices (SDs) with virtualized images that will provide their functionalities, the INPUT system will provide to the end-users integrated virtualized devices functionalities as services. The project aims to overcome current limitations on the cloud service design by introducing computing and storage capabilities to edge network devices in order to allow users, operators and service providers to create/manage private clouds "in the network". Essentially, through the introduction of Cloud capabilities such as cloud-images and virtualization it is realized a Cloud-IoT environment for the future internet, focusing on the end-users. Specifically, particular interest has been positioned on moving Cloud services closer to the end-user. Moving the cloud services closer to end-users and smart devices, the project aims to avoid pointless network infrastructure and data-center overloading, and to provide lower latency to services. The project technologies allow the integration among the Cloud and IoT, and enable next-generation cloud applications to go beyond classical service models, namely Infrastructure-as-a-Service (IaaS), Platform-as-a-Service (PaaS), and Software-as-a-Service (SaaS). The project enablers aims to a new Cloud infrastructure that replace physical Smart Devices (SD), which are usually placed in users' homes (e.g., network-attached storage servers, set-top-boxes, video recorders, home automation control units, etc.) or deployed around for monitoring purposes (e.g., sensors), with their "virtual images", providing them to users "as a Service" (SD as a Service – SDaaS). For the validation of the project, different proof-of-concept implementations are planned, such as Intelligent Transportation Systems (ITS) in large cities, including traffic status monitoring [60].

SPECS: Secure Provisioning of Cloud Services based on SLA Management

The SPECS project aims [61] at developing and implementing an open source framework to offer Security-as-a-Service based on particular Service Level Agreements (SLAs), by providing comprehensible and enforceable security assurance by Cloud Service Providers (CSP), which is a critical factor to deploy trustworthy Cloud ecosystems, such as those related to smart cities infrastructures. The SPEC framework architecture includes tools and mechanisms that are distributed in building blocks for negotiation among multi-Cloud environment modules, monitoring of decentralized, cloud deployments and the enforcement of real-time on-demand Cloud environment (re-)configuration. The implementation of a multi-Cloud environment, supporting among other the IoT, is based on the particular application of the above three architectural principles. Specifically, for the composition and use of Cloud services the project introduces a user-centric negotiation of security parameters in Cloud SLA, along with a trade-off evaluation process among users and CSPs. The Cloud SLAs are evaluated fulfilling a minimum required security level that is called Quality of Security (QoSec). Moreover, the framework, through the introduction of advanced tools and techniques for the enforcing agreed Cloud SLAs, aims to keep a sustained QoSec that fulfils the specified security parameters. SPECS' enforcement framework will also "react and adapt" in real-time to fluctuations in the QoSec by advising/applying the correct countermeasures (e.g. triggering a two-factor authentication mechanism). Consequently, the project aims to realize multi-Cloud environments focusing on security aspects for the secure and reliable collaboration among distributed modules.

SOCIOTAL: Creating a socially aware and citizen-centric Inter-net of Things

The SOCIOTAL Project [62] works towards an IoT eco-system that has trust, user control and transparency at its heart in order to gain the confidence of everyday users and citizens. By providing adequate socially aware tools and mechanisms that simplify complexity and lower the barriers of entry this encourages citizen participation in the Internet of Things. The project designs and provides key enablers for a reliable, secure and trusted IoT environment that enable creation of a socially aware citizen-centric Internet of Things by encouraging people to contribute their IoT devices and information flows. The project proposes an architecture combined by three core parts that allow the integration among heterogeneous distributed IoT deployments with Cloud services. The architectural building modules are: a) the application level components, b) the core components and c) the communication layer. The application levels includes all the related components to applications, services, management interfaces and Cloud clients for the interconnection among the platform components with distributed Cloud infrastructures for the service provisioning. The core components include different technological aspects, with main focus on security modules and IoT services orchestration and management. Finally, the communication layer provides the modules for the bridging between the platform and the external entities, such as IoT devices. Essentially, this project realizes the Cloud-IoT architectural approach, not by hosting technological solutions over the Cloud, but through the integration of IoT services with Cloud services for the provision of secure IoT applications.

COSMOS: Cultivate resilient smart objects for sustainable city applications

The COSMOS project [63] aims at enhancing the sustainability of Smart City applications by allowing IoT based systems to reach their full potential, by enabling in the same time things to evolve and act in a more autonomous way, becoming more reliable and smarter. The project combines multiple technological aspects from the Cloud computing field and the IoT area, aiming to create a combined solution that will enable the things of the IoT to be able to learn based on others experiences, being in the same, aware about their context time through the acquisition of situational knowledge and analysis. The introduction of the Complex Event Processing (CEP) building block, combined with appropriate mechanisms and/or APIs that enable the interaction with the social media, leads to the deployment of a Cloud-based IoT platform. This platform enables innovative feature and capabilities on the data delivering and processing, as well as the information management with appropriate mechanisms for the handling of the exponentially increasing "born digital" data. Essentially, the project aims to realize a Cloud-based IoT ecosystem, realized by smart object, innovative data gathering mechanisms connected to social media, and advanced data processing mechanism including complex event processing of multi-dimensional datasets.

CITY PULSE: Real-time IoT stream processing and large-scale data analytics for Smart City applications

The CITY PULSE project [64] focuses on the smart city applications challenges, such as integration of heterogeneous data sources and the challenge of extracting up-to-date information in real-time from large-scale dynamic data. The project's main aim is to provide a scalable, adaptive and robust framework that provides Virtualization capabilities (virtualization of Internet of People and IoT), supports large-scale data analytics (cloud-based infrastructure for the distributed data processing), integrates semantic technologies for machine-interpretable descriptions of data and knowledge and allows the easy creation of real-time smart city applications by re-usable intelligent components. As general purpose, the project aims to develop, build and test a framework for semantic discovery and processing of large-scale real-time IoT and relevant social data streams for reliable knowledge extraction in a real city environment. The project introduces a distributed architecture, enriched with Cloud computing capabilities and features that realize the distributed IoT large-scale data analysis and processing, by producing data for the end-user applications. The project provides a set of different tools and datasets that work as enablers for the Cloud-IoT architectural aspects. Such tools are the ontologies such as the Quality Ontology and the Stream Annotation Ontology, tools for the sensor data streaming, annotation and managements, knowledge building tools using the sensor data and application management tools. Consequently, the project integrates IoT and Cloud in the level of the sensors streaming data processing over distributed cloud-based facilities, as well as through the provision and support of innovative IoT applications that cooperate with existing Cloud services and CITY PULSE project enablers' tools.

FIESTA: Federated Interoperable Semantic IoT/cloud Testbeds and Applications

The FIESTA project [66] investigates the aspects with respect to the production of a "first-of-a-kind" blueprint experimental infrastructure (tools, techniques and best practices) enabling testbed operators to interconnect their facilities in an interoperable way, while at the same time facilitating researchers in deploying integrated experiments, which seamlessly transcend the boundaries of multiple IoT platforms. Essentially the project is providing a Cloud-IoT testbed infrastructure, for experimentation purposes, that is realized over the interconnected/interoperable underlying testbeds. The main idea is the provision a single entry point to all FIESTA Experimentation-as-a-Service (EaaS) services using a single set of credentials. They will be able to design and execute experiments across a virtualized infrastructure i.e. access the data and resources from multiple testbeds and IoT platforms using a common approach. FIESTA offers various Cloud-based tools for enabling capabilities such as a) to design and execute experimental work-flows, b) dynamically discover IoT resources, and c) access data in a testbed agnostic manner. FIESTA enables Cloud-IoT architectural infrastructure that lies on the provision of an IoT EaaS atop a middle-ware infrastructure that adapts and federates existing IoT platforms and testbeds. This entails the adaptation of the data of those testbeds to a common FIESTA ontology (i.e. compliance to common semantics), as well as the provision of a common standards based API for accessing the IoT services of the testbeds. FIESTA will be validated and evaluated based on the interconnection of different testbeds, as well as based on the execution of novel experiments in the areas of mobile crowd-sensing, IoT applications portability, and dynamic intelligent discovery of IoT resources.

iKaaS: Intelligent Knowledge-as-a-Service

The work in the context of the iKaaS project [67] relies on the definition of the multi-Cloud architectures for the IoT, and proposes the design and the deployment of an "intelligent Knowledge-as-a-Service" (iKaaS) platform for the IoT environments. The iKaaS project is developing an intelligent and secure multi-Cloud IoT Smart City platform based on Semantics and Data Models, Big Data resources and heterogeneous Cloud environments, with data collected from a variety of sensors from IoT environments deployed as mobile terminals, smart devices, and smart homes. The platform features will be applied by means of Smart City applications promoting self-management of health and safety of citizens, as well as an information system improving data analysis for a smarter life in the city. A well-defined approach has been structured so as to address the whole life-cycle of such a platform. This approach focuses on the definition of a universal data model based on the Semantic Web for data collected from IoT and stored in cloud platforms, complemented with security-by-design features for the data. Furthermore, the project's approach focuses on the development of a decentralized heterogeneous secure multi-Cloud environment, building an integrated knowledge-as-a-service platform concept. A multi-dimensional Cloud architecture with multiple Local Clouds and a Global Cloud will be deployed, validating its operation with multiple applications, as well as determining the utility of the distributed knowledge-base through experiments in model smart cities and Smart Homes. The separation between 'Local' and 'Global' cloud, in the context of iKaaS, is determined as follows. The 'Local Cloud' is a cloud infrastructure that covers a specific geographical area in a specific time period, by providing sufficient computing, storage and networking capabilities, responsible for the provisioning of particular requested services. The 'Global Cloud' is considered as a traditional cloud infrastructure that provides on demand/elastic (illusion of infinite) processing power and storage capability, ensuring at the same time the increase of the business opportunities for service providers, and the ubiquity, reliability, performance, efficiency, scalability of ser-vice provision.

Having identified the different challenges (section 6.3.1), as well as having described the different research projects, initiatives and related research activities, with respect to the design and the development of Cloud-IoT architectures for smart cities, Table 6 presents, a correlation between the challenges and the projects. The correlation is performed in terms of the challenges that are covered in the context of the corresponding project.

Table 6: Identified challenges vs. projects for Cloud-IoT architectures

Challenges	**Development of distributed, federated and heterogeneous cloud computing model**	**Deployment and management of resources**	**Security, privacy**	**Trust**	**Federated environments**
Projects					
ClouT		X			X
MUSA	X		X		
RAPID	X	X	X		

INPUT		X			
SPECS		X	X	X	X
SOCIOTAL			X	X	X
COSMOS		X			X
CITY PULSE		X			X
SMARTIE			X	X	X
FIESTA	X	X			X
iKaaS	X	X	X	X	X

6.3.3 Overview of a powerful multi-Cloud architecture prototype

Bsed on the previous results arise through the study of a wide range of existing and/or ongoing multi-Cloud architectures, this ection aims to provide the overview and the high-level principles of the iKaaS project architecture. This architecture can be used as the basis for the design of a distributed Cloud-IoT architecture enabled by the operational capabilities of the Semantic Framework.

The iKaaS architecture (Figure 25) introduces the approach of the Local Cloud environments and a Global Cloud environment, having the ability to interconnect with each other. The introduction of the Local Clouds and the Global Cloud focuses to the development of an intelligent, privacy preserving and secure Big Data analytics engine build atop a multi-Cloud infrastructure, that will be fed with large scale ubiquitous data collected from heterogeneous sensing networks and data sources, including cyber-physical systems, wearable sensors, and social or crowd-sources.

The Local Cloud environment comprises the sufficient computing, storage and networking capabilities, and provides requested services to users in a certain geographical area and time period, as well as it offers additional processing and storage capability to services. The Local Clouds can involve an arbitrary large number of nodes (sensors, actuators, smart-phones, etc.). The aggregation of resources comprises sufficient processing power and storage space and networking can rely on heterogeneous network technologies. The goal is mainly to serve users of a certain area. In this respect, a Local Cloud is the virtualized processing, storage and networking environment, which comprises IoT devices in the vicinity of the users; users will exploit the various services composed of the Local Cloud devices capabilities.

The Global Cloud is seen in the "traditional" sense, as a construct with on-demand/elastic (illusion of infinite) processing power and storage capability. It is a "backbone infrastructure", which increases the business opportunities for service providers, and the ubiquity, reliability, performance, efficiency, scalability of service provision. In this way, the Global Cloud offers more opportunities for offering services, more options on which to base service features in case of context changes, more resources for contributing to the decisions, elastic provision of resources on demand, etc. Further to that, the Global Cloud can enable, as a special (yet important) case, the existence of IoT service providers capable of providing larger scale services without owning actual IoT infrastructure.

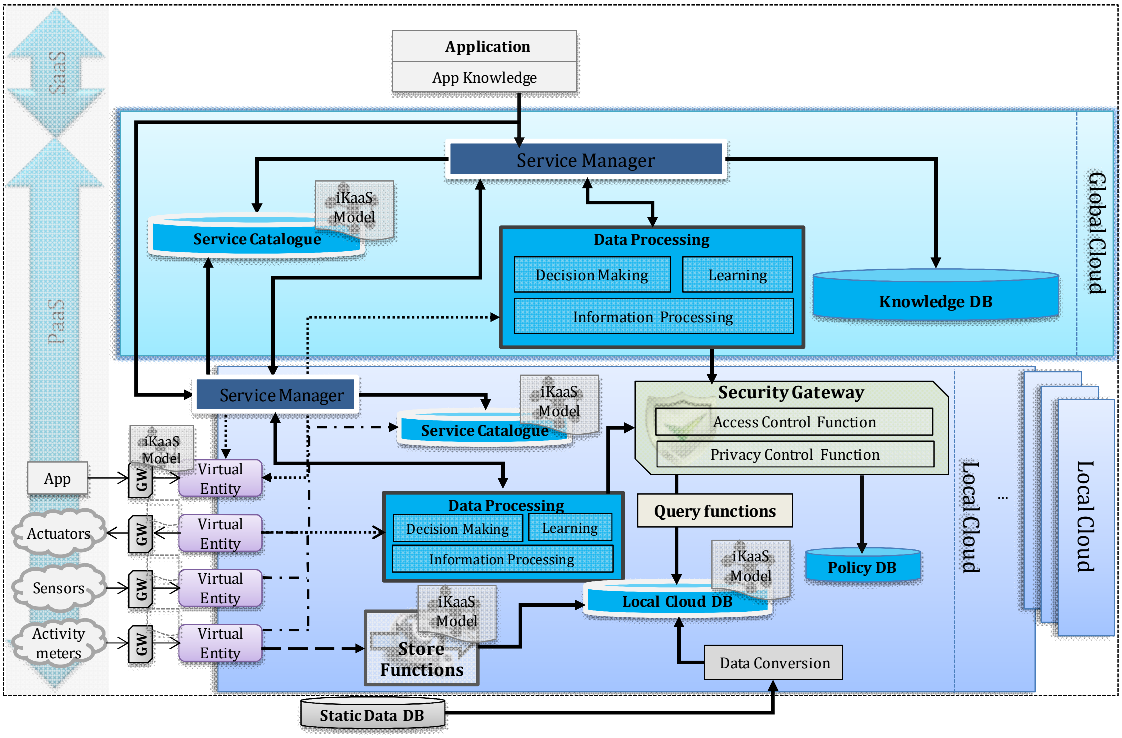


Figure 25: iKaaS multi-Cloud architecture [67]

The iKaaS platform encompasses a wide range of innovative functionalities that range from semantic data storage, management and protection to autonomic service management and knowledge building on various concepts including the service provision. In particular, the platform provides distributed data storage and processing capabilities for efficiently communicating, processing and storing massive amounts of, quickly-emerging, versatile data (i.e. "big data"), produced by a huge number of diverse IoT devices, while aiming at the same time to ensure the security and privacy of the available data and information [67]. A core architectural feature of iKaaS refers to the Knowledge-as-a-service (KaaS). This includes capabilities for the derivation of information and knowledge (e.g. on device behavior, service provision, user aspects, etc.). KaaS enables the reuse of knowledge (on users, devices, services, etc.) allowing the realization of enhanced situation aware applications as well as new business models where various stakeholders may provide knowledge to other service providers, which can in turn exploit this knowledge to develop new applications.

In addition, KaaS can contribute to the improvement of service provisioning through additional reliability (e.g. due to the exploitation of experience in the decisions), performance (e.g. due to the potential for faster decisions), efficiency (e.g., reuse of knowledge enables the realization of faster and more reliable decisions on resource/service provision). The platform involves both in the local and the global level, consolidated data and service logic descriptions and semantic storage repositories, referred as catalogues. These enable the reuse of data/data-sources, services and service logic, enabling capabilities for autonomic service management. The latter includes a) dynamically understanding the requirements, decomposing the service (finding the components that are needed), b) finding the best service configuration and migration (service component deployment) pattern, and c) during the service execution, reconfiguring the service, (i.e. conducting dynamic additions, cessations, substitutions of components).

As it can be observed, part of the iKaaS functionality determines the optimal way to offer a service. For instance, service components may need to be migrated as close as possible to the required (IoT) data sources. IoT services may need generic service support functionality that is offered within the Global Cloud, and at the same time, they do rely on local information (e.g. streams of data collected by sensors in a given geographic area), therefore, the migration of components close to the data sources (i.e. in Local Clouds) will help in the reduction of the data traffic.

Having elaborate the prototype multi-Cloud architecture, proposed by iKaaS project, in the next sections of this chapter, it is presented a multi-Cloud IoT architecture for the Future Internet. The proposed Cloud-IoT architecture merges features from different sectors, such as the IoT, the Cloud Computing and the 5G communication technologies. The basic design of the proposed architecture is based on the Cognitive Management Framework that was analyzed in Chapter 5, whereas it focuses on the deployment of the "Semantic Storage System" (proposed by this dissertation) over a 5G enabled federated Cloud-IoT environment.

6.3.4 Federated Cloud-IoT Architecture

The proposed architecture involves two main parts: a) the Edge Cloud-IoT infrastructures and b) the Cloud federation. The Edge Cloud-IoT infrastructures constitute distributed small and/or medium scale deployments of Cloud-IoT platforms applied in a particular application domain, such as smart homes and smart city. The Cloud federation constitutes the federation of the distributed Edge Clouds under a large-scale Cloud deployment that includes a set of mechanisms for the federated service management, as well as for the federated analysis, storage and management of heterogeneous data, such as semantic data and sensor measurements. The next sections present the architectural concepts as well as the supported functionalities by the proposed architecture.

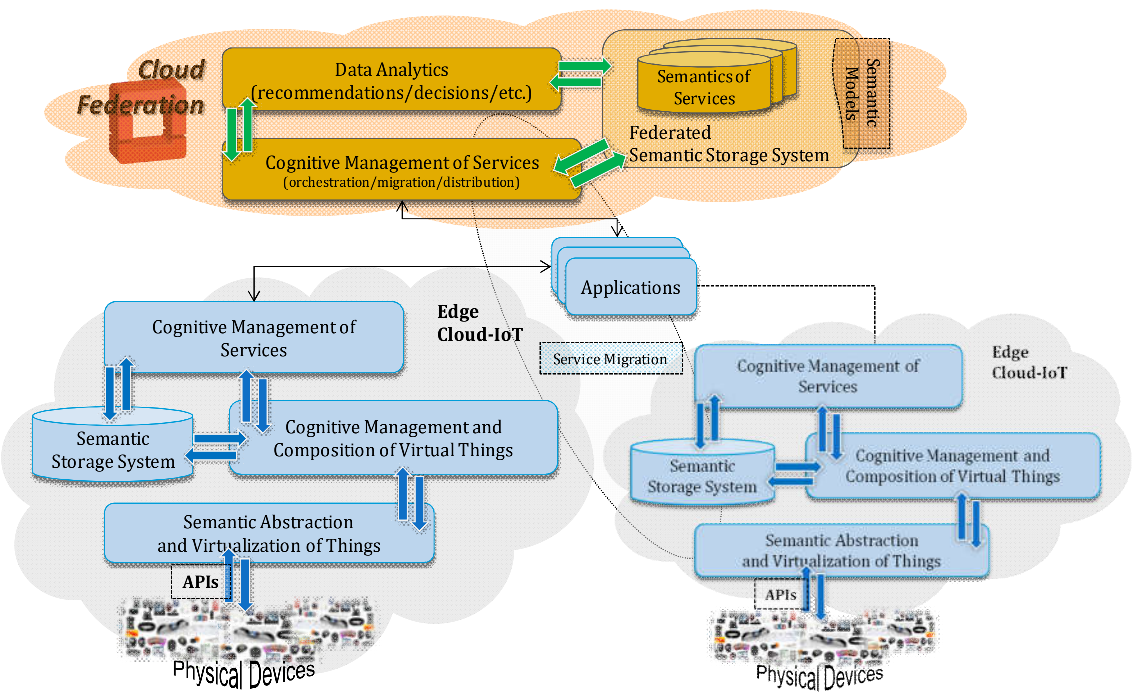


Figure 26: Proposed Architecture

6.3.4.1 Concepts

The proposed architecture (Figure 26) is structured by Edge Clouds and Federated Cloud that collaborate for the support of the dynamic creation, composition and provision of IoT services in particular application domain (e.g. smart home IoT services), as well as enable the IoT service migration among heterogeneous Edge Cloud-IoT environments, ensuring the seamless interoperability of the end-user services. The IoT services are consumed by end-user, using smart mobile devices, such as smart phones with multiple wireless connectivity capabilities. In the context of this architecture, the end-users may use complex services that essentially constitute the combination of isolated distributed services in the Edge Clouds, comprising powerful IoT applications for the end-user, such as remote health monitoring applications. For the provision of such innovative IoT applications there are two main phases: a) the creation of the complex services and b) the cognitive management of the existing services, including the service migration in the different Edge Clouds that the user may be presented. The following sections present more details with respect to the above two phases.

Semantic based Cloud-IoT Service creation

The complex service creation deals with the operation that should be performed, in the proposed architecture, so as to achieve the combination of existing services in the Edge Cloud-IoT that will fit particular requirements for the provision of an IoT application. The existing services are composed based on particular users' requests for the application provision, and they are collaborated with each other under a specific service logic that essentially corresponds to the application capabilities (e.g. monitoring of the indoor/outdoor environmental conditions). The isolated services are composed by different functionalities proposed by the virtualized IoT devices that are deployed in the corresponding Edge Cloud-IoT. The virtualized devices are named Virtual Things, and the composition of them for the provision of advanced more complex functionalities, is named Composite Virtual Thing. An Edge Cloud-IoT service may involve the composition of Virtual Things so as to provide an integrated functionality (e.g. data retrieval from sensors), and in turn each isolated service can be combined with another existing service that provides different functionality (e.g. control of actuation devices) so as to create the complex service. As the final result the complex service is associated with an IoT application that is used by an end-user, using a smart mobile device that allows the mobility features of a ubiquitous IoT application with multiple functional capabilities.

Cloud-IoT Service migration

In order to allow the mobility capabilities of the ubiquitous IoT applications, the proposed architecture supports the seamless migration of the complex service among different Edge Cloud-IoT environments. The migration of the service is realized through the collaboration among the Cloud Federation mechanisms and the distributed Edge Cloud-IoT mechanisms. The migration is triggered based on the contextual information that corresponds to the end-user location, which is fetched by the smart mobile device that hosts the IoT application. Each Edge Cloud-IoT environment has a particular location of coverage in terms of a mental geo-location area. Since the end-user is moved out of this area the IoT application should be reconfigured realizing the migration of the service functionalities from the one Edge Cloud to the other that covers the location that the user is moving. Indicatively, if the IoT application used the smart home Edge Cloud services for the indoor environmental conditions monitoring, considering that the user is moving outside in the smart city, the environmental monitoring service should be reconfigured so as to consume data from the data sources that are available in the smart city Edge Cloud. In this way, seamless migration of the IoT application functionalities is achieved, hiding the technological complexity by the end-user. Thus, the IoT application is always up&running across heterogeneous Edge Cloud-IoT environments, realizing mobility features and capabilities.

6.3.5 Architecture overview and instantiation

The proposed architecture includes different architectural blocks and mechanisms that are distributed across the Edge Cloud-IoT environments and the Cloud Federation. The next sections present the details of the architectural components and mechanisms in the Edge and in the Federated Cloud respectively.

6.3.5.1 Edge Cloud

The mechanisms in the Edge Clouds implement IoT related features, such as the abstraction and virtualization of real devices, the composition of the devices capabilities and the interoperability among heterogeneous entities. Furthermore, the Edge Clouds perform store semantic data of the existing entities, such as (Composite) Virtual Things and service, and also support management capabilities for their services. The subsections below present the four different architectural blocks that comprise the Edge Cloud-IoT.

Semantic Abstraction and Virtualization of Things

This building block provides relevant functionality for the semantic-based virtualization of IoT devices (e.g. sensors, actuators, wearable). Each device is represented by a unique semantic description that is structured based on a semantic model with meta-data information, which describes the device functional capabilities and its features (e.g. type, connectivity capabilities, etc.). The semantic description is combined with appropriate software module that virtualizes the device functionalities, composing the Virtual Thing. The software module includes: a) the Backend part that constitutes a type of the device driver with particular software implementation to allow the connection with the device, and b) the Frontend part that works as a generic communication interface that allows access to the virtualized device.

Cognitive Management and Composition of Virtual Things

The composition of the functional capabilities that are provided by the isolated Virtual Things is performed by this building block. Essentially, it supports required capabilities for the composition of the existing isolated virtualized devices, in order to provide more complex functionality that will enable the provision of services to the end-users. An indicative example relates to the existence of three isolated sensors; temperature, humidity and luminosity, that should be combined for the provision of a more complex functionality that will allow the environmental condition monitoring. The complex functionality can be associated with a service that provides aggregated sensing data of the environment. Aiming to ensure the proper execution, control and availability of composite things, this block can support the management of such entities, such as in terms of their association with particular services that are authorized to use them. Essentially, this block allows the composition of virtual things so as to support more complex services in the context of the small and medium scale Edge Cloud-IoT environments.

Cognitive Management of Services

The Edge Cloud-IoT services are managed by the functionalities provided by this building block. Specifically, services are used to support innovative Cloud-IoT applications for the end-users. The services are described by semantic data that represents service capabilities and features. The application can involve many Edge Cloud-IoT services. This block can support the autonomous creation of combined services for the IoT applications, as well as ensure the seamless migration of services in terms of their reconfiguration, while the mobile IoT application is moving among the Edge Cloud-IoT environments. Consequently, the end-user of the application will continuously be facilitated without caring about its operation in the different Edge Cloud-IoT deployments.

Semantic Storage System

The "Semantic Storage System" works as the cloud storage repository for semantic data that describes the entities deployed in the Edge Cloud-IoT environments, such as the services. This system provides appropriate functionalities that allow the semantic data management, in terms of queries and modifications. The cognitive components require semantically annotated data that allow them to perform advanced decision making processes, to make inferences, etc. These components can interact with the storage system either in a local scale (inside the Edge Cloud) or in global scale through the "Federated Semantic Storage Systems". In the last case, federated SPARQL queries are supported by the federated system, towards the distributed semantic data among the Edge Cloud-IoT environments. Consequently, this block works as the semantic data manager for the overall system.

6.3.5.2 Cloud Federation

The mechanisms in the Cloud federation enable the long-term data processing of the data that is associated with the operation of the IoT applications, as well as integrate the distributed semantic storage systems so as to allow the semantic data management and the performance of federated queries on data. Further to that, it includes service management capabilities that allow the manipulation of the distributed Edge Clouds services, such as service creation and migration. The subsections below present the three different architectural blocks that comprise the Federated Cloud.

Cognitive Management of Services

This building block enables management functionalities for the complex services, such as orchestration, migration, distribution, etc. The mechanisms in this block support the dynamic creation of complex services and take over the seamless migration among the distributed environments. Further to that, the mechanisms monitors continuously the IoT application as it is launched in the distributed environments and reconfigure its functionalities when is needed. Essentially, this building block constitutes the contact point among the heterogeneous Edge Clouds and allows the federation of the functional capabilities among the distributed heterogeneous IoT services.

Data Analytics

This building block includes functionalities that allow the long-term data processing and analysis. The IoT applications are able to perform some short-term data processing (e.g. thresholding sensors measurements), but for heavy load data processing such as the analysis of sensing data for the provision some recommendation can be performed by the mechanisms in this building block. Moreover, functional capabilities of this block can allow the massive processing of semantic data, during complex service creations (e.g. processing of federated queries' results).

Federated Semantic Storage System

The distributed semantic data that correspond to the description of the Edge- Cloud-IoT services is federated in the context of this building block. Specifically, this block offers a single point for the interaction with the huge amount of the semantic data that represents the distributed services that can compose an IoT application. It allows the performance of federated queries on the semantic data, enabling the semantic-based complex service creation by the complex service management building block. Through this block the integration of the distributed semantic storage systems, that contributes to the efficient data management of the distributed semantic large-scale data, is achieved.

6.3.6 Case study and validation

This section intends to demonstrate the use of the proposed Federated Edge Cloud-IoT architecture and how it is benefited by the application of 5G technologies for the creation, provision and support of a multi-Cloud application scenario that connects horizontally different Edge Cloud environments, with heterogeneous communication technologies. In particular the distributed Edge Clouds are federated, namely interconnect, over the federation network. The implementation of the federation network, by applying Wi-Fi and 3G/4G wireless communication technologies is elaborated, whereas the implementation of the federation network is studied through the introduction of a Network-as-a-Service (NaaS) infrastructure, supporting Network Functions Virtualization (NFV) and Software Defined Network (SDN). Particular focus is positioned on the elaboration of the "Semantic Storage System" performance over different wireless communication technologies for different amount of data.

6.3.6.1 Storyline summary

This scenario presents how the proposed architecture, complemented by 5G technologies, can ideally fit the contemporary trends of ubiquitous smart mobile applications in the Future Internet era. Specifically, the deployment of a Federated Edge Cloud environment comprised by two different Edge Cloud instances is considered: a) the Smart Home cloud and b) the Smart City cloud. A user has been opted for an ambient assisted living cloud-based ubiquitous application that takes over the real-time monitoring of the indoor/outdoor environmental conditions using distributed sensors, while it also supports the health status monitoring using wearable devices. Furthermore, the application supports the provision of recommendations with respect to user's health status quality improvement and/or protection.

6.3.6.2 Proof of Concept description

Considering the above storyline, a smart mobile application, hosted on a smart phone device, is used so as to realize the ambient assisted living services for the end-user. The application interacts with the Edge Cloud-IoT and the Federated Cloud for the data gathering, data processing and services management respectively. Moreover, the application should always be "up and running", following the end-user everywhere, tracking its real-time location, monitoring its health and environment, as well as taking over the seamless migration of the supported services in the distributed edge cloud environments. In the above processes the "Semantic Storage System" has critical role.

For the studied proof-of-concept, it is considered that the end-user is initially located in the smart home, and decides to go outside (in the smart city) for shopping. While the user is moving in different environments, the application is reconfigured so as to communicate over different wireless communication interfaces. The "Cognitive Management of Services" components both in federated and distributed Edge Clouds, in collaboration with "Cognitive Management and Composition of Virtual Things" and the "Semantic Abstraction and Virtualization of Things" components, take over the completion of this process. Moreover, the "Cognitive Management of Services", in the Federated Cloud, uses the semantics data in the distributed Edge Clouds' "Semantic Storage System" and completes the seamless migration of the application's services among the Edge Clouds where the user is moving. The "Semantic Storage System", will be elaborated in combination with 5G technologies, so as to highlight how it affects the overall performance of the proposed architecture.

6.3.6.3 Performance evaluation

For the evaluation of the impact of the 5G wireless technologies in the proposed architecture an indicative experiment that studies the storyline described above has been conducted. Specifically, it is studied how "service migration" from the smart home to the smart city cloud is affected in terms of time, using different communication technologies for the implementation of the federated network. For the performance evaluation of the proposed solution, the overall required time for the complementation of the "service migration" is estimated, in conjunction with the wireless communication and networking technology (e.g. Wi-Fi, 3G/4G, SDN) and the amount of semantic data that are available in the semantic storage system, in terms of the number of RDF Triples. It is considered that each service semantic description corresponds to 100 RDF Triples. During "service migration" all required information for the reconfiguration of the application is available in the semantic storage system and is transferred over the federation network. Consequently, the performance time is depending on the data amount that should be transferred among the Edge Cloud-IoT environments and over the federation network. The Edge Cloud-IoT environments and the Federated Cloud are hosted as Virtual Machines (VMs) on a mixed virtualized environment composed by OpenStack and VirtualBox. The VMs can communicate with each other, using Wi-Fi, 3G/4G and SDN. The SDN is implemented using the OpenStack Neutron, the NaaS for NFV and SDN deployment in OpenStack cloud environments.

The experiments performed in an indicative number of loops, considering the performance of "service migration" requests towards the semantic data that was available on the distributed semantic storage systems. The requests were performed as federated SPARQL queries on the Federated Semantic Storage System that communicated with the Semantic Storage Systems in the Edge Clouds over the federation network. The experiments were conducted for three different implementation approaches of the federation network (Wi-Fi, 3G/4G, SDN), with the same type of "service migration" requests towards the same amount of data. The required time for the Internet fixed access network (i.e. ISP and/or Telecom operator) is considered as negligible and is not taken into account in the performance results

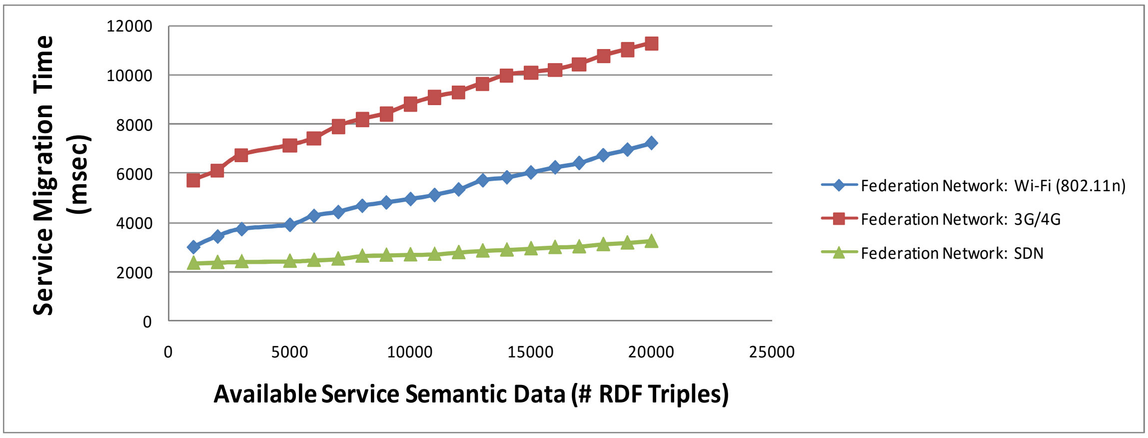


Figure 27: Service Migration Time depending on available semantic data and the communication technology

The diagram in Figure 27 collates "service migration" time with the underlying networking technology and the amount of semantic data. In all cases, "service migration" time is increased, as the amount of the semantic data (RDF Triples) is increased. This is normal, since the increase of the stored data in the distributed semantic storage systems, implies the increase of the amount of data that are transferred over the federation network to the Federated Cloud. Furthermore, the proposed Cloud-IoT architecture presents the best possible performance, in terms of time completion for service migration, over SDN networking technology, with Wi-Fi (802.11n) being the second best option and 3G/4G being the less efficient communication technology. Consequently, Cloud-IoT architecture is benefited by SDN in terms of the lower performance time, with fast and reliable deployment of Cloud-IoT applications and services. Moreover, the contemporary era of Future Internet demands high-performance, scalability and reliability that can be ideally fitted by SDN communication deployments for the Cloud-IoT.

6.3.7 Consepts Implementation

The implementation of the proof-of-concept prototype processes as they are described in section 6.3.6.2 is depicted in Figure 28. Such implementation would be realized using 5G heterogeneous access infrastructure. The smart phone device supports different wireless communication interfaces, such as Wi-Fi (IEEE 802.11 n) and 3G/4G mobile network. In addition to that, Edge Clouds include heterogeneous wireless technologies for the interaction with IoT data sources, such as ZigBee and BT4.0 enabled Wireless Sensor Networks (WSNs). The main focus of the implementation is given to the realization of the federation aspects for the "Semantic Storage System".

The implementation of the federated semantic storage system plays a critical role for the successful and efficient realization of the architecture supported operations with respect to the cognitive management of the (e.g. deployment, migration, etc.) services. In particular, the already introduced, in Chapter 4, semantic and virtualization mechanisms, have been evolved, adapted and enhanced so as to support the semantic data management of Cloud-IoT services and their associated entities. The Semantic data storages and their associated mechanisms for the data management have been re-structured so as to support their deployment on the Cloud environments.

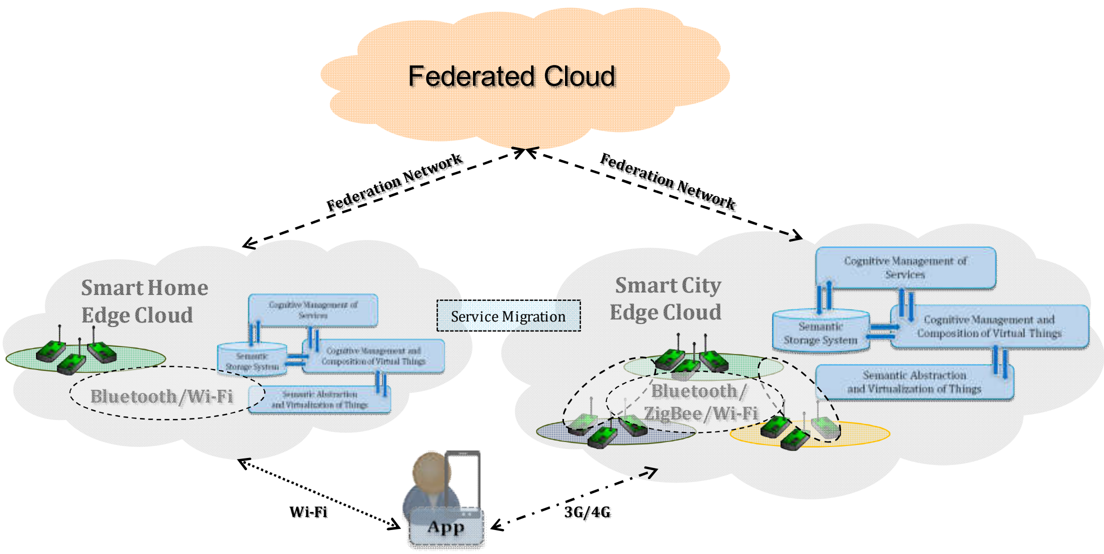


Figure 28: Indicative architecture instantiation for case study and validation

Through this evolvement it has arise the "Semantic Storage System" API. Specifically, using the capabilities of this API, the "Semantic Storage System" can be easily installed over any Unix-based guest VM (in various cloud systems, such as VirtualBox [69], OpenStack [70], etc.), and/or Docker Containers [71]. The installation, configuration and management of the "Semantic Storage System" are realized by using appropriate Cloudification Scripts that have been implemented as Linux Shell scripts [72]. The storage system after the installation can be used as a Linux Service, while it can be easily configured (using external configuration files) so as to connect to a semantic storages federation.

The federation of the "Semantic Storage System" is realized through the exploitation of the RDF4j API [73] that provides appropriate functionality for the deployment of Federation Stores [74]. The logical workflow for the deployment of a new semantic repository in the semantic storage system federation is depicted in the Figure 29. As it can be observed, the "Semantic Storage System" API supports the automated registration of a new instance of a local semantic storage system, to the federated cloud (namely to the federated semantic storage system). Since the new instance will be deployed on the federation, it is accessible for the performance of federated queries and modification requests on the semantic data. Depending on the federation network, the semantic storage system can improve its efficiency. Specifically, if the federation of the distributed semantic storages is performed over a dedicated storage Software Defined Network (SDN), then the federated system can get the best possible performance in comparison to other network setups. The last consideration could be easily observed and proved by elaborating the experimentation results of this research work that were presented in the section 6.3.6.3. The implemented "Semantic Storage System" API, complemented with its Cloudification scripts, is distributed on GitLab source control system [75], under the owned repository of dissertation's author.

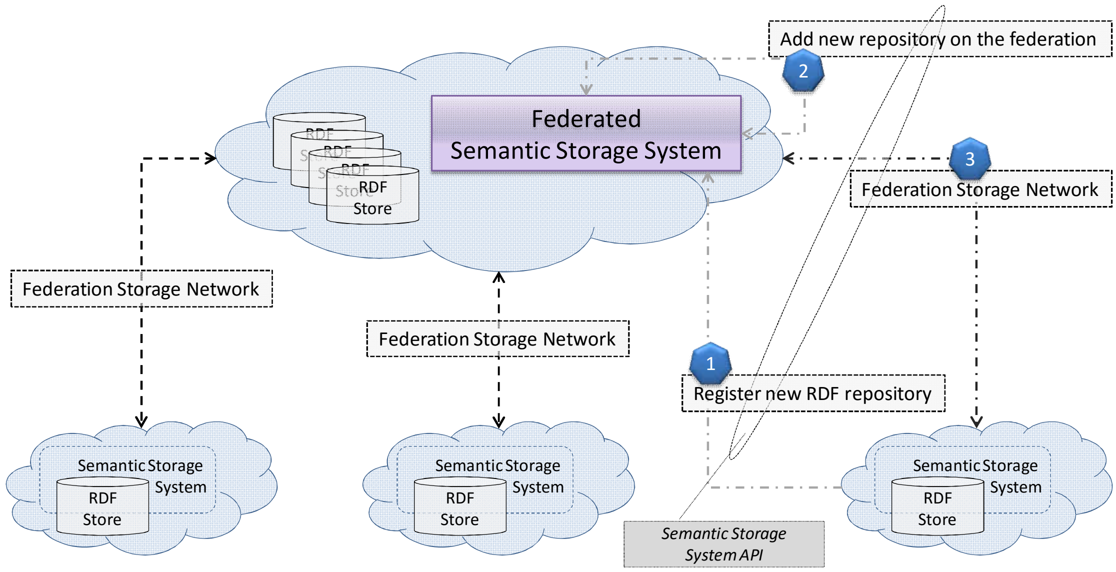


Figure 29: Semantic Storage System federation process - High Level overview

6.3.8 Conclusions

The Cloud-IoT convergence introduces new requirements for services and applications, demanding innovative architectures and powerful networking infrastructures for their realization. New challenges, such as service migration, data aggregation near the end-users, cloud peering, distributed data processing over small and medium scale mobile cloud environments (aka Edge Clouds), should be taken into account. The impact of 5G technologies could ideally contribute to handle the emerging challenges both at the end-user side as well as in the system side, leading to a new form of interaction between Cloud-IoT environments. In our work we studied how 5G infrastructures could contribute to the enhancement of the Cloud-IoT, proposing an appropriate Edge Cloud-IoT architecture. This architecture allows the federation so as to support cross-domain services that use different Cloud-IoT resources. We applied the semantic technologies, through the "Semantic Storage System" component, as enablers for the creation and the management of such services. To validate and evaluate our work, we studied the performance of the communication among the end-user IoT Application and the Cloud environments over different wireless communication technologies. For the simulation of the Edge Cloud-IoT and the Federated environments we deployed VM instances on OpenStack, interconnected through Neutron SDN. For the benchmarking of our system, we performed application requests from the smart phone towards the semantic data stored into the distributed semantic storage systems. Indicative results with respect to the studied processes were elaborated and presented.

Concluding, the benefits of introducing 5G wireless technologies into the proposed Edge Cloud-IoT federation architecture can be summarized in the following: a) easy creation and efficient delivery of ubiquitous Cloud-IoT applications, b) provision of real-time services dynamically tailored to the needs of end-users, even being able to act on behalf of them (e.g. smart recommendations), c) deployment of innovative multi-Cloud applications due to service migration, d) deployment of fast, reliable and high-performance smart applications for the improvement of the daily people life.

6.4 Chapter References

[1]. Dimitrios Kelaidonis, Panagiotis Vlacheas, Vera Stavroulaki, Stylianos Georgoulas, Klaus Moessner, Yuichi Hashi, Kazuo Hashimoto, Yutaka Miyake, Keiji Yamada, Panagiotis Demestichas. (2016). "Cloud Internet of Things framework for enabling services in Smart Cities". Springer Book.

[2]. Dimitrios Kelaidonis, Angelos Rouskas, Panagiotis Vlacheas, Vera Stavroulaki, Panagiotis Demestichas. (2016). "A Federated Edge Cloud-IoT Architecture – Enabling semantic-based service provisioning in Future Internet". Accepted. EUCNC June, 2016, Athens Greece.

[3]. Dimitrios Kelaidonis, Angelos Rouskas, Panagiotis Vlacheas, Vera Stavroulaki, Panagiotis Demestichas. (2016). "Federated Edge Cloud Internet of Things Architecture over 5G infrastructures". Submitted to Communications

Magazine, IEEE, Feature Topic: Impact of next-generation mobile technologies on IoT-Cloud convergence, April, 2016.

[4].Naphade, M., Banavar, G., Harrison, C., Paraszczak, J., & Morris, R. (2011). Smarter cities and their innovation challenges. Computer, 44(6), 32-39.

[5].Jalali, R., El-khatib, K., & McGregor, C. (2015, February). Smart city architecture for community level services through the internet of things. In Intelligence in Next Generation Networks (ICIN), 2015 18th International Conference on (pp. 108-113). IEEE.

[6].European Smart Cities 4.0 (2015). [Online]: http://www.smart-cities.eu/?cid=01&ver=4.

[7].Li, S., Da Xu, L., & Zhao, S. (2014). The internet of things: a survey. Information Systems Frontiers, 17(2), 243-259.

[8].Heo, N. (2015). Deployment issues for the Internet of Things: A Survey. International Information Institute (Tokyo). Information, 18(4), 1313.

[9].Al-Fuqaha, A., Guizani, M., Mohammadi, M., Aledhari, M., & Ayyash, M. (2015). Internet of things: a survey on enabling technologies, protocols and applications.

[10]. Want, R., Schilit, B. N., & Jenson, S. (2015). Enabling the Internet of Things. Computer, (1), 28-35.

[11]. Bonde, M. J., & Rane, K. P. (2014). Radio Frequency Identification (RFID) Misplaced Objects. International Journal of Electronic and Electrical Engineering, 7(7), 657-662.

[12]. RFID Journal, What is RFID. [Online]: http://www.rfidjournal.com/articles/view?1339.

[13]. Katiyar, K., Gupta, H., & Gupta, A. (2014, September). Integrating contactless Near Field Communication and context-aware systems: Improved Internet-of-Things and cyberphysical systems. In Confluence The Next Generation Information Technology Summit (Confluence), 2014 5th International Conference- (pp. 365-372). IEEE.

[14]. Near Field Communication (NFC). [Online]: http://www.nearfieldcommunication.org/.

[15]. Yang, K. (2014). Wireless sensor networks. Principles, Design and Applications.

[16]. P. Vlacheas, et al. (2013). "Enabling smart cities through a cognitive management framework for the Internet of Things". IEEE Communications Magazine, vol.51, no.6, Journal Papers.

[17]. V. Foteinos , (2014). "A Cognitive Management Framework for Enabling Autonomous Applications in the Internet of Things", IEEE Vehicular Technology Magazine.

[18]. Zanella, A., Bui, N., Castellani, A., Vangelista, L., & Zorzi, M. (2014). Internet of things for smart cities. Internet of Things Journal, IEEE, 1(1), 22-32.

[19]. Jin, J., Gubbi, J., Marusic, S., & Palaniswami, M. (2014). An information framework for creating a smart city through Internet of things. Internet of Things Journal, IEEE, 1(2), 112-121.

[20]. Misra, P., Rajaraman, V., Dhotrad, K., Warrior, J., & Simmhan, Y. (2015). An Interoperable Realization of Smart Cities with Plug and Play based Device Management. arXiv preprint arXiv:1503.00923.

[21]. IERC – European Research Cluster on the Internet of Things. [Online]: http://www.internet-of-things-research.eu/.

[22]. IoT-A FP7 EU Project. (2013). Duration: 2010-2013. Grant Agreement No. 257521. [Online]: http://www.iot-a.eu/public/.

[23]. VITAL FP7 EU Project. (2013). Duration: 2007-2013. Grant Agreement No. 608682. [Online]: http://vital-iot.eu/.

[24]. EBBITS FP7 EU Project. (2014). Duration: 2010 - 2014. Grant Agreement No. 257852. [Online]: http://www.ebbits-project.eu/.

[25]. iSURF EU FP7 Project. (2013). Duration: 2007-2013. Grant Agreement No. 213031. [Online]: http://www.isurfproject.eu/.

[26]. IoT.est EU FP7 Project. (2014). Duration: 2011-2014. Grant Agreement No. 288385. [Online]: http://ict-iotest.eu/iotest/.

[27]. iCore FP7 EU Project. (2014). Duration: 2011-2014. Grant Agreement No. 287708. [Online]: http://www.iot-icore.eu/.

[28]. BUTLER FP7 EU Project. (2014). Duration: 2011-2014. Grant Agreement No. 287901. [Online]: http://www.iot-butler.eu/.

[29]. A. Rabbachin, T. Q. S. Quek and H. Shin, "Cognitive Network Interference," IEEE Journal on Selected Areas in Communications, Vol. 29, No. 2, 2011, pp. 480-493.

[30]. Howard, P. N. (2015). Pax Technica: How the Internet of Things May Set Us Free or Lock Us Up. Yale University Press.

[31]. Clusters of European Projects on Cloud, New Approaches for Infrastructure Services. [Online]: https://eucloudclusters.wordpress.com/new-approaches-for-infrastructure-services/.

[32]. iCore EU Project, No. 287708. [Online] http://www.iot-icore.eu/.

[33]. Hsu, W. C. et al. (2016). Utilization of a cloud-based diabetes management program for insulin initiation and titration enables collaborative decision making between healthcare providers and patients. Diabetes technology & therapeutics.

[34]. Li, W., et al. (2015). Mechanisms and challenges on mobility-augmented service provisioning for mobile cloud computing. Communications Magazine, IEEE, 53(3), 89-97.

[35]. Stojmenovic, I., & Wen, S. (2014, September). The Fog computing paradigm: Scenarios and security issues. In Computer Science and Information Systems (FedCSIS), 2014 Federated Conference on (pp. 1-8). IEEE.

[36]. Demchenko, Y.,et al. (2013). Intercloud Architecture Framework for Heterogeneous Multi-Provider Cloud based Infrastructure Services Provisioning. International Journal of Next-Generation Computing, 4(2).

[37]. Chandra, A., Weissman, J., & Heintz, B. (2013). Decentralized edge clouds. Internet Computing, IEEE, 17(5), 70-73.

[38]. Ngan, L. D., & Kanagasabai, R. (2013). Semantic Web service discovery: state-of-the-art and research challenges. Personal and ubiquitous computing, 17(8), 1741-1752.

[39]. Wang, P., Ding, Z., Jiang, C., & Zhou, M. (2014). Automated web service composition supporting conditional branch structures. Enterprise Information Systems, 8(1), 121-146.

[40]. Pawar, P. S., Sajjad, A., Dimitrakos, T., & Chadwick, D. W. (2015). Security-as-a-Service in Multi-cloud and Federated Cloud Environments. In Trust Management IX (pp. 251-261). Springer International Publishing.

[41]. Darabseh, A., Al-Ayyoub, M., Jararweh, Y., Benkhelifa, E., Vouk, M., & Rindos, A. (2015, March). Sdstorage: a software defined storage

experimental framework. In 2015 IEEE International Conference on Cloud Engineering (IC2E) (pp. 341-346). IEEE.

[42]. Alba, A., Alatorre, G., Bolik, C., Corrao, A., Clark, T., Gopisetty, S., ... & Traeger, A. (2014). Efficient and agile storage management in software defined environments. IBM Journal of Research and Development, 58(2/3), 5-1.

[43]. Nunes, B., Mendonca, M., Nguyen, X. N., Obraczka, K., & Turletti, T. (2014). A survey of software-defined networking: Past, present, and future of programmable networks. Communications Surveys & Tutorials, IEEE, 16(3), 1617-1634.

[44]. Kreutz, D., Ramos, F. M., Esteves Verissimo, P., Esteve Rothenberg, C., Azodolmolky, S., & Uhlig, S. (2015). Software-defined networking: A comprehen-sive survey. proceedings of the IEEE, 103(1), 14-76.

[45]. Zhou, H. (2012). The internet of things in the cloud: A middleware perspective. CRC Press.

[46]. Biswas, A. R., & Giaffreda, R. (2014, March). IoT and cloud convergence: Opportunities and challenges. In Internet of Things (WF-IoT), 2014 IEEE World Forum on (pp. 375-376). IEEE.

[47]. Botta, A., de Donato, W., Persico, V., & Pescapé, A. (2014, August). On the Integration of Cloud Computing and Internet of Things. In Future Internet of Things and Cloud (FiCloud), 2014 International Conference on (pp. 23-30). IEEE.

[48]. Demchenko, Y., Ngo, C., De Laat, C., Rodriguez, J., Contreras, L. M., Garcia-Espin, J. A., ... & Ciulli, N. (2013, March). Intercloud architecture framework for heterogeneous cloud based infrastructure services provisioning on-demand. In Advanced Information Networking and Applications Workshops (WAINA), 2013 27th International Conference on (pp. 777-784). IEEE.

[49]. Bruneo, D., Fritz, T., Keidar-Barner, S., Leitner, P., Longo, F., Marquezan, C., ... & Woods, C. (2014, June). Cloudwave: where adaptive cloud management meets devops. In Computers and Communication (ISCC), 2014 IEEE Symposium on (pp. 1-6). IEEE.

[50]. Hiray, S., & Ingle, R. (2013, November). Context-aware middleware in cyber physical cloud (CAMCPC). In Cloud & Ubiquitous Computing &

Emerging Technologies (CUBE), 2013 International Conference on (pp. 42-47). IEEE.

[51]. Suciu, G., Vulpe, A., Halunga, S., Fratu, O., Todoran, G., & Suciu, V. (2013, May). Smart cities built on resilient cloud computing and secure internet of things. In Control Systems and Computer Science (CSCS), 2013 19th International Conference on (pp. 513-518). IEEE.

[52]. Roman, R., Zhou, J., & Lopez, J. (2013). On the features and challenges of security and privacy in distributed internet of things. Computer Networks, 57(10), 2266-2279.

[53]. Villari, M., Celesti, A., Fazio, M., & Puliafito, A. (2014). A secure self-identification mechanism for enabling iot devices to join cloud computing. In Internet of Things. IoT Infrastructures (pp. 306-311). Springer International Publishing.

[54]. Cloud-of-Things - (ClouT) Project. Call: FP7-ICT-2013- EU-Japan. Type: STREP. Duration: 3 years (started on 01 April 2015). Web site: http://clout-project.eu.

[55]. MUlti-cloud Secure Applications (MUSA) Project. Call: H2020-ICT-2014-1. Topic: ICT-07-2014, Type: RIA, Duration: 3 years (started on 1st Jan, 2015), Web site: http://www.musa-project.eu.

[56]. Erkuden Rios, Eider Iturbe, Leire Orue-Echevarria, Massimiliano Rak, Valentina Casola: Towards Self-Protective Multi-Cloud Applications - MUSA - a Holistic Framework to Support the Security-Intelligent Lifecycle Management of Multi-Cloud Applications. CLOSER 2015 - Proceedings of the 5th International Conference on Cloud Computing and Services Science, Lisbon, Portugal, 20-22 May, 2015.SciTePress 2015, ISBN 978-989-758-104-5, pp 551-558

[57]. Heterogeneous Secure Multi-level Remote Acceleration Service for Low-Power Integrated Systems and Devices - (RAPID) Project. Call: H2020-ICT-2014-1, Topic: ICT-07-2014, Type: RIA, Duration: 3 years (started on 1st Jan, 2015), Web site: http://www.rapid-project.eu.

[58]. CUDA Toolkit Documentation. [Online]: http://docs.nvidia.com/cuda/cuda-runtime-api/#axzz4237B8rWd

[59]. In-network programmability for next-generation personal cloud service sup-port(INPUT) Project. Call: H2020-ICT-2014-1, Topic: ICT-07-

2014, Type: RIA, Duration: 3 years (started on 01/01, 2015), Web site: http://input-project.eu.

[60]. George Lyberopoulos, Eleni Theodoropoulou, Ioanna Mesogiti, Konstantinos Filis, Roberto Bruschi, Paolo Lago, Chiara Lombardo, Luigi Atzori, Antonio Iera, Giacomo Morabito,"INPUT: A Distributed Cloud Infrastructure for Intelligent Transport Systems", 19th International Conference on Circuits, Systems, Communications and Computers (CSCC 2015), Zakynthos Island, Greece, July 16-20, 2015, 2015.

[61]. SPECS: Secure Provisioning of Cloud Services based on SLA Management. Call: FP7-ICT-2013-1, Topic: Trustworthy ICT, Type: STREP, Duration: 2,5 years (started on 1/11/2013), Web site: http://www.specs-project.eu.

[62]. SOCIOTAL: Creating a socially aware and citizen-centric Internet of Things. Project reference: 609112. Funded under: FP7-ICT. From 2013-09-01 to 2016-08-31. Web site: http://sociotal.eu/.

[63]. COSMOS: Cultivate resilient smart objects for sustainable city applications. Project reference: 609043. Funded under: FP7-ICT. From 2013-09-01 to 2016-08-31. Web site: http://iot-cosmos.eu/.

[64]. CITY PULSE: Real-time IoT stream processing and large-scale data analytics for Smart City applications. Project reference: 609035. Funded under: FP7-ICT. From 2013-09-01 to 2016-08-31. Web site: http://www.ict-citypulse.eu/page/.

[65]. SMARTIE: Secure and smarter cities data management. Project reference: 609062. Funded under: FP7-ICT. From 2013-09-01 to 2016-08-31. Web site: http://www.smartie-project.eu/.

[66]. FIESTA: Federated Interoperable Semantic IoT/cloud Testbeds and Applications. Project reference: 643943. Funded under: H2020-EU.2.1.1.3. From 2015-02-01 to 2018-02-01, ongoing project. Web site: http://www.fiesta-iot.eu/.

[67]. Intelligent Knowledge-as-a-Service (iKaaS) Project. Call: H2020-EUJ-2014. Topic: EUJ-1-2014. Type: R&I. Duration: 3 years (started on 1 October, 2014). Web site: http://www.ikaas.com.

[68]. S. Hidano, S. Kiyomoto, Y. Murakami, P. Vlacheas, and Klaus Moessner “Design of a Security Gateway for iKaaS platform”, in Proc. of the

6th EAI International Conference on Cloud Computing, 28-29 October 2015, Daejeon, South Korea.

[69]. Oracle VM VirtualBox. [Online]: https://www.virtualbox.org/.

[70]. OpenStack: The Path To Cloud. [Online]: https://www.openstack.org/.

[71]. Docker An open platform for distributed applications for developers and sysadmins. [Online]: https://www.docker.com/.

[72]. Writing shell scripts. [Online]: http://linuxcommand.org/writing_shell_scripts.php.

[73]. Programming with RDF4j Eclipes. [Online]: http://rdf4j.org/doc/programming-with-rdf4j/.

[74]. RDF4j Reposiroty API. [Online]: http://rdf4j.org/doc/programming-with-rdf4j/#The_Repository_API.

[75]. GitLab - Code, test, and deploy together. [Online]: https://about.gitlab.com/.

7 SUMMARY – ON GOING CHALLENGES

The "Internet of Thing" – IoT constitutes one of the milestones for the Future Internet vision. The IoT includes a huge number of devices, communication infrastructures and applications. This leads to the technological heterogeneity of the IoT available entities that should be effectively addressed in order to hide the technological complexity, as well as to allow the seamless interoperability among the heterogeneous entities. The interoperability among the IoT entities will allow the deployment of more complex technological solutions for the end-users in the context of the contemporary IoT ecosystems. The IoT entities are characterized as objects/things, and classified as ICT and non-ICT entities, that can be provided with particular abstract capabilities for their communication, as well as it includes the data that is exchanged among the heterogeneous available entities. The IoT entities data can be re-used from different objects/things, enabling the dynamic deployment or the evolution of the existing IoT applications and services.

The introduction of the Semantic Framework that is proposed in this dissertation should support and ensure the smooth operation of the processes for the management of the technological heterogeneity and the hiding of the complexity, in the IoT, by exploiting the innovative mechanisms that are distributed in its three functional layers. The Semantic Framework has been designed based on Cloud computing architectural principles and it is comprised by three different functional layers: a) Semantic Data Management, b) Semantic Abstraction and Virtualization and c) Semantic Storage System. For the addressing of the requirements with respect to the semantic data modelling of the heterogeneous IoT entities related data and information, as well as in order to ensure the interoperability it will be used the mechanisms from the Semantic Abstraction and Virtualization layer. The mechanism from the Semantic Data Management and the Semantic Storage System will be used for the management of semantic data in terms of its distributed storage, query and modification, enabling the large-scale semantic data management in current and future IoT environments. The distributed storage and management of the semantic data can be applied in different use cases, such as the virtualization of things and applications, the dynamic deployment of virtualized hardware capabilities through software functionalities and in large-scale heterogeneous semantic data reconciliation and representation (e.g. knowledge representation).

Towards the future steps of this work, the Semantic Framework facilitates the extension of its functional capabilities so as to allow the future integration of additional innovative mechanisms for the Future Internet. Various rising technologies and application domains that will be integrated with the IoT ecosystem can be enhanced through the Semantic Framework capabilities. Potential integration activities may be associated with the Smart Cities (V2X, Smart Transportation, etc), Smart Health (e.g. Ambient Assisted Living applications), and the Wearables field (e.g. wearables for people with disabilities). Further to that, it can be further elaborated the deployment of an Energy-Efficient Cloud infrastructure build on embedded computers technology (e.g. Cloud-IoT in-the-box infrastructure).

Concluding, it should be highlighted that the dissertation focused on the detailed study of the proposed concepts by investigating the existing scientific and technological solutions, aiming to produce innovative results based on the legacy work. The research results that are presented in the dissertation chapters are associated with a set of different scientific publications that are included in the current literature.

8 APPENDIX A – ΕΚΤΕΤΑΜΕΝΗ ΕΛΛΗΝΙΚΗ ΠΕΡΙΛΗΨΗ

8.1 Επισκόπηση Κεφαλαίου

Το παρόν κεφάλαιο αποτελεί την εκτεταμένη περίληψη της διδακτορικής διατριβής στην Ελληνική γλώσσα. Αρχικά στην ενότητα 8.2 παρουσιάζεται η εισαγωγή της διατριβής αποτελούμενη από την περιγραφή του προβλήματος (υποενότητα 8.2.1) και της σχετικής συνεισφοράς (υποενότητα 8.2.2). Στη συνέχεια στην ενότητα 8.3 παρουσιάζονται και αναλύονται οι ερευνητικές δραστηριότητες που σχετίζονται με την θεματική περιοχή της διδακτορικής διατριβής. Η ενότητα 8.4 παρουσιάζει και αναλύει τις προτεινόμενες επιστημονικές λύσεις όπως αυτές διαρθρώνονται στα πλαίσια της διδακτορικής διατριβής, περιγράφοντας σχετική αρχιτεκτονική για την ανάπτυξη σημασιολογικού πλαισίου διαχείρισης για το διαδίκτυο του μέλλοντος. Στις ενότητες 8.5 έως και 8.7 παρουσιάζεται η ανάλυση των προβλημάτων με τα οποία ασχοληθήκαμε στην ερευνά μας και η συνεισφορά της διδακτορικής διατριβής, καθώς και η μεθοδολογία επίλυσης των προβλημάτων και η αξιολόγηση των προτεινόμενων λύσεων. Κάθε κεφάλαιο συμπληρώνεται με περιγραφή από τις δημοσιεύσεις κατά τις οποίες εφαρμόστηκε και επικυρώθηκε το ερευνητικό έργο της διδακτορικής διατριβής. Το κεφάλαιο κλείνει με την ενότητα 8.8 συνοψίζοντας τα σχετικά συμπεράσματα και περιγράφοντας μελλοντικές εξελικτικές δυνατότητες.

8.2 Εισαγωγή

Η παρούσα ενότητα αποτελεί την εισαγωγή της διδακτορικής διατριβής και διαρθρώνεται σε δύο κύρια σκέλη, α) την περιγραφή του προβλήματος με το οποίο καταπιάνεται η διδακτορική διατριβή και β) την συνεισφορά της διδακτορικής διατριβής στοχεύοντας στην επίλυσης του προβλήματος.

8.2.1 Περιγραφή προβλήματος

Η αλματώδης εξέλιξη των διαδικτυακών τεχνολογιών έχει οδηγήσει στην ανάπτυξη νέων υποδομών που επιτρέπουν την διασύνδεση όλο και περισσότερων συσκευών και μηχανών στο διαδίκτυο. Ο θεαματικά αυξανόμενος αριθμός συσκευών και μηχανών με δυνατότητες διασύνδεσης στο διαδίκτυο έχει οδηγήσει στην εκκίνηση μιας νέας εποχής του διαδικτύου, που αναφέρεται ως το «Διαδίκτυο των Αντικειμένων» (Internet of Things). Το «Διαδίκτυο των Αντικειμένων» αποτελεί ένα από τα οράματα για το «Διαδίκτυο του Μέλλοντος» (Future Internet), το οποίο εισέρχεται στην σύγχρονη εποχή δυναμικά την στιγμή που το «σημερινό» διαδίκτυο έχει μετατραπεί σε πλατφόρμας επικοινωνίας συσκευών και μηχανών από πλατφόρμα ανταλλαγής πληροφοριών για τελικούς-χρήστες.

Το μεγάλο πλήθος αντικειμένων, του πραγματικού κόσμου, που δύναται να γίνουν μέρος του «Διαδικτύου των Αντικειμένων» και η ποικιλία των δικτύων και των επικοινωνιών που θα πρέπει να υποστηρίζονται, απαιτούν τον σχεδιασμό, την ανάπτυξη και την χρήση νέων τεχνολογιών που θα καταστήσουν δυνατή την αποτελεσματική διαχείριση ετερογενών υποδομών. Η ιδέα του «Διαδικτύου των Αντικειμένων» συνίσταται όχι μόνο στην παροχή των αντικειμένων με υποδομές για την υποστήριξη της φυσικής επικοινωνίας, αλλά επίσης και στην ανταλλαγή των δεδομένων που μπορούν να (επανα-)χρησιμοποιηθούν από άλλα αντικείμενα, καθιστώντας δυνατή την ανάπτυξη νέων ή την εξέλιξη υπαρχόντων εφαρμογών με περισσότερες και πιο σύνθετες δυνατότητες [1].

Στην εποχή μας, υπάρχει ένα σύνολο τεχνολογιών που χρησιμοποιούνται για την πραγματοποίηση του «Διαδικτύου των Αντικειμένων». Η τεχνολογία Radio Frequency Identification (RFID) και/η τα Ασύρματα Δίκτυα Αισθητήρων (Wireless Sensor Networks - WSN) υποστηρίζουν την δυνατότητα ταυτοποίησης των αντικειμένων που ανήκουν στον πραγματικό κόσμο. Επιπλέον, η εκμετάλλευση άλλα και η εξέλιξη της «Σημασιολογικής Τεχνολογίας» (Semantic Technology) [2][3] επιτρέπει την δημιουργία «εικονικών αναπαραστάσεων» (abstract virtual representations) των πραγμάτων/αντικειμένων και βοηθά στο να αντιμετωπιστούν πρόβλημα που σχετίζονται με την διαλειτουργικότητα και την ενοποίηση των αντικειμένων σε ετερογενή περιβάλλοντα "ubiquitous computing". Ωστόσο η επικοινωνία μεταξύ των αντικειμένων μέσω του διαδικτύου, σε παγκόσμιο επίπεδο, θα μπορούσε να αποτελέσει σημαντικό πρόβλημα για το "ubiquitous computing" εξαιτίας της εκτεταμένης τεχνολογικής ετερογένειας και των περιορισμένων ανθρώπινων δυνατοτήτων [4]. Πράγματι, ακολουθώντας το παράδειγμα που αναφέρει «τα 7 τρισεκατομμύρια συσκευές για 7 δισεκατομμύρια ανθρώπους» [5] με τον συνεχώς αυξανόμενο αριθμό των ετερογενών αντικειμένων αποτελεί ένα από τα σημαντικότερα τεχνικά και τεχνολογικά θέματα που σχετίζονται με το «Διαδίκτυο των Αντικειμένων» [6] και κατ' επέκταση με το «Διαδίκτυο του Μέλλοντος». Παράλληλα, η ετερογένεια των εφαρμογών που αναπτύσσονται και μπορούν να επικοινωνήσουν μέσω διαδικτύου, αποτελεί ένα επιπλέον σημαντικό ζήτημα, το οποίο εντάσσεται στην αντιμετώπιση προβλημάτων ετερογένειας σε επίπεδο επικοινωνίας και διαχείρισης των εφαρμογών.

Η «αφαιρετικότητα» (abstraction) αντικειμένων και εφαρμογών αποτελεί ακρογωνιαίο λίθο για την αποτελεσματική αντιμετώπιση των προβλημάτων που αναφέρονται παραπάνω, πραγματοποιώντας την ιδέα κατά την οποία, κάθε αντικείμενο που είναι διαθέσιμο, προσβάσιμο και ελέγξιμο στον πραγματικό κόσμο, μπορεί να έχει μια "εικονική αναπαράσταση" (virtual representation) στο «Διαδικτύου των Αντικειμένων».

Η χρήση της «Σημασιολογίας» (Semantics) στο διαδίκτυο, προέκυψε από την ανάγκη που επέβαλε την εύρεση μια πιθανής δυνατής λύσης για την περιγραφή του τεράστιου όγκου δεδομένων [7] που συγκεντρώνονται στον Παγκόσμιο Ιστό (World Wide Web or Web). Η εισαγωγή της «Σημασιολογίας» στο Web οδηγεί στην εμφάνιση του «Σημασιολογικού Ιστού» (Semantic Web) [8][9], που αποτελεί την επέκταση του σημερινού Παγκόσμιου Ιστού, όπου οι πληροφορίες παρέχονται με «καλά ορισμένη» σημασία επιτρέποντας την αποδοτικότερη συνεργασία μεταξύ «Ανθρώπου – Μηχανής» (Human to Machine) και «Μηχανής-Μηχανης» (Machine-to-Machine). Την ίδια στιγμή, εστιάζοντας στις τεχνολογίες και τις τεχνικές που χρησιμοποιούνται στο «σημερινό» διαδίκτυο για την αντιμετώπιση της τεχνολογικής ετερογένειας, εντοπίζουμε την χρήση των «Τεχνολογιών του Σημασιολογικού Ιστού» (Semantic Web Technologies), οι οποίες ουσιαστικά ανήκουν στο ευρύτερο πεδίο της «Σημασιολογικής Τεχνολογίας» και εφαρμόζονται προκειμένου να υποστηρίξουν την διαδικασία εικονικοποίηση των υποδομών υλικού και λογισμικού (Hardware and Software Virtualization) ως «Διαδικτυακούς Πόρους» (Web Resources). Στο σημείο αυτό θα πρέπει να αναφερθεί ότι η διαδικασία εικονικοποίησης των υποδομών, εφαρμόζεται κατά κόρον στο τεχνολογικό πεδίο του «Υπολογιστικού νέφους» (Cloud Computing) [10] όπου το διαδίκτυο χρησιμοποιείται ως η κύρια υποδομή επικοινωνίας, των οντοτήτων που το απαρτίζουν. Η ενοποίηση των «Σημασιολογικών Τεχνολογιών» (Semantic Technologies) με τις σύγχρονες τεχνολογίες του Cloud Computing δύναται να υποστηρίξει την παροχή καινοτόμων και υψηλής ποιότητας σύνθετες υπηρεσίες που θα ανταποκρίνονται στις νέες τεχνολογικές τάσεις που συνδέονται με το «Μελλοντικό Διαδίκτυο». Ο σχεδιασμός τεχνολογικών λύσεων που θα βασίζονται στη σύνθεση «Σημασιολογικών Τεχνολογιών» με τεχνολογίες και τεχνικές εικονικοποίησης πόρων (Virtualization of resources, Platform-as-a-Service (PaaS)[11][12] και Infrastructure-as-a-Service (IaaS)[13][14]), καθώς και ο συνδυασμός τεχνολογιών διαχείρισης δεδομένων μεγάλης κλίμακας με υπηρεσίες Cloud Storage (Cloud storage services)[15][16], θα αποτελέσουν την σταθερή βάση για την υποστήριξη των τεχνολογικών και μετέπειτα βιομηχανικών αναγκών στην ραγδαία αναπτυσσόμενη εποχή του «Διαδικτύου του Μέλλοντος».

8.2.2 Συνεισφορά Διδακτορικής Διατριβής

Λαμβάνοντας υπόψη τα παραπάνω, κρίνεται αναγκαίος ο συνδυασμός διαφορετικών τεχνικών και τεχνολογιών του «Μελλοντικού Διαδικτύου», προκειμένου να αντιμετωπιστούν και να ικανοποιηθούν οι απαιτήσεις που προκύπτουν στον τομέα ενοποίησης και αποτελεσματικής διαχείρισης της ετερογενούς πληροφορίας που περιλαμβάνεται στους τομείς αυτού. Η παρούσα διατριβή εστιάζει στον συνδυασμό της «Σημασιολογίας» (Semantics) και του «Υπολογιστικού νέφους» (Cloud Computing), οι οποίες εντάσσονται στο πλαίσιο των τεχνικών και των τεχνολογιών του «Μελλοντικού Διαδικτύου».

Το κομμάτι της «Σημασιολογίας», με τον «Σημασιολογικό Ιστό», αναφέρεται σε δυο διαφορετικά πεδία εφαρμογής [17][18]. Το πρώτο πεδίο περιλαμβάνει θέματα που αφορούν την ανάπτυξη τεχνικών συλλογής/λήψης ετερογενών δεδομένων από ποικίλες και διαφορετικές πηγές. Το δεύτερο πεδίο εφαρμογής επικεντρώνεται στην προσέγγιση κατά την οποία θα καταστεί δυνατή η μοντελοποίηση ετερογενών δεδομένων (data modeling) τα οποία σχετίζονται με οντότητες/αντικείμενα του πραγματικού κόσμου. Από τα παραπάνω παρατηρούμε ότι η εφαρμογή της «Σημασιολογίας», θα μπορούσε να αποτελέσει το 'κλειδί' για την κάλυψη των αναγκών που προκύπτουν στο «Μελλοντικό Διαδίκτυο» το οποίο συγκεντρώνει τεράστιο αριθμό διασυνδεδεμένων συσκευών και τεράστιο όγκο διαθέσιμων δεδομένων. Συνεπώς, η χρήση της «Σημασιολογίας» μπορεί να συνεισφέρει στην πραγματοποίηση της ιδέας των «εικονικών αναπαραστάσεων» (virtual representations) των πραγμάτων, των υπηρεσιών και των εφαρμογών. Το τελευταίο θα οδηγήσει στην ανάπτυξη καινοτόμων και υψηλής ποιότητας υπηρεσιών εικονικοποίησης πόρων υλικού και λογισμικού (Hardware and Software Virtualization), δομώντας κατά αυτόν τον τρόπο ένα από τα βασικά συστατικά για την υλοποίηση του οράματος του «Μελλοντικού Διαδικτύου».

Επιπλέον, όπως ήδη έχει αναφερθεί η διδακτορική διατριβή μελετά την σύγκλιση των τεχνολογιών της «Σημασιολογίας» με τεχνολογίες από το «Υπολογιστικό Νέφος». Αφενός, όπως έχει ήδη επισημανθεί, η αξιοποίηση των «Σημασιολογικών Τεχνολογιών» θα διασφαλίσει την πραγματοποίηση της εικονικοποίησης αντικειμένων, υπηρεσιών και εφαρμογών, καθώς και την διαλειτουργικότητα μεταξύ ετερογενών οντοτήτων. Αφετέρου, οι τεχνολογίες από το πεδίο του «Υπολογιστικού νέφους» (Cloud Computing) θα ενισχύσουν σημαντικά τις προβλεπόμενες ερευνητικές δραστηριότητες που καταγράφονται στα πλαίσια διδακτορικής διατριβής. Συγκεκριμένα η εισαγωγή Cloud τεχνολογιών για την εικονικοποίηση και διαχείριση κατανεμημένων υποδομών, όπως το OpenStack [19], CloudStack [20] και Docker [21], θα ενισχύσει πολύ σημαντικά την απόδοση, την ακρίβεια και την τεχνολογική ποιότητα των μηχανισμών του σημασιολογικού πλαισίου. Οι μηχανισμοί ως συστατικά μέρη του σημασιολογικού πλαισίου θα μπορούν να παρέχονται ως κατανεμημένα υποσυστήματα/μηχανισμοί (distributed mechanisms) με δυνατότητες επεκτασιμότητας (scalability), ανάγοντας με αυτόν τον τρόπο το Σημασιολογικό Πλαίσιο σε ένα κατανεμημένο Cloud-based Semantic Framework. Ταυτόχρονα με τον συνδυασμό των παραπάνω, θα υλοποιηθούν καινοτόμες τεχνολογικές λύσεις, ως αποτέλεσμα της διατριβής, που θα συνδυάσουν Cloud με Σημασιολογικές τεχνολογίες, όπως η ανάπτυξη κατανεμημένου συστήματος αποθήκευσης και διαχείρισης σημασιολογικών δεδομένων.

8.3 Σχετικές Ερευνητικές Δραστηριότητες

Μια σειρά από ερευνητικές δραστηριότητες έχουν πραγματοποιηθεί σχετικά με «Εικονικοποίηση των Αντικειμένων» (Virtualization of Objects) μέσω της εφαρμογής της «Σημασιολογίας» (Semantics) για την υποστήριξη των αναγκών στις σύγχρονες μορφές του διαδικτύου, όπως το «Διαδίκτυο των Αντικειμένων» [22]-[24]. Η πλειοψηφία αυτών, εισήγαγε την «Σημασιολογική Τεχνολογία» στο «Μελλοντικό Διαδίκτυο» κυρίως ως μέσο για την εξασφάλιση της διαλειτουργικότητας. Επιπλέον, την τελευταία δεκαετία, πληθώρα ερευνητικών δραστηριοτήτων έχει εστιάσει στον συνδυασμό των «Σημασιολογικών Τεχνολογιών» με τεχνολογίες από το «Υπολογιστικού νέφους».

Η παρούσα ενότητα αναλύει τις ερευνητικές δραστηριότητες που έχουν πραγματοποιηθεί έως τώρα και σχετίζονται με το ερευνητικό αντικείμενο της διδακτορικής διατριβής. Συγκεκριμένα, παρουσιάζει ένα σύνολο από σημαντικές ερευνητικές δραστηριότητες που έχουν πραγματοποιηθεί: α) στο πεδίο της σημασιολογικής αφαιρετικότητας και εικονικοποίησης αντικειμένων, β) την γνωσιακή διαχείριση εικονικοποιημένων αντικειμένων και υπηρεσιών, και γ) τον συνδυασμό των παραπάνω τεχνολογιών με τεχνολογίες από το πεδίο του Internet of Things που βασίζεται στο «Υπολογιστικό Νέφος» (Cloud Internet of Things).

8.3.1 Σημασιολογική Αφαιρετικότητα και Εικονικοποίηση Αντικειμένων στο Μελλοντικό Διαδίκτυο

Στην ενότητα αυτή πραγματοποιείται η ανασκόπηση των εφαρμογών της Σημασιολογίας και της εικονικοποίησης αντικειμένων στο «Διαδίκτυο του Μέλλοντος», σύμφωνα με το καταγεγραμμένο ερευνητικό έργο έως σήμερα. Οι καταγεγραμμένες ερευνητικές δραστηριότητες σχετίζονται με το ερευνητικό αντικείμενο της παρούσας διατριβής το οποίο αναλύεται στις ενότητες 8.4.1.2 και 8.4.1.3.

Συγκεκριμένα, παρουσιάζονται τα μέχρι στιγμής εδραιωμένα standards στο πεδίο της «Σημασιολογικής Μοντελοποίησης» οι τεχνικές και τεχνολογίες διαχείρισης Σημασιολογικών Δεδομένων, καθώς και ένα ευρύ σύνολο διεθνών ερευνητικών προγραμμάτων και δραστηριοτήτων που πραγματεύονται την εφαρμογή της «Σημασιολογίας» στο «Διαδίκτυο του Μέλλοντος».

Τις τελευταίες δύο δεκαετίες έχουν μελετηθεί, αναπτυχθεί και επικυρωθεί διάφορα και διαφορετικά standards για την μοντελοποίηση των σημασιολογικών δεδομένων (Semantic Data Modeling standards). Ο οργανισμός Open Geospatial Consortium (OGC) [25] παρέχει ένα σύνολο από διαφορετικά standards στο συγκεκριμένο τομέα τα οποία έχουν ήδη αρχίσει να ενοποιούνται με τα τεχνολογικά standards του παγκόσμιου οργανισμού World Wide Web Consortium – W3C (W3C Semantic Web technological standards) [26] στοχεύοντας στην βελτίωση της διαλειτουργικότητας και την ενοποίηση ετερογενών δεδομένων στο «Σημασιολογικό Διαδίκτυο» [27]. Ο παραπάνω συνδυασμός έχει ως αποτέλεσμα την παροχή μιας μεγάλης γκάμας standards για το «Σημασιολογικό Διαδίκτυο» και κατ' επέκταση για την εφαρμογή της «Σημασιολογίας» στο «Διαδίκτυο του Μέλλοντος». Τα παρεχόμενα standards περιλαμβάνουν την μοντελοποίηση, την περιγραφή, την αναπαράσταση, καθώς και την διαχείριση των Σημασιολογικών δεδομένων [27][28] που περιλαμβάνονται στο «Διαδίκτυο του Μέλλοντος». Αυτά τα δεδομένα μπορεί να αναφέρονται σε υπηρεσίες, εφαρμογές, αντικείμενα, τοποθεσίες, ανθρώπους, δικτυακές και διαδικτυακές υποδομές, καθώς και σε κάθε οντότητα που αποτελεί ή μπορεί να αποτελέσει τμήμα του «Μελλοντικού Διαδικτύου». Συγκεκριμένα, στον τομέα της μοντελοποίησης δεδομένων που αφορούν υπηρεσίες, εφαρμογές και αντικείμενα ενδεικτικά συγκαταλέγονται τα standards μοντελοποίησης όπως τα μοντέλα: Catalog Service for the Web (CSW) [29], Observations and Measurements (O&M) [30], SensorML [31], Sensor Observation Service (SOS) [32], TransducerML (TML) [33], Web Processing Service (WPS) [34], Web Registry Service (WRS) [35], IoT-A Entity Model [36], IoT-A Resource Model [36], IoT-A Service Model [36]. Διάφορα standards έχουν αναπτυχθεί για την υποστήριξη της μοντελοποίησης δεδομένων που αφορούν χώρους/τοποθεσίες και τεχνολογικές υποδομές, όπως ενδεικτικά: Geography Mark-up Language (GML) [37], CityGML [38], Geographically Encoded Objects for RSS feeds (GeoRSS) [39], Geographic Query Language for RDF Data (GeoSPARQL) [40], WaterML [41]. Επιπροσθέτως, ο Σημασιολογικός Ιστός περιλαμβάνει ένα σύνολο διαφορετικών τεχνολογικών προτύπων ή / και εννοιολογικών εργαλείων που υποστηρίζουν τη διαχείριση δεδομένων, καθώς και την αναζήτηση και την τροποποίηση (ενημέρωση / διαγραφή). Συγκεκριμένα, οι τεχνολογίες του Σημασιολογικού Ιστού επιτρέπουν στους ανθρώπους να δημιουργήσουν αποθήκες δεδομένων στον Παγκόσμιο Ιστό, να χτίσουν λεξιλόγια, και να καταγράφουν τους κανόνες και τις αρχές που αφορούν στο χειρισμό των σημασιολογικών δεδομένων. Λαμβάνοντας υπόψη την προσέγγιση του οργανισμού W3C [42], οι τεχνολογίες του Σημασιολογικού Ιστού και τα εργαλεία μπορούν να ταξινομηθούν στις ακόλουθες κατηγορίες: α) Διασυνδεδεμένα Δεδομένα (Linked Data) [43]-[45], β) Λεξιλόγια / Οντολογίες (Vocabularies/Ontologies) [46]-[50], γ) Συλλογιστική και συμπερασματολογία των σημασιολογικών δεδομένων (Semantic Data Reasoning and Inference) [51]-[54], και δ) τη διαχείριση των Σημασιολογικών δεδομένων (Semantic Data Management) όπου περιλαμβάνει την αποθήκευση δεδομένων, την πραγματοποίηση αναζήτησης και ανακάλυψης δεδομένων, και την τροποποίηση των δεδομένων (ενημέρωση / διαγραφή) [55]-[64]. Ο κύριος κορμός των σημασιολογικών τεχνολογιών που συγκαταλέγονται στις παραπάνω κατηγορίες συμπεριλαμβάνει τα εξής: Resource Description Framework (RDF) [49], RDF Schema (RDFS) [50], Web Ontology Language (OWL) [47], SPARQL query language [56], RDF Stores / Triple Stores [57], καθώς και γλώσσες για την συμπερασματολογία σε σημασιολογικά δεδομένα, όπως η Prolog Reasoning Language [54].

8.3.2 Γνωσιακή Διαχείριση Εικονικοποιημένων Αντικειμένων και Υπηρεσιών στο Μελλοντικό Διαδίκτυο

Στην ενότητα αυτή πραγματοποιείται η ανασκόπηση των ερευνητικών δραστηριοτήτων στο πεδίο της γνωσιακή διαχείρισης και της εικονικοποίησης αντικειμένων και υπηρεσιών στο «Διαδίκτυο του Μέλλοντος», σύμφωνα με το καταγεγραμμένο ερευνητικό έργο έως σήμερα. Οι καταγεγραμμένες ερευνητικές δραστηριότητες σχετίζονται με το ερευνητικό αντικείμενο της παρούσας διατριβής το οποίο αναλύεται στις ενότητες 8.4.1.4 και 8.4.1.5.

Η πλατφόρμα EBBITS [65] στοχεύει στην παροχή σημασιολογικής ανάλυσης στο «Διαδίκτυο των Αντικειμένων» - "Internet of Things" και έτσι παρουσιάζει μια νέα γέφυρα διασύνδεσης μεταξύ backend εταιρικών εφαρμογών, ανθρώπων, υπηρεσιών και του φυσικού κόσμου. Ένα άλλο παράδειγμα αποτελεί το SPITFIRE (Semantic-Service Provisioning for the Internet of Things using Future Internet Research by Experimentation) πρόγραμμα [66] το οποίο αποσκοπεί στην διερεύνηση ενοποιημένων εννοιών, μεθόδων και υποδομών λογισμικού που θα διευκολύνουν την αποτελεσματική ανάπτυξη εφαρμογών που θα πραγματοποιήσουν την ενοποίηση του διαδικτύου και με τον πραγματικό κόσμο. Η αποστολή του προγράμματος SOFIA [67] περιλαμβάνει την δημιουργία μιας σημασιολογικής δυσλειτουργικής πλατφόρμας για νέες υπηρεσίες που θα επιτρέπουν και θα υποστηρίζουν την διεπαγγελματική (cross-industry) διαλειτουργικότητα. Το πρόγραμμα SENSEI [68] εστιάζει, σε κάποιο βαθμό, στα σημασιολογικά χαρακτηριστικά για την ενοποίηση της πρόσβασης σε πληροφορίες περιεχομένου και την ενεργοποίηση υπηρεσιών, επικαλούμενο αντικείμενα του πραγματικού κόσμου. Το DIEM (Devices and Interoperability Ecosystems) [69] αποτελεί μια άλλη ερευνητική δράση η οποία εστιάζει στα «έξυπνα περιβάλλοντα» - "smart environments" όπου διαλειτουργικές συσκευές και υπηρεσίες, παρέχουν νέα είδη πληροφοριών. Ένα βασικό στοιχείο στο DIEM είναι η σημασιολογική διαλειτουργικότητα μεταξύ συσκευών από διαφορετικούς χώρους. Το OPUTE (Open Ubiquitous Technologies) πρόγραμμα [70] υλοποιεί και παρουσιάζει την σημασιολογική διαλειτουργικότητα μεταξύ ενσωματωμένων συστημάτων με δυνατότητες που κυμαίνονται από την απλή παθητική ετικέτα RFID μέσω ενεργών ετικετών σε πολύπλοκα καταναλωτικά προϊόντα και συσκευές με ενσωματωμένες δυνατότητες επεξεργασία και προσωπικές συσκευές κινητής τηλεφωνίας. Το Internet of Things Architecture (IoT-A) [71] Ευρωπαϊκό πρόγραμμα εισάγει την εφαρμογή μοντέλων περιγραφής των αντικειμένων μέσω της ανάπτυξης των μοντέλων [72] IoT-A Domain Model και IoT-A Information Model. Τα μοντέλα αυτά, ορίζουν τις συσχετίσεις μεταξύ αντικειμένων και χαρακτηριστικών / γνωρισμάτων (attributes) και ενσωματώνουν ιδιότητες Μέτα-δεδομένων (meta-data properties) για την περιγραφή των αντικειμένων. Επιπλέον, εισάγουν και συνδυάζουν τους όρους «Αντικείμενο» – "Object" και «Οντότητα» - "Entity" προκειμένου να αναπτύξουν και να προωθήσουν ένα πολύ καλά ορισμένο και εμπλουτισμένο, μέσω Μέτα-δεδομένων, συνονθύλευμα πληροφοριών που αφορούν τις ιδιότητες και τα χαρακτηριστικά συσκευών ή/και των οντοτήτων που εισάγονται/εμπλέκονται στο επίπεδο συσκευή (device level) σε ένα περιβάλλον του «Διαδικτύου των Αντικειμένων» που αναπτύσσεται με βάση της IoT-

A αρχιτεκτονικής. Στο Internet of Things Initiative (IoT-i) [73] εισάγεται ο όρος IoT Device όπου αναφέρεται στην οντότητα που χρησιμοποιείται προκειμένου να αναπτύξει την διεπαφή των IoT συστημάτων με τον πραγματικό / φυσικό κόσμο (Physical World). Το IoT-i για την περιγραφή των συσκευών παρουσιάζει ένα device-centric αναφορικό μοντέλο περιγραφής το οποίο περιέχει ιδιότητες / χαρακτηριστικά των συσκευών, συμπληρωμένες με τις μεταξύ τους συσχετίσεις.

Η ερευνητική δράση [74] αναφέρεται στην ανάπτυξη «εικονικών αισθητήρων» - "virtual sensors" για την 'απόκρυψη' των λεπτομερειών της υλοποίησης από τον χρήστη, συμπεριλαμβάνοντας παράλληλα και ένα μεγάλο αριθμό πραγματικών συσκευών όπως κινητά τηλέφωνα και κάμερες. Πλήθος προσεγγίσεων όπως η [74], εστιάζουν στην εικονικοποίηση (virtualization) των πραγματικών συσκευών. Η ερευνητές στις εργασίες [75] και [76] περιγράφουν τις προσπάθειες τους για την ενίσχυση εικονικών αντικειμένων με 'έξυπνες λειτουργίες' προκειμένου να καταστήσουν δυνατή την μεταξύ τους επικοινωνία. Η [77] στοχεύει στον σχεδιασμό και την ανάπτυξη ενός στάνταρντ μοντέλου περιγραφής για την περιγραφή και την διαλειτουργικότητα των αντικειμένων βάση μιας συγκεκριμένης περιγραφικής γλώσσας. Η ερεύνα που πραγματοποιείται στην [78] εξετάζει την έννοια του «Εικονικού Δικτύου Αισθητήρων» - Virtual Sensor Network (VSN) ως ακρογωνιαίο λίθο για την ανάπτυξη συστημάτων του «Διαδικτύου των Αντικειμένων» (IoT Systems). Συγκεκριμένα το VSN μπορεί να διαχειριστεί την δυναμική συνεργασία υποσυνόλων αισθητήρων στοχεύοντας στην ανάπτυξη λύσεων για την υποστήριξη συλλογικών υπολογιστικών δραστηριοτήτων. Επιπλέον η [79] προτείνει ένα πλαίσιο εικονικοποίησης για το «Διαδικτύου των Αντικειμένων» - "Internet of Things"όπου άπτεται στην έννοια sensor-as-a-service. Το συγκεκριμένο πλαίσιο παρουσιάζει την διασύνδεση και επικοινωνία ετερογενών αντικειμένων στο υπολογιστικό νέφος (Cloud computing) του «Διαδικτύου των Αντικειμένων» - "Internet of Things", ως διαδικτυακές υπηρεσίες"Web Services". Το Versatile Digital Item (VDI) [80], μία πολλή γενική μορφή για την δομή των δεδομένων, υποστηρίζει τον διαμοιρασμό πληροφοριών μεταξύ εικονικών και φυσικών οντοτήτων, λειτουργώντας υποστηρικτικά προς την προσέγγιση που παρουσιάζεται στην [81] για την ενίσχυση ενός μοντέλου Δημοσίευσης – Εγγραφής (publish-subscribe model). Η έννοια των Active Digital Identities (ADI) παρουσιάζεται στην [82] ως το μέσω που θα οδηγήσει στην πραγματοποίηση του «Ιστού των Αντικειμένων» (Web of Things). Το ADI παρουσιάζει μοναδικά κάθε αντικείμενο που εμπλέκεται / συμπεριλαμβάνεται στον διαδικτυακό ιστό των αντικειμένων, χρησιμοποιώντας ένα Uniform Resource Locator

(URL). Προς την κατεύθυνση του «Ιστού των Αντικειμένων» – "Web of Things" προσανατολίζεται και η ερευνητική δραστηριότητα στο [83] προτείνοντας την ανάπτυξη κατάλληλης διαδικτυακής πλατφόρμας για την υποστήριξη της προσθήκης, της χρήσης και του διαμοιρασμού διασυνδεδεμένων έξυπνων αντικειμένων, υιοθετώντας έννοιες και τεχνολογικές τάσεις από τα πεδία της Εικονικοποίηση των Αντικειμένων (Objects Virtualization) και τις Σημασιολογικές Τεχνολογίες (Semantic Technologies). Επιπλέον, ιδιαίτερο ενδιαφέρον παρουσιάζουν οι προσεγγίσεις που παρουσιάζονται στις [84]-[87] όπου προτείνεται η μίξη των αντικειμένων του φυσικού κόσμου για την ανάπτυξη ολοκληρωμένων λύσεων που θα οδηγήσουν στην ενοποίηση του φυσικού με τον εικονικό κόσμο, εφαρμόζοντας τεχνολογικές λύσεις από το πεδίο της Σημασιολογίας (Semantics) και της Εικονικοποίηση των αντικειμένων (Objects Virtualization).

8.3.3 Cloud Internet of Things περιβάλλοντα

Στη ενότητα αυτή πραγματοποιείται η ανασκόπηση των ερευνητικών δραστηριοτήτων που αφορούν τον συνδυασμό σημασιολογικών τεχνολογιών και των τεχνικών εικονικοποίησης αντικειμένων και υπηρεσιών σε συνδυασμό με Cloud τεχνολογίες για την ανάπτυξη αποδοτικών συστημάτων. Οι καταγεγραμμένες ερευνητικές δραστηριότητες σχετίζονται με το ερευνητικό αντικείμενο της παρούσας διατριβής το οποίο αναλύεται στην ενότητα 8.4.1.6.

Ο συνδυασμών αυτών των τεχνολογιών μπορεί να αφορά διαφορετικές περιπτώσεις εφαρμογής. Ενδεικτικά στην παρούσα μελέτη εστιάζουμε: α) σε πτυχές που αφορούν τον σχεδιασμό συστημάτων που βασίζονται στο «Νέφος» (Cloud) ενοποιώντας την σημασιολογική περιγραφή για την υποστήριξη υπηρεσιών «Νέφους» - (Cloud Services) ([88]-[104]), και β) η διαχείριση δεδομένων μεγάλης κλίμακας ([105]-[113]). Στη συνέχεια παρουσιάζονται ενδεικτικά, κάποιες από τις σημαντικότερες, έως τώρα, ερευνητικές εργασίες στο συγκεκριμένο εξεταζόμενο πεδίο.

Η ερευνητική δραστηριότητα στο [88] παρουσιάζει την ανάπτυξη ενός σχεδιαστικού μοντέλου παραγωγής υπηρεσιών που βασίζονται στον συνδυασμό των σημασιολογικών τεχνολογιών και των τεχνολογιών του «Νέφους». Το μοντέλο ανάπτυξης προϊόντων για τον «Νέφος» ονομάζεται Cloud-based design manufacturing (CBDM). Η ερευνητική ομάδα, προκειμένου να αναπτύξει το CBDM ταυτοποίησε αρχικά τα κοινά χαρακτηριστικά ανάπτυξης και εν συνεχεία επέλεξε το σύνολο εκείνων που πρέπει να ικανοποιούνται από το CBDM σύστημα. Κατόπιν πραγματοποίησαν σύγκριση του αναπτυσσόμενου συστήματος με αντίστοιχα συστήματα ανάπτυξης και επικύρωσαν την λειτουργία του μέσα από ένα ολοκληρωμένο σενάριο εφαρμογής. Με το αντικείμενο του Cloud manufacturing (CMfg) ασχολείται η [89] παρουσιάζοντας το ως ένα προηγμένο service-oriented μοντέλο βιομηχανοποίηση (manufacturing) για την βιομηχανία. Ο τρόπος οργάνωσης της παραγωγής των επιχειρήσεων αλλάζει βάση του CMfg οργανώνοντας τις παραγωγικές δραστηριότητες υλικών και άυλων πόρων ως έγκλειστες διαδικασίες όπως συμβαίνει με τις εικονικές υπηρεσίες που παρέχονται στους τελικούς χρήστες. Για την επίτευξη των παραπάνω προτείνεται η εισαγωγή των semantics για την ανάπτυξη των διαδικασιών μοντελοποίησης και περιγραφής των διαφόρων διαδικασιών. Συγκεκριμένα προτείνεται η ανάπτυξη κατάλληλης οντολογίας (GCMT Ontology) για την σημασιολογική περιγραφή των λειτουργικών διαδικασιών σε συνδυασμό με κατάλληλα μοντέλα περιγραφής και αλγορίθμους semantic similarity. Η [90] εστιάζει στις Cloud-based Mobile Augmentation (CMA) προσεγγίσεις. Στις κύριες ερευνητικές δραστηριότητες συμπεριλαμβάνονται ο αναλυτικός έλεγχος των ήδη ανεπτυγμένων λύσεων και ο συνδυασμός αυτών για την ανάπτυξη κατάλληλου συστήματος για την υποστήριξη resource-intensive κινητών εφαρμογών. Επιπλέον, η ανάπτυξη Cloud-based συστημάτων για augmentation σε κινητές εφαρμογές, εισάγει την ανάγκη για μελέτη taxonomies, σημασιολογίας (semantics) και τύπων augmentation, τα οποία συνδέονται με το πεδίο των σημασιολογικών τεχνολογιών. Η εικονικοποίηση των υπηρεσιών της «τεχνολογίας της πληροφορίας»-"Information Technology(IT)" αποτελεί το κύριο αντικείμενο μελέτης στην ερευνητική μελέτη [91]. Συγκεκριμένα πραγματοποιείται μελέτη σχετικά με τον τρόπο που θα μπορούσαν να παρέχονται λειτουργικές δυνατότητες από Cloud-based σύστημα για την εφαρμογή και χρήση IT Cloud-based Services κατ' απαίτηση (on-demand). Οι ερευνητές εξετάζουν τέσσερις (4) διαφορετικές κατηγορίες απαιτήσεων για την ανάπτυξη του κύκλου ζωής των υπηρεσιών: α) ανακάλυψη (discovery) β) διαπραγμάτευση (negotiation) γ) σύνθεση (composition) και δ) κατανάλωση (consumption). Στην ίδια κατεύθυνση κινούνται και οι ερευνητές στην [92] προτείνοντας κατάλληλη μεθοδολογία για την ανάπτυξη διαδικτυακών υπηρεσιών που χρησιμοποιούν την Service-oriented αρχιτεκτονική (SoA). Ωστόσο, η προσέγγισή τους περιορίζεται στη δημιουργία και την ανάπτυξη των διαδικτυακών υπηρεσιών και δεν επεκτείνεται σε εικονικοποιημένα περιβάλλοντα (virtualized environments) όπου οι υπηρεσίες αναπτύσσονται και χρησιμοποιούνται κατά παραγγελία (on-demand). Οι μελετητές στην [93] ασχολούνται με τα θέματα μοντελοποίησης επαναδιαμορφώσιμων υπηρεσιών (modelling of reconfigurable services) και την υποστήριξη λειτουργικότητας για την αποτελεσματική λήψη αποφάσεων δημιουργίας σύνθεση υπηρεσιών. Εισάγουν μια νέα συνθετική διαδικασία λήψης αποφάσεων, το CDP, η οποία διερευνά τις βέλτιστες λύσεις των επιμέρους υπηρεσιών σύστασης και χρησιμοποιεί τις γνώσεις για να αντλήσει την βέλτιστη QoS με γνώμονα τις διαθέσιμες προτεινόμενες συνθέσεις. Ωστόσο, η εφαρμογή τους περιορίζεται σε προϋπάρχουσες υπηρεσίες Web και δεν επεκτείνεται σε virtualized υπηρεσίες που αποτελούν πρώτη προτεραιότητα για το «Διαδίκτυο των Αντικειμένων». Στην [94] παρουσιάζεται η GoodRelations οντολογία η οποία αναπτύχθηκε για την περιγραφή των προϊόντων στο ηλεκτρονικό εμπόριο. Ενώ αυτή η οντολογία είναι χρήσιμη για την περιγραφή της σύστασης μιας Cloud-based υπηρεσίας, είναι δύσκολο να περιγράψει σύνθετες εικονικές υπηρεσίες που παρέχονται από πολλαπλούς παρόχους που χρησιμοποιούν αυτήν την οντολογία. Στην [95] προτείνεται μια τεχνική για την πιο αποτελεσματική σύνθεση σημασιολογικών υπηρεσιών. Πολύ σημαντικό ερευνητικό υλικό παρουσιάζεται σε σχέση με τον τομέα του Grid computing όπου σε διάφορες ερευνητικές δραστηριότητες ([96]-[101]) οι οποίες εξετάζουν ζητήματα που αφορούν την on-demand πρόβλεψη, ανακάλυψη και σύνθεση υπηρεσιών. Τα αποτελέσματα των ερευνητικών δραστηριοτήτων στο Grid computing επικεντρώνονται και μπορούν περισσότερο να συνεισφέρουν κυρίως στην παροχή Cloud-based υπηρεσιών. Η επιστημονική έρευνα που παρουσιάζεται στην [102] μελετά το θέμα της ποιότητας υπηρεσιών (Quality-of-Service - QoS) σε Cloud και Service Oriented Αρχιτεκτονικές, χρησιμοποιώντας την σημασιολογία. Επιπλέον οι ερευνητές μελετούν το σύνολο των απαιτήσεων που συνδέονται με τις τεχνικές διαχείρισης των Big Data και προτείνουν την ανάπτυξη αρχιτεκτονικής λάμδα (Lambda Architecture) η οποία θα βασίζεται στην εφαρμογή των Semantics και των Big Data . Στην [103] παρουσιάζεται η ανάπτυξη ενός νέο καινοτόμου μοντέλου αρχιτεκτονική για το IoT το οποίο βασίζεται στις σημασιολογικές τεχνολογίες και τις τεχνολογίες του υπολογιστικού νέφους. Συγκεκριμένα το μοντέλο ονομάζεται Semantic Fusion Model (SFM) και στόχος του είναι η ενσωμάτωση ενός σημασιολογικού πλαισίου το οποίο θα παρέχει τα μέσα για την εξεργασία πληροφοριών από τα δίκτυα αισθητήρων. Το σύστημα ενσωματώνει semantic logic και semantic-based πληροφορίες που το προσδίδουν δυνατότητες ευφυΐας. Η ερευνητική ομάδα στην [104] εξετάζει τις διάφορες απαιτήσεις που συνδέονται με την ανακάλυψη κινητών υπηρεσιών Web οι οποίες ενσωματώνουν επιπλέον πολυπλοκότητα εξαιτίας τις ετερογένειας των συσκευών και των δικτύων.

Συγκεκριμένα οι ερευνητές προτείνουν την ανάπτυξη ενός Cloud-based συστήματος το οποίο θα υποστηρίζει την ανακάλυψη υπηρεσιών Web βάση ενός πλαισίου που ονομάζεται Discovery-as-a-service (Daas). Το Daas ενσωματώνει στα κριτήρια αναζήτησης τις προτιμήσεις χρηστών (user preferences) και παραμέτρους του γενικού πλαισίου (context parameters) προκειμένου να επιτύχει τα καλύτερα δυνατά αποτελέσματα στις διαδικασίες αναζήτησης υπηρεσιών.

Η ερευνητική ομάδα στην [105] παρουσιάζει την προσέγγιση της σχετικά με την βελτιστοποίηση της αποθήκευσης και επεξεργασίας κλιμακούμενων δεδομένων στον σημασιολογικό ιστό. Συγκεκριμένα οι ερευνητές περιγράφουν την ανάπτυξη ενός ολοκληρωμένου πλαισίου λειτουργιών βασισμένο στο Hadoop, όπου και χρησιμοποιούν τους μηχανισμούς του για την αποθήκευση και την ανάκτηση δεδομένων από το Hadoop Distributed File System (HDFS). Επιπλέον, έχουν αναπτύξει ένα συγκεκριμενοποιημένο αλγόριθμο εξυπηρέτησης SPARQL ερωτημάτων ο οποίος χρησιμοποιεί το Hadoop MapReduce framework προκειμένου να απαντήσει τα σχετικά SPARQL ερωτήματα. Στην ίδια κατεύθυνση κινείται και η δημοσίευση [106] όπου οι συγγραφείς περιγράφουν τον προβληματισμό σχετικά με τον διαρκώς αυξανόμενο όγκο των σημασιολογικών δεδομένων, ενώ για την αντιμετώπιση του παρουσιάζουν ένα επεκτάσιμο σύστημα διαχείρισης RDF δεδομένων. Το σύστημα εισάγει τρείς διαφορετικές τεχνικές διαχείρισης RDF δεδομένων: α) αξιοποίηση τεχνολογιών ενιαίου κόμβου αποθήκευσης RDF δεδομένων, β) κατακερματισμός RDF δεδομένων σε διαφόρους κόμβους και γ) ανάλυση SPARQL ερωτημάτων σε υψηλής απόδοσης τμήματα για την ανάκτηση πληροφοριών σχετικά με το μέγεθος κατακερματισμού των δεδομένων. Η ερευνητική δραστηριότητα [107] εξετάζει τα ζητήματα διαχείρισης RDF γράφων μεγάλης κλίμακας και προτείνει ένα πλαίσιο λειτουργιών το οποίο θα καταστεί ικανό να υποστηρίξει την αποθήκευση και ανάκτηση μεγάλου όγκου RDF δεδομένων αξιοποιώντας τις λειτουργικές δυνατότητες του Hadoop και χρησιμοποιώντας το HDFS για την αποθήκευση των εν λόγο δεδομένων. Επιπλέον, παρουσιάζεται σχετικός αλγόριθμος επεξεργασίας και αποθήκευση RDF δεδομένων σε κατανεμημένες Hadoop συστάδες. Στην [108] παρουσιάζεται η εφαρμογή του HBase [109] συστήματος αποθήκευσης και των MapReduce τεχνικών για την ανάπτυξη μιας μεγάλης κλίμακας RDF συστήματος αποθήκευσης. Η συγκεκριμένη προσέγγιση βασίζεται στην ιδέα της Hexastore [110] σε συνδυασμό με την RDF μοντελοποίηση δεδομένων και τις δυνατότητες του HBase συστήματος αποθήκευσης. Συγκεκριμένα πραγματοποιείται αποθήκευση από RDF Triples (τριπλέτες δεδομένων) σε έξι διαφορετικούς πίνακες HBase (S_PO, P_SO, O_SP, PS_O, SO_P και PO_S) οι οποίοι καλύπτουν όλους τους πιθανούς συνδυασμούς RDF Triple προτύπων, και χρησιμοποιούν ως κλειδί εύρεσης (index key) μια στήλη από κάθε πίνακα. Επιπλέον χρησιμοποιείται η τεχνική των SPARQL Basic Graph Pattern (BGP) τα οποία εκτελούνται από MapReduce αλγορίθμους, συμβατούς με το σχήμα αποθήκευσης δεδομένων της βάσης δεδομένων που προτείνει η συγκεκριμένη ερευνητική δραστηριότητα. Στην κατεύθυνση δημιουργίας αποδοτικών βάσεων δεδομένων μεγάλης κλίμακας κινείται και η ερευνητική δραστηριότητα στη δημοσίευση [111] όπου οι συγγραφείς παρουσιάζουν σχετικό αλγόριθμο για την εκτέλεση γρήγορης αναζήτησης σε μεγάλης κλίμακας RDF δεδομένων (αποθηκευμένα ως RDF Triples) αξιοποιώντας τις λειτουργικές δυνατότητας των τεχνικών MapReduce. Στην [112] οι συγγραφείς παρουσιάζουν μια ολοκληρωμένη έρευνα στα ζητήματα της μίξης τεχνικών του MapReduce και εκτέλεσης ερωτημάτων σε μεγάλης κλίμακας σημασιολογικά δεδομένα. Παρουσιάζονται τεχνικές ανάπτυξης και εφαρμογής προτύπων ερωτημάτων σε σημασιολογικά δεδομένα, καθώς και τεχνικές εφαρμογής των προτύπων σε MapReduce αλγορίθμους που θα αναλαμβάνουν την εκτέλεση τους. Η [113] ασχολείται με το ζήτημα των σημασιολογικών δεδομένων μεγάλης κλίμακας από μια διαφορετική πτυχή, αυτή της απεικόνισης τους για την διευκόλυνση της επεξεργασίας τους με διάφορα ειδικευμένα εργαλεία. Η ερευνητική δραστηριότητα προτείνει την ανάπτυξη ενός συστήματος βασισμένου στο Hadoop για την ανάλυση σύνθετων και μεγάλης κλίμακας οντολογιών. Το προτεινόμενο σύστημα αποτελείται από τρία συστατικά μέρη: α) έναν εξυπηρετητή για την ανάλυση των δεδομένων της οντολογίας, β) έναν εξυπηρετητή για την απεικόνιση των αναλυμένων δεδομένων και γ) την εφαρμογή του τελικού χρήστη η οποία θα απεικονίζει τα δεδομένα της ανάλυσης των οντολογιών. Σύμφωνα με τους ερευνητές το σύστημα που παρουσιάζεται είναι επεκτάσιμο και μπορεί να χρησιμοποιηθεί για την ανάλυση μεγάλης κλίμακας οντολογικών δεδομένων.

8.4 Σημασιολογικό Πλαίσιο για το Διαδίκτυο του Μέλλοντος

Ένας από του βασικούς σκοπούς αυτής της διατριβής αφορά την ανάπτυξη «Σημασιολογικού Πλαισίου» (Semantic Framework) για το «Διαδίκτυο των Αντικειμένων» και συνεπώς για το «Μελλοντικό Διαδίκτυο». Κατά την διάρκεια της εκπόνησης της διδακτορικής διατριβής, έχουν δημοσιευτεί σχετικές ερευνητικές μελέτες ([115]-[121] και [127]-[133]) που αφορούν την προτεινόμενη αρχιτεκτονική και τους επιμέρους μηχανισμούς του Σημασιολογικού Πλαισίου (Semantic Framework).

Συγκριμένα, οι δημοσιεύσεις [115]-[121] αφορούν το σχεδιασμό, την ανάπτυξη και εφαρμογή καινοτόμου αρχιτεκτονικής για την σημασιολογικά βασιζόμενη εικονικοποίηση και την γνωσιακή διαχείριση αντικειμένων και υπηρεσιών σε περιβάλλοντα του «Διαδικτύου των Αντικειμένων». Επιπλέον, οι δημοσιεύσεις [127]-[133] παρουσιάζουν την εφαρμογή των μηχανισμών του προτεινόμενου πλαισίου για την σημασιολογικά βασιζόμενη γνωσιακή διαχείριση εικονικών αντικειμένων και υπηρεσιών σε multi-Cloud / Federated Cloud IoT οικοσυστήματα. Μέσα από τις παραπάνω μελέτες καταλήξαμε στην ανάπτυξη του αρχιτεκτονικού σχεδιασμού του Σημασιολογικού Πλαισίου, ο οποίος απεικονίζεται στην Εικόνα 1.

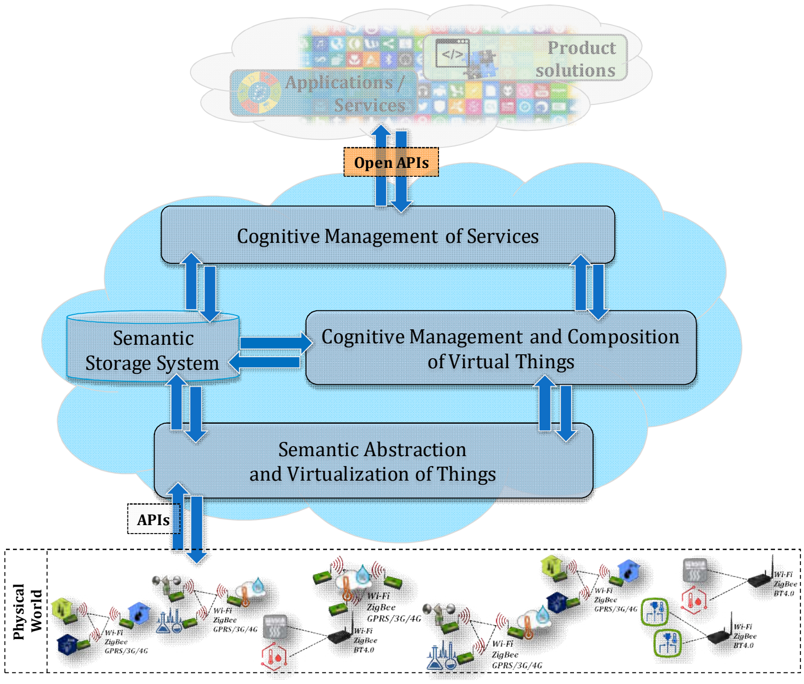
Στο σημείο αυτό θα πρέπει να επισημανθεί ότι ο προτεινόμενος αρχιτεκτονικός σχεδιασμός διαμορφώνεται σύμφωνα με τα διεξαχθέντα ερευνητικά αποτέλεσμα, στοχεύοντας στην ανάπτυξη αποτελεσματικών, επαναχρησιμοποιήσιμων και επεκτάσιμων τεχνολογικών λύσεων. Ο σκοπός αυτών των τεχνολογικών λύσεων αφορά την δυνατότητα να ανταποκριθούν στο μέγιστο δυνατό στις τρέχουσες απαιτήσεις που προκύπτουν με την εφαρμογή της Σημασιολογίας στον χώρο του «Διαδικτύου των Αντικειμένων» και κατ' επέκταση του «Μελλοντικού Διαδικτύου», συνδυάζοντας αποτελεσματικές και ισχυρές τεχνολογικές λύσεις από τον χώρο του Cloud Computing.

8.4.1 Αρχιτεκτονική Σημασιολογικού Πλαισίου για το Διαδίκτυο των Αντικειμένων

8.4.1.1 Δομή προτεινόμενης αρχιτεκτονικής

Το «Σημασιολογικό Πλαίσιο» (Semantic Framework) έχει σχεδιαστεί ώστε να μπορεί να είναι κατανεμημένο και επεκτάσιμο υιοθετώντας τις αρχιτεκτονικές αρχές του «Υπολογιστικού Νέφους» (όπως OpenStack [19] και Docker [21]). Η αρχιτεκτονική του διαρθρώνεται στα εξής κατανεμημένα δομικά τμήματα (building blocks):

- «Σημασιολογική Αφαιρετικότητα και Εικονικοποίηση Αντικειμένων» (Semantic Abstraction and Virtualization of Things)
- «Σημασιολογικό Σύστημα Αποθήκευσης» (Semantic Storage System)
- «Γνωσιακή Διαχείριση και Σύνθεση Εικονικών Αντικειμένων» (Cognitive Management and Composition of Virtual Things)
- «Γνωσιακή Διαχείριση Υπηρεσιών» (Cognitive Management of Services)



Εικόνα 1: Υψηλού επιπέδου σχεδιασμός πρωτότυπης αρχιτεκτονικής για το προτεινόμενο Σημασιολογικό Πλαίσιο για το Διαδίκτυο των Αντικειμένων (Semantic Framework for the Internet of Things)[128][129]

Επιπλέον, «Διεπαφές Προγραμματισμού Εφαρμογών» ανοιχτού κώδικα (open Application Programming Interfaces – Open APIs) παρέχονται προς τους τελικούς χρήστες του σημασιολογικού πλαισίου, προκειμένου να υποστηρίξουν την αλληλεπίδραση με αυτό. Οι τελικοί χρήστες του πλαισίου μπορεί να είναι διάφορες οντότητες όπως ετερογενείς εφαρμογές, υπηρεσίες και προϊόντα. Στη συνέχεια παρουσιάζεται η περιγραφή της προτεινόμενη αρχιτεκτονικής.

8.4.1.2 Σημασιολογική Αφαιρετικότητα και Εικονικοποίηση Αντικειμένων

Το δομικό τμήμα σημασιολογικής αφαιρετικότητας και εικονικοποίησης αντικειμένων, στοχεύει στην επίλυση προβλημάτων που αφορούν στην τεχνολογική ετερογένεια μεταξύ των αντικειμένων, των συσκευών και των εφαρμογών του «Μελλοντικού Διαδικτύου». Μελετάται ο συνδυασμός των Σημασιολογικών τεχνολογιών (Semantic Technologies) και των Τεχνικών Εικονικοποίησης (Virtualization Techniques) για την επίτευξη ενός καινοτόμου αποτελέσματος.

Συγκεκριμένα, αναπτύσσεται κατάλληλο σημασιολογικό μοντέλο (semantic model) για την περιγραφή των χαρακτηριστικών και των ιδιοτήτων των συσκευών του πραγματικού κόσμου, καθώς και αφαιρετικά τμήματα λογισμικού (abstract software modules) από τον συνδυασμό των οποίων προκύπτει το εικονικό αντικείμενο (Virtual Thing). Το λογισμικό του εικονικού αντικειμένου αναπτύσσεται ως διαδικτυακή υπηρεσία (RESTful web service) και αποτελείται από δύο κύρια λειτουργικά μέρη: α) το Front-End και β) το Back-End. Το Front-End αποτελεί το αφαιρετικό τμήμα (abstract module) για το εικονικό αντικείμενο επιτρέποντας την αλληλεπίδραση με αυτό μέσω κοινής/ενιαίας διεπαφής αποκρύπτοντας κατ' αυτόν τον τρόπο την τεχνολογική ετερογένεια μεταξύ του τεράστιου αριθμού των αντικειμένων του πραγματικού κόσμου. Το Back-End τμήμα αποτελεί στην ουσία τον οδηγό (driver) της συσκευής, εξασφαλίζοντας την συμβατότητα της με το σύστημα, παρέχοντας ταυτόχρονα δυνατότητες ελέγχου και διαχείρισης της λειτουργίας του υλικού της συσκευής (control and management of hardware operations). Για την δυναμική ανάπτυξη (dynamic deployment) και διαχείριση των εικονικών αντικειμένων υπάρχουν κατάλληλα πρότυπα (templates) τα οποία εμπεριέχουν πληροφορίες για την εκτέλεση του εικονικού αντικειμένου στο περιβάλλον του Virtual Thing Container.

Κάθε εικονικό αντικείμενο αντιστοιχεί σε ένα αντικείμενο του πραγματικού κόσμου (π.χ. αισθητήρα) υποστηρίζοντας την πλήρη διαχείριση των λειτουργικών δυνατοτήτων του υλικού μέσω κατάλληλου λογισμικού. Επιπλέον, με την ανάπτυξη των σημασιολογικών περιγραφών του κάθε αντικειμένου είναι εφικτή η ανακάλυψη του και η επαναχρησιμοποίηση του σε διαφορετικές περιπτώσεις εφαρμογής. Συγκεκριμένα, κάθε νέο εικονικό αντικείμενο εισάγεται στο περιβάλλον του σημασιολογικού πλαισίου σε δύο φάσεις α) την φάση ανάπτυξης την σημασιολογικής περιγραφής ακολουθώντας το σημασιολογικό μοντέλο και β) την φάση εγκατάστασης και εκτέλεσης του λογισμικού στον Virtual Thing Container. Η πρώτη φάση περιλαμβάνει τη δημιουργία της σημασιολογικής περιγραφής του αντικειμένου ώστε η πληροφορία να είναι καταχωρημένη, προσβάσιμη και διαχειρίσιμη μέσω του συστήματος σημασιολογικής αποθήκευσης. Η δεύτερη φάση περιλαμβάνει την καταχώριση δεδομένων στο πρότυπο (template) ανάπτυξης του εικονικού αντικειμένου για την ανάπτυξη συνιστώσας προτύπου (template instance) που θα χρησιμοποιηθεί για την εγκατάσταση και εκτέλεση του λογισμικού του εικονικού αντικειμένου ως διαδικτυακή υπηρεσία στον Virtual Thing Container. Οι συνιστώσες των προτύπων (templates instances) εναλλακτικά θα ονομάζονται Virtual Thing Deployment Files, καθώς αποτελούν την πλήρη περιγραφή του τρόπου εφαρμογής και ανάπτυξης ενός εικονικού αντικειμένου στο περιβάλλον εκτέλεσης.

Συνεπώς το δομικό τμήμα για την σημασιολογική αφαιρετικότητα και εικονικοποίηση των αντικειμένων (semantic abstraction and virtualization of things) επιτυγχάνει την γεφύρωση του πραγματικού κόσμου (real-world) με τον εικονικό κόσμο (virtual world).

8.4.1.3 Σημασιολογικό Σύστημα Αποθήκευση

Το σημασιολογικό σύστημα αποθήκευσης (semantic storage system) παρέχει κατάλληλες λειτουργικές δυνατότητες για την αποθήκευση και διαχείριση σημασιολογικών δεδομένων τα οποία προκύπτουν από την ανάπτυξη συνιστωσών του σημασιολογικού μοντέλου περιγραφής των αντικειμένων και των προτύπων (templates) ανάπτυξης των εικονικών αντικειμένων στον Virtual Thing Container. Επιπλέον, το σημασιολογικό σύστημα αποθήκευσης περιλαμβάνει σημασιολογικά δεδομένα (π.χ. RDF/XML) τα οποία αντιστοιχούν σε σύνθετα εικονικά αντικείμενα (Composite Virtual Things), καθώς και σε υπηρεσίες που χρησιμοποιούν τα (σύνθετα) εικονικά αντικείμενα.

Το πρόβλημα που στοχεύει να επιλύσει το σημασιολογικό σύστημα αποθήκευσης (semantic storage system) σχετίζεται με την αποθήκευση και διαχείριση ετερογενών σημασιολογικών δεδομένων μεγάλης κλίμακας (Large Scale Semantic Data) σε περιπτώσεις όπου οι υποδομές αδυνατούν να παρέχουν πολύ μεγάλο χώρο αποθήκευσης ή/και αδυνατούν να υποστηρίξουν την αποθήκευση δεδομένων λόγω έλλειψη πόρων (out-of-storage-resources ή/και capacity problem). Τα σημασιολογικά δεδομένα που αντιστοιχούν στις περιγραφές και τα πρότυπα (templates) των (Composite) Virtual Things απαιτούν αποθήκευση σε προηγμένα και ευκόλως επεκτάσιμα συστήματα αποθήκευσης (storage systems). Αυτό προκύπτει από το γεγονός ότι θα έχουμε μια πληθώρα διαφορετικών τύπων αρχείων σε πολλαπλά αντίγραφα που θα αντιστοιχούν σε έναν τεράστιο αριθμό προτύπων για τις συσκευές. Εκτός των προτύπων (templates), στο σύστημα θα αποθηκεύονται και συνιστώσες αυτών (templates instances) οι οποίες ουσιαστικά θα βρίσκονται διαρκώς διαθέσιμα για να μπορούν να επαναχρησιμοποιηθούν από το σύστημα με αυτοματοποιημένο τρόπο μέσω του Virtual Thing Container.

Συνεπώς, θα καταστεί δυνατή η αποθήκευση σημασιολογικών δεδομένων μεγάλης κλίμακας σε ετερογενείς μορφές αναπαράστασης (π.χ. RDF/XML, RDF/JSON, YAML). Η αντιστοιχία αποθήκευσης των αρχείων των προτύπων (templates) θα πραγματοποιείται με κατάλληλη κατηγοριοποίηση που θα αφορά τον τύπο και την μορφή των αρχείων. Συγκεκριμένα, αρχεία του ίδιου τύπου και μορφής θα αποθηκεύονται σε συγκεκριμένο Object Storage Container. Συνεπώς κάθε φορά αναλόγως με την μορφή του προτύπου (template) ή/και του αρχείου ανάπτυξης (deployment file) θα πραγματοποιείται αλληλεπίδραση με συγκεκριμένο Object Storage Container, επιτυγχάνοντας την βελτίωση του χρόνου απόκρισης τον διεργασιών. Τέλος, θα δίνεται η δυνατότητα συνεχούς επέκτασης του χώρου αποθήκευσης (on-the-fly storage space mounting) καθώς το OpenStack Swift ως Cloud Storage μηχανισμός, υποστηρίζει την συγκεκριμένη δυνατότητα.

8.4.1.4 Γνωσιακή Διαχείριση και Σύνθεση Εικονικών Αντικειμένων

Έχοντας επιτύχει την ανάπτυξη των εικονικών αντικειμένων το παρόν δομικό τμήμα της αρχιτεκτονικής περιλαμβάνει το σύνολο των διεργασιών που θα επιτρέψουν την σύνθεση και την γνωστική διαχείριση των (συνθετών) εικονικών αντικειμένων για την υποστήριξη και παροχή σύνθετων υπηρεσιών σε έξυπνα περιβάλλοντα του Μελλοντικού Διαδικτύου, όπως έξυπνα σπίτια, και έξυπνες πόλεις.

Το πρόβλημα που στοχεύει να λύσει η εισαγωγή των λειτουργικών δυνατοτήτων αυτού του δομικού τμήματος, αφορά την δυναμική σύνθεση των λειτουργικών δυνατοτήτων των εικονικών αντικειμένων προκειμένου να αναπτυχθούν σύνθετα εικονικά αντικείμενα (Composite Virtual Things) τα οποία θα έχουν την δυνατότητα να παρέχουν πιο εξελιγμένες και σύνθετες λειτουργικές δυνατότητες. Με τον τρόπο αυτό θα καταστεί δυνατή η επαναχρησιμοποίηση των εικονικών δεδομένων σε διαφορετικά πλαίσια λειτουργίας, ακόμη και έξω από το αρχικό πλαίσιο λειτουργίας για το οποίο αναπτύχθηκαν.

Τα σύνθετα εικονικά αντικείμενα προκύπτουν μέσα από μια γνωσιακή διαδικασία λήψης αποφάσεων για την ανάπτυξη τους βάση των απαιτήσεων ανάπτυξης της σύνθεσης και των χαρακτηριστικών των διαθέσιμων εικονικών αντικειμένων σε ένα συγκεκριμένο πλαίσιο συνθηκών (contextual). Ο μηχανισμός λήψης αποφάσεων χρησιμοποιεί τα σημασιολογικά δεδομένα περιγραφής των εικονικών αντικειμένων, που είναι διαθέσιμα στο σημασιολογικό σύστημα αποθήκευσης, προκειμένου να αναπτύξει τον καταλληλότερο συνδυασμό που θα παρέχει τις σύνθετες λειτουργικές δυνατότητες για την τρέχουσα κατάσταση. Ως αποτέλεσμα της σύνθεσης των εικονικών αντικειμένων, προκύπτει μια λογική ροή εργασιών (workflow) που χρησιμοποιεί τα εικονικά αντικείμενα που εκτελούνται στον Virtual Thing Container προκειμένου να αντλήσει δεδομένα από διαθέσιμους αισθητήρες ή/και να ελέγξει την λειτουργία άλλων συστημάτων, όπως συσκευές φωτισμού.

Για την ανάπτυξη των σύνθετων εικονικών αντικειμένων δεν απαιτείται η ανάπτυξη νέου λογισμικού που θα είναι απαραίτητο για να χρησιμοποιήσει τις συσκευές του πραγματικού κόσμου. Αντιθέτως κάθε σύνθετο εικονικό αντικείμενο αποτελείται από μία λίστα από μοναδικά αναγνωριστικά εικονικών αντικειμένων που το αποτελούν. Κάθε αναγνωριστικό είναι συνδεδεμένο με την σημασιολογική περιγραφή του εικονικού αντικειμένου και συνεπώς με την περιγραφή των λειτουργικών του δυνατοτήτων. Επομένως, κάθε οντότητα που αξιοποιεί το σύνθετο εικονικό αντικείμενο έχει απευθείας πρόσβαση στις λειτουργίες των αντίστοιχων εικονικών αντικειμένων χρησιμοποιώντας το ήδη υπάρχων λογισμικό (Virtual Thing Front-End & Back-End).

Συνεπώς μέσα από την γνωσιακή διαχείριση των εικονικών αντικειμένων υποστηρίζεται η δυναμική προσαρμογή των λειτουργικών δυνατοτήτων των εικονικών αντικειμένων για την κάλυψη απαιτήσεων σε δυναμικά μεταβαλλόμενα περιβάλλοντα του Μελλοντικού Διαδικτύου.

8.4.1.5 Γνωσιακή Διαχείριση Υπηρεσιών

Το δομικό τμήμα γνωσιακής διαχείριση υπηρεσιών αφορά την δυναμική ανάπτυξη και παροχή υπηρεσιών προς τους τελικούς χρήστες του σημειολογικού πλαισίου, είτε πρόκειται για εφαρμογές, είτε για πραγματικούς χρήστες. Μέσα από την παροχή ανοιχτών διεπαφών προγραμματισμού (open Application Programming Interface - APIs) οι τελικοί χρήστες θα έχουν την δυνατότητα χρήσης υπηρεσιών οι οποίες θα δημιουργούνται κατ’ απαίτηση (on-demand) και σύμφωνα με τις τρέχουσες απαιτήσεις.

Οι υπηρεσίες θα χρησιμοποιούν τα σύνθετα εικονικά αντικείμενα (Composite Virtual Things) με σκοπό την υποστήριξη πολύπλοκων εφαρμογών που θα εξυπηρετούν τελικούς χρήστες και συστήματα στο Μελλοντικό Διαδίκτυο. Για την δυναμική ανάπτυξη των υπηρεσιών εφαρμόζεται γνωστικός μηχανισμός ο οποίος βασίζει την λειτουργία του στα σημασιολογικά δεδομένα για την ανάπτυξη υπηρεσιών που χρησιμοποιούν απευθείας ή εκκινούν την διαδικασία δυναμικής ανάπτυξης σύνθετων εικονικών αντικειμένων. Συνεπώς είναι εφικτή η δυναμική ανάπτυξη και αποσύνθεση υπηρεσιών βάση των τρεχουσών αναγκών, διασφαλίζοντας έτσι την ορθή χρήση των διαθέσιμων εικονικών αντικειμένων, καθώς και την επαναχρησιμοποίηση των λειτουργικών τους δυνατοτήτων υπο διαφορετικά λειτουργικά πλαίσια.

Για την περιγραφή των υπηρεσιών που δημιουργούνται χρησιμοποιούνται σημασιολογικά μοντέλα που παρέχουν πληροφορίες σχετικά με τα χαρακτηριστικά των υπηρεσιών όπως η σύνθεσή τους από Composite Virtual Things. Οι πληροφορίες περιγραφής των υπηρεσιών αποθηκεύονται στο σύστημα σημασιολογικής αποθήκευσης και μέσω κατάλληλων γνωστικών μηχανισμών είναι δυνατή η διαχείριση τους σε επίπεδο εκτέλεσης, πρόσβασης και χρήσης. Περαιτέρω γνωστικές λειτουργίες για την διαχείριση των υπηρεσιών μπορεί να αφορούν την (επανα-)τοποθέτηση τους σε διάφορα κατανεμημένα υπολογιστικά συστήματα που διαθέτουν τους απαραίτητους πόρους για την εκτέλεση και υποστήριξη των υπηρεσιών.

Τέλος το δομικό τμήμα γνωσιακής διαχείρισης υπηρεσιών περιλαμβάνει μηχανισμούς που επιτρέπουν την αλληλεπίδραση μεταξύ υπηρεσιών που εκτελούνται σε διαφορετικά περιβάλλοντα, τα οποία βασίζονται στο σημασιολογικό πλαίσιο. Ενδεικτικό είναι το παράδειγμα κατανεμημένων αυτόνομων υποδομών υπολογιστικού νέφους μικρής κλίμακας οι οποίες μπορεί να φιλοξενούν τα λειτουργικά τμήματα μιας σύνθετης υπηρεσίας που εξυπηρετεί μια διασυνοριακή εφαρμογή (cross-border applications) στο Μελλοντικό Διαδίκτυο.

8.4.1.6 Ανάπτυξη Πλαισίου στο Υπολογιστικό Νέφος

Το σημασιολογικό πλαίσιο έχει αναπτυχθεί με προδιαγραφές εφαρμογής σε κατανεμημένα περιβάλλοντα του υπολογιστικού νέφους (multi-Cloud environments) τα οποία μπορούν να φιλοξενήσουν και να υποστηρίξουν την εκτέλεση των διεργασιών που αντιστοιχούν στα δομικά τμήματα της αρχιτεκτονικής. Επιπροσθέτως, το σημασιολογικό πλαίσιο μπορεί να αναπτύσσεται σαν αυτόνομη υποδομή του υπολογιστικού νέφους εξυπηρετώντας ένα μικρότερο αριθμό εξωτερικών οντοτήτων και εφαρμογών σε μια έξυπνη υποδομή μικρή κλίμακας, όπως ένα έξυπνο σπίτι.

Η προτεινόμενη προσέγγιση ανάπτυξης στοχεύει την αξιοποίηση της σύγκλησης των Cloud και IoT τεχνολογιών, ενισχυμένων από τις σημασιολογικές τεχνολογίες για την ανάπτυξη προηγμένων λύσεων λογισμικού για την διάτμηση και την μετάπτωση υπηρεσιών σε ετερογενή Cloud-IoT περιβάλλοντα μέσω των τεχνολογιών δικτύωσης του Μελλοντικού Διαδικτύου, όπως τεχνολογίες 5G. Συγκεκριμένα, δεν επιδιώκεται η ανάπτυξη νέων τεχνικών για την κατάτμηση και μετάπτωση εφαρμογών και υπηρεσιών (application/service partitioning and migration), αλλά εστιάζει στην μελέτη των συνθηκών υπο τις οποίες θα πρέπει να πραγματοποιηθούν οι διαδικασίες κατάτμησης και μετάπτωσης. Οι σημασιολογικές τεχνολογίες έρχονται να συνεισφέρουν στην ενίσχυση των διαδικασιών, μέσω της αξιοποίησης κατάλληλων σημασιολογικών μοντέλων περιγραφή υπηρεσιών, σε συνδυασμό με τις λειτουργικές δυνατότητες του δομικού τμήματος γνωσιακής διαχείριση υπηρεσιών.

Μέσω της αξιοποίησης των μηχανισμών συστήματος σημασιολογικής αποθήκευσης, για την διαχείριση των σημασιολογικών δεδομένων, σε συνδυασμό με του γνωστικούς μηχανισμού λήψης αποφάσεων, επιδιώκεται η υποστήριξη δυναμικής ανάπτυξη αποφάσεων ακριβείας (high accuracy) και υψηλή αξιοπιστίας, σχετικά με την κατάτμηση ή/και μετάπτωση των εφαρμογών σε Cloud-IoT περιβάλλοντα. Η ανάπτυξη και εισαγωγή των 5G ασύρματων τεχνολογιών στα Cloud-IoT περιβάλλοντα, θα αποτελέσει τεχνολογική περιοχή κλειδί για την υλοποίηση των παραπάνω διαδικασιών.

Η ανάπτυξη κατανεμημένων μικρής και μεσαίας κλίμακας Cloud περιβαλλόντων, που αναπτύσσονται στο άκρο των 5G δικτυακών υποδομών (Edge Network), θα μπορούσε ιδανικά να οδηγήσει στην ανάπτυξη Federated Edge Cloud Computing υποδομών εντός των οποίων θα μπορεί να πραγματοποιείται η διανομή των λειτουργικών τμημάτων λογισμικού, προς εκτέλεση, θεωρώντας διάφορα και διαφορετικά κριτήρια λήψης αποφάσεων. Τέτοια κριτήρια θα βασίζονται στην ερμηνεία σημασιολογικών δεικτών απόδοσης και ποιότητας (Performance and Quality Indicators) που συνδέονται με τις εφαρμογές και τις υπηρεσίες. Τα κριτήρια αυτά, επιπλέον, θα μπορούσαν να χαρακτηριστούν ως Partitioning & Migration Indicators (PMIs).

Συνεπώς, η ανάπτυξη του σημασιολογικού πλαισίου σε περιβάλλοντα του υπολογιστικού νέφους, επιφέρει ποικίλα οφέλη που αφορούν στην αποτελεσματική δημιουργία, παροχή και διαχείριση υπηρεσιών, διευκολύνουν την επεκτασιμότητα των λειτουργικών δυνατοτήτων (π.χ. αποθήκευση σημασιολογικών δεδομένων) και επιτρέπουν την ανάπτυξη διασυνοριακών εφαρμογών που χρησιμοποιούν κατανεμημένες υπηρεσίες αποτελούμενες από σύνθετα εικονικά αντικείμενα.

8.5 Σημασιολογική Μοντελοποίηση για την Ανάπτυξη Εικονικών Αντικειμένων στο Μελλοντικό Διαδίκτυο

Η εικονικοποίηση (Virtualization) των αντικειμένων του πραγματικού κόσμου, αποτελεί μια από τις πιο αποτελεσματικές λύσεις για την απόκρυψη της τεχνολογική ετερογένειας, καθώς και για την ελαχιστοποίηση και απόκρυψη της πολυπλοκότητας των διαδικασιών ενοποίησης και διαλειτουργικότητας μεταξύ ετερογενών οντοτήτων υλικού και λογισμικού. Η ανάπτυξη τεχνικών εικονικοποίησης που βασίζονται στη Σημασιολογική Μοντελοποίηση (Semantic Modeling) περιλαμβάνει την δημιουργία αφαιρετικών εικονικών αναπαραστάσεων (abstract virtual representations) οι οποίες αποτελούνται από δύο βασικά συστατικά μέρη: α) την Σημασιολογική Περιγραφή των ιδιοτήτων και των χαρακτηριστικών τους (Semantic Description) και β) το αφαιρετικό τμήμα λογισμικού (abstract software module). Η εφαρμογή των παραπάνω οδηγεί στην ανάπτυξη των Εικονικών Αντικειμένων (Virtual Objects) τα οποία αποτελούν αφαιρετικές οντότητες λογισμικού οι οποίες συνδέουν τα αντικείμενα του πραγματικού κόσμου (Real World Objects) με τον εικονικό / ψηφιακό κόσμο (Virtual/Digital World) των υποδομών του Μελλοντικού Διαδικτύου (Future Internet). Τα Virtual Object αποτελούν ουσιαστικά υλοποιημένες συνιστώσες της οντότητας Virtual Thing του «Σημασιολογικού Πλαισίου». Η αφαιρετική φύση των Εικονικών Αντικειμένων, καθώς και η σημασιολογική περιγραφή τους, επιτρέπει την επαναχρησιμοποίηση τους σε διαφορετικά πλαίσια λειτουργίας τα οποία μπορεί να βρίσκονται ακόμη και εκτός του αρχικού πλαισίου λειτουργίας για το οποίο αναπτύχθηκαν. Πρακτικά αυτό σημαίνει ότι ένα εικονικό αντικείμενο που αναπτύχθηκε για την σύνδεση μιας συσκευής του πραγματικού κόσμου με το εικονικό περιβάλλον μιας πλατφόρμας για ένα Έξυπνο Σπίτι (Smart Home), μπορεί να επαναχρησιμοποιηθεί ως αυτούσια οντότητα για την διασύνδεση μιας ίδιας συσκευής του πραγματικού κόσμου με το εικονικό περιβάλλον μιας πλατφόρμας για μια Έξυπνη Πόλη (Smart City).

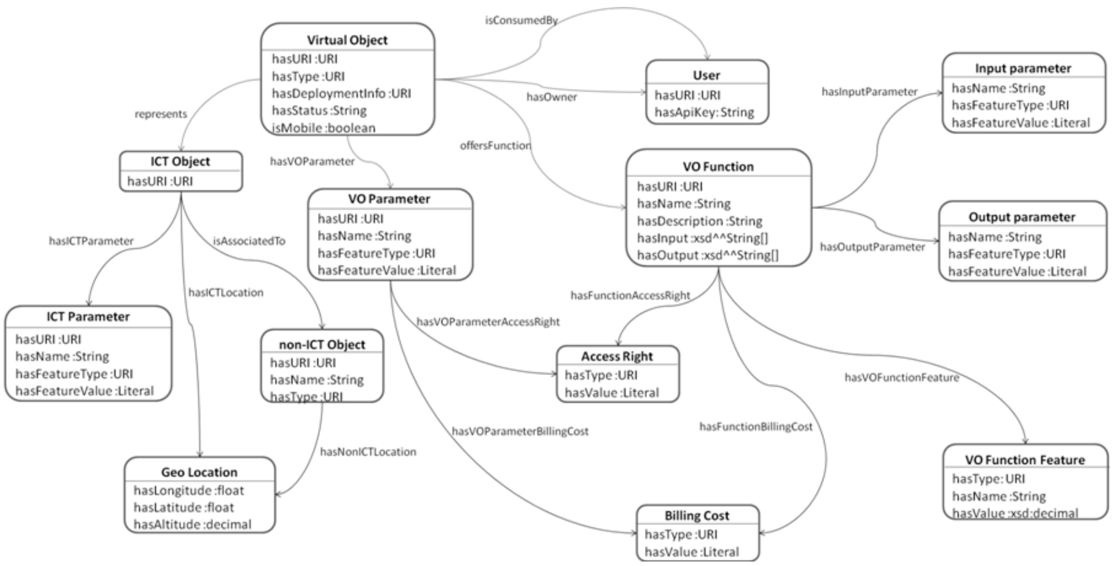
8.5.1 Διατύπωση Προβλήματος – Συνεισφορά Διατριβής

Στη παρούσα υποενότητα παρουσιάζουμε μια επίσημη διατύπωση του προβλήματος που αφορά την σημασιολογική μοντελοποίηση και ανάπτυξη εικονικών αναπαραστάσεων για τα αντικείμενα του πραγματικού κόσμου. Λαμβάνοντας υπόψη τον τεράστιο αριθμό των διαθέσιμων συσκευών που θα αποτελέσουν κομμάτι του «Μελλοντικού Διαδικτύου» δημιουργείται η ανάγκη για ανάπτυξη ενός κοινού μοντέλου αναπαράστασης που θα μπορεί να καλύψει τις απαιτήσεις περιγραφής των χαρακτηριστικών των ετερογενών συσκευών (π.χ. αισθητήρες, έξυπνες συσκευές, κλπ.). Επιπλέον, απαιτείται ο σχεδιασμός και η ανάπτυξη αφαιρετικού λογισμικού, όπου μέσω αυτού θα καταστεί δυνατή η διαχείριση των λειτουργικών δυνατοτήτων των συσκευών. Ο συνδυασμό του σημασιολογικού μοντέλου και του αφαιρετικού λογισμικού θα υποστηρίξει την διαλειτουργικότητα μεταξύ των ετερογενών συσκευών, πραγματοποιώντας την διασύνδεση του πραγματικού κόσμου με τον εικονικό κόσμο. Συνεπώς το πρόβλημα που καλούμαστε να αντιμετωπίσουμε αφορά την ανάπτυξη λογισμικού για την εικονικοποίηση των λειτουργικών δυνατοτήτων των ετερογενών συσκευών του «Μελλοντικού Διαδικτύου» προκειμένου να επιτύχουμε την διαχείριση και τον έλεγχό τους μέσω καινοτόμων υποδομών καθώς και να εξασφαλίσουμε την μεταξύ τους διαλειτουργικότητα.

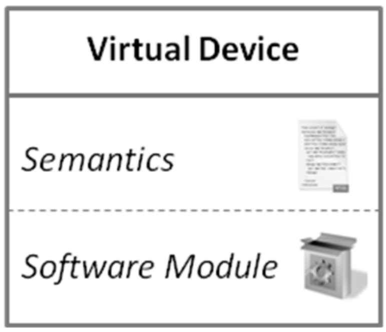
Το Σημασιολογικό Πλαίσιο αποτελείται από δομικά τμήματα όπως το τμήμα «Σημασιολογικής Αφαιρετικότητας και Εικονικοποίησης Αντικειμένων» και το τμήμα «Σημασιολογικό Σύστημα Αποθήκευσης» τα οποία μπορούν να παρέχουν την απαιτούμενη λειτουργικότητα για την υποστήριξη των παραπάνω. Συγκεκριμένα, συνεισφέρει μέσω της κάλυψης των απαιτήσεων των διαδικασιών της μοντελοποίησης και της διαχείρισης των Σημασιολογικών Δεδομένων που ανήκουν στις Σημασιολογικές Περιγραφές των αφαιρετικών εικονικών αναπαραστάσεων. Επιπλέον συνεισφέρει με την εισαγωγή της έννοιας Virtual Thing το οποίο προσαρμόζεται στις ανάγκες τις εκάστοτε επιστημονικής μελέτης και παρουσιάζεται με διάφορες εννοιολογικές μορφές, όπως Virtual Object, Virtual Device, κλπ. Η εφαρμογή και η επικύρωση των μηχανισμών του Σημασιολογικού Πλαισίου, καθώς και η προστιθέμενη αξία τους στο Διαδίκτυο των Αντικειμένων, πραγματοποιείται μέσα από ένα σύνολο δημοσιεύσεων, όπως οι [115]-[117].

8.5.2 Επίλυση Προβλήματος

Το «Σημασιολογικό Πλαίσιο» που προτείνεται στην παρούσα διατριβή μπορεί να αντιμετωπίσει το πρόβλημα της σημασιολογικής μοντελοποίησης και εικονικοποίησης ετερογενών συσκευών του «Μελλοντικού Διαδίκτυο», εισάγοντας κατάλληλο σημασιολογικό μοντέλο και κατάλληλη δομή ανάπτυξης αφαιρετικού λογισμικού. Συγκεκριμένα το σημασιολογικό μοντέλο που παρουσιάζεται στην Εικόνα 2 καλύπτει την περιγραφή ενός τεράστιου εύρους συσκευών όπως αισθητήρες και κόμβους ασύρματων δικτύων αισθητήρων, ενεργοποιητές, έξυπνα κινητά τηλέφωνα, wearables, κλπ. Η περιγραφή κάθε συσκευής αναπτύσσεται ως συνιστώσα του σημασιολογικού μοντέλου και αποθηκεύεται σε κατανεμημένες σημασιολογικές βάσεις δεδομένων (π.χ. RDF Databases). Για την εικονικοποίηση των συσκευών του πραγματικού κόσμου (Information and Communication Technologies - ICT Objects) αναπτύσσεται κατάλληλο λογισμικό όπου αποτελεί συνιστώσα του Virtual Thing και ονομάζεται Virtual Device (Εικόνα 3). Κάθε εικονική συσκευή αποτελείται από δύο μέρη: α) τη σημασιολογική περιγραφή της και β) το τμήμα λογισμικού ελέγχου και διαχείρισης της συσκευής στον εικονικό κόσμο.



Εικόνα 2: Σημασιολογικό Μοντέλο Περιγραφή Αντικειμένων [115][116]



Εικόνα 3: Αναπαράσταση της δομής της εικονικής συσκευής [117]

8.5.3 Αποτίμηση Επίδοσης

Η διαδικασία αξιολόγησης εστίασε σε δύο βασικούς στόχους α) την ανάπτυξη και διαχείριση σημασιολογικών δεδομένων για την περιγραφή συσκευών και την διασφάλιση της πρόσβασης σε αυτές και β) τον σχεδιασμό και ανάπτυξη εικονικών αναπαραστάσεων λογισμικού για την διαχείριση συσκευών σε πραγματικό περιβάλλον.

Για την ανάπτυξη και διαχείριση των σημασιολογικών δεδομένων αναπτύχθηκαν κατάλληλες οντολογίες για την περιγραφή των χαρακτηριστικών του σημασιολογικού μοντέλου, ενώ για την ανάπτυξη της δομής των δεδομένων και για την διαχείριση τους εφαρμόστηκαν οι σημασιολογικές τεχνολογίες RDF και SPARQL αντιστοίχως. Τα σημασιολογικά δεδομένα αποθηκεύονταν και είναι διαχειρίσιμα μέσω του «Σημασιολογικού Συστήματος Αποθήκευσης» του σημασιολογικού πλαισίου. Ενδεικτική μορφή της δομής αποθήκευσης παρουσιάζεται στην Εικόνα 4. Επιπλέον ιδιαίτερη έμφαση δόθηκε στην διαχείριση της πρόσβασης των εικονικοποιημένων συσκευών, αναπτύσσοντας κατάλληλα δικαιώματα πρόσβασης (Εικόνα 5) που συνδέονται με τελικούς χρήστες και εμπεριέχονται στις σημασιολογικές περιγραφές. Κάθε εικονικό αντικείμενο συνδέεται με ένα σύνολο δικαιωμάτων πρόσβασης τα οποία ελέγχουν την πρόσβαση και χρήση της συσκευής. Το σημασιολογικό μοντέλο επιπλέον περιλαμβάνει ιδιότητες περιγραφής για τον χαρακτηρισμό και την αποτίμηση των λειτουργικών δυνατοτήτων της συσκευής.

Subject	Predicate	Object
<http://icore/vo/VO001>	vo:hasURI	"http://icore/vo/VO001"
<http://icore/vo/VO001>	vo:represents	<http://icore/vo/ict/CNET_Temperature_Sensor>
<http://icore/vo/ict/CNET_Temperature_Sensor>	ICT_Object:hasURI	"http://icore/vo/ict/CNET_Temperature_Sensor"
<http://icore/vo/ict/CNET_Temperature_Sensor>	ICT_Object:hasLongitude	"639.5478080711716"
<http://icore/vo/ict/CNET_Temperature_Sensor>	ICT_Object:hasLatitude	"347.5868607501319 6"
<http://icore/vo/ict/CNET_Temperature_Sensor>	ICT_Object:hasAltitude	"0.0"
<http://icore/vo/ict/CNET_Temperature_Sensor>	ICT_Object:offersFunction	<http://icore/vo/ict/function/VO001_Function_1>
<http://icore/vo/ict/CNET_Temperature_Sensor>	ICT_Object:isConnectedTo	<http://icore/vo/ict/non_ict/Sarahs_Living_Room>

Εικόνα 4: Δομή Σημασιολογικής Βάσης Δεδομένων RDF/XML [115]

```
PREFIX vo: <http://IoT.com/virtualobject/>
PREFIX location: <http://IoT.com/locations/>

SELECT ?VO

WHERE {
  ?VO vo:Function "getTemperature".
  ?VO location:City "Amsterdam".
}
```

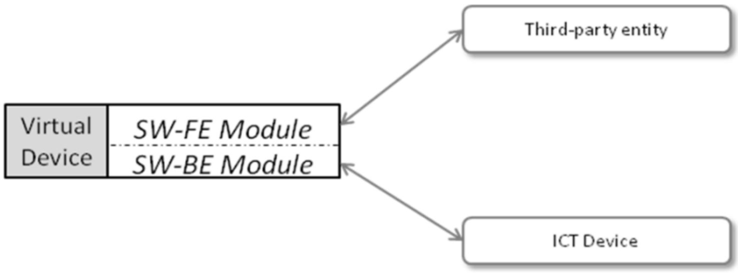
```
PREFIX rights: <http://IoT.com/accesrights/>
PREFIX vo: <http://IoT.com/virtualobject/>
PREFIX location: <http://IoT.com/locations/>

SELECT ?VO

WHERE
  ?VO vo:Function "getTemperature".
  ?VO location:City "Amsterdam".
  ?VO rights:Read "UserB".
}
```

Εικόνα 5: SPARQL δομή ερωτημάτων σημασιολογικών δεδομένων με ελεγχόμενα δικαιώματα πρόσβασης [116]

Για τον σχεδιασμό και ανάπτυξη εικονικών αναπαραστάσεων λογισμικού για την διαχείριση συσκευών σε πραγματικό περιβάλλον υλοποιήθηκε κατάλληλο λογισμικό για την δημιουργία των διεπαφών αλληλεπίδρασης (Εικόνα 6) τελικών χρηστών με το εικονικό αντικείμενο (Frontend Module) και εικονικού αντικειμένου με την πραγματική συσκευή (Backend Module). Το λογισμικό του Frontend αναπτύχθηκε σε Java ως RESTful διαδικτυακή υπηρεσία η οποία είναι προσβάσιμη με κοινό τρόπο για κάθε εξωτερική οντότητα. Το Backend αναπτύχθηκε χρησιμοποιώντας διάφορες γλώσσες προγραμματισμού, όπως C/C++ και Python, αναλόγως την περίπτωση εφαρμογής. Το Backend ουσιαστικά λειτούργησε ως driver για τις ετερογενείς συσκευές, όπως κόμβοι ασύρματων δικτύων αισθητήρων. Το Frontend λειτούργησε ως το κοινό σημείο πρόσβασης το οποίο αποκρύπτει την ετερογένεια των τεχνολογιών πρόσβασης και διαδικασιών των ετερογενών συσκευών, από τις τελικές οντότητες. Συνεπώς, μέσω του Frontend επιτυγχάνεται η ομογενοποιημένη πρόσβαση σε ετερογενείς συσκευές, υποστηρίζοντας την διαχείριση των λειτουργικών τους δυνατοτήτων μέσω ομογενοποιημένης διεπαφής. Το Frontend χρησιμοποιεί τις πληροφορίες του σημασιολογικού μοντέλου περιγραφής προκειμένου να διασφαλίσει την διαλειτουργικότητα μεταξύ των ετερογενών Backends που είναι στην ουσία οι drivers των ετερογενών συσκευών.



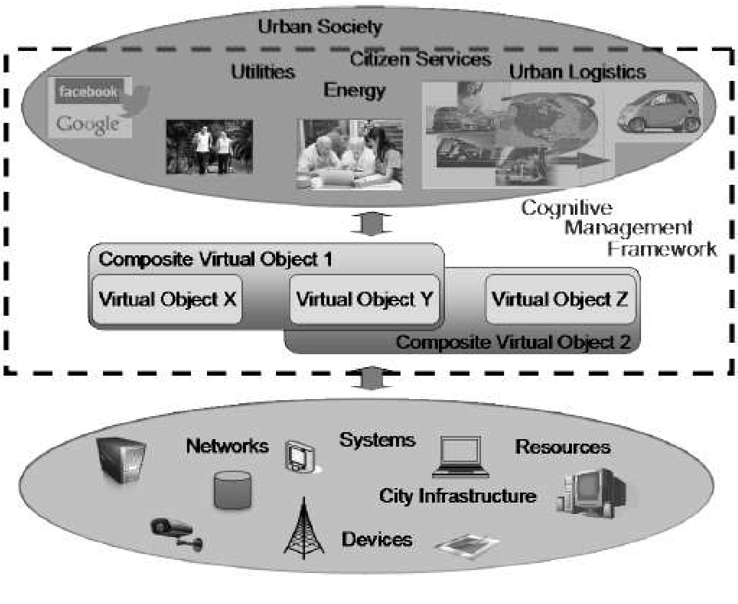
Εικόνα 6: Δομή τμήματα λογισμικού για την υποστήριξη των δυνατοτήτων επικοινωνίας της εικονικής συσκευής [117]

8.6 Γνωσιακή Διαχείριση (Σύνθετων) Εικονικών Αντικειμένων και Υπηρεσιών στο Μελλοντικό Διαδίκτυο

Η εισαγωγή των αρχών της εικονικοποίησης των αντικειμένων καθώς και η ανάπτυξη σύνθετων εικονικών αντικειμένων για την αντιμετώπιση της τεχνολογικής ετερογένειας και την αυτόνομη παροχή υπηρεσιών προς τους τελικούς χρήστες, απαιτεί την ανάπτυξη κατάλληλων αρχιτεκτονικών λύσεων διαχείρισης. Ο σχεδιασμός και ανάπτυξη κατάλληλης αρχιτεκτονικής για την ανάπτυξη πλαισίου γνωσιακής διαχείρισης (σύνθετων) εικονικών αντικειμένων και υπηρεσιών παρουσιάζεται σε αυτή την ενότητα ως η προτεινόμενη λύση. Η βασική διαφοροποίηση της συγκεκριμένης προσέγγισης, έγκειται στην μελέτη της τεχνολογικής ετερογένειας καθώς και στον σχεδιασμό και ανάπτυξη εναλλακτικών λύσεων διασύνδεσης και επικοινωνίας ποικίλων ετερογενών αντικειμένων του πραγματικού κόσμου στο πλαίσιο διαχείρισης. Η εφαρμογή των σημασιολογικών τεχνολογιών έρχεται να ενισχύσει την λειτουργικότητα του πλαισίου σε όλα τα επίπεδα που το αποτελούν, μέσα από την εφαρμογή σημασιολογικών μοντέλων και μηχανισμών του «Σημασιολογικού Συστήματος Αποθήκευσης». Τα σημασιολογικά δεδομένα που αποθηκεύονται στο γνωσιακό πλαίσιο παρέχουν πληροφορίες σχετικά με τα χαρακτηριστικά των εικονικών αντικειμένων, συμπεριλαμβάνοντας ειδικούς σημασιολογικού δείκτες που εφαρμόζονται σε γνωσιακούς μηχανισμούς λήψης αποφάσεων (Decision Making). Οι μηχανισμοί λήψης αποφάσεων είναι υπεύθυνοι για την δυναμική σύνθεση εικονικών αντικειμένων τα οποία θα υποστηρίξουν την παροχή υπηρεσιών οι οποίες διαμορφώνονται σύμφωνα με τις απαιτήσεις των τελικών χρηστών. Οι υπηρεσίες που αναπτύσσονται μπορούν να χρησιμοποιηθούν από τους τελικούς χρήστες προκειμένου να παρέχουν ενοποιημένες σύνθετες λειτουργικές λύσεις που υποστηρίζουν συνθέτες εφαρμογές, όπως ολοκληρωμένα συστήματα ενεργειακής διαχείρισης σε τεχνολογικές υποδομές, ή συστήματα παρακολούθησης και προσαρμογής των περιβαλλοντολογικών συνθηκών σε έξυπνα σπίτια (environmental conditions monitoring and adjustment in smart homes). Πρακτικά αυτό σημαίνει ότι τα απομονωμένα εικονικά αντικείμενα μπορούν να ενοποιηθούν σε ένα κοινό πλαίσιο λειτουργιών με αυτόνομο – δυναμικό τρόπο παρέχοντας εξελιγμένες υπηρεσίες για τις εφαρμογές τελικών χρηστών.

8.6.1 Διατύπωση Προβλήματος – Συνεισφορά Διατριβής

Στην παρούσα υποενότητα παρουσιάζεται μια επίσημη διατύπωση του προβλήματος που αφορά τη γνωσιακή διαχείριση (σύνθετων) εικονικών αντικειμένων και υπηρεσιών στο νευραλγικό τομέα του «Διαδικτύου των Αντικειμένων» που εντάσσεται στο «Μελλοντικό Διαδίκτυο». Το «Διαδίκτυο των Αντικειμένων» αναμένεται να συμβάλει ουσιαστικά στη βιώσιμη ανάπτυξη των μελλοντικών έξυπνων περιβαλλόντων διαβίωσης, όπως οι έξυπνες πόλεις. Η παραπάνω θεώρηση αναλύεται στην επιστημονική μελέτη [121] η οποία προσδιορίζει και αναλύει το κύρια θέματα που ενδέχεται να προκύψουν ως απαιτήσεις κατά την εφαρμογή του IoT στα περιβάλλοντα των έξυπνων πόλεων. Τέτοιου είδους απαιτήσεις μπορεί να αφορούν την ετερογένεια μεταξύ των συνδεδεμένων αντικειμένων, καθώς και την αξιοπιστία των συναφών υπηρεσιών. Για την επίλυση αυτών των ζητημάτων, προτείνεται ένα Γνωσιακό Πλαίσιο Διαχείρισης για το «Διαδίκτυο των Αντικειμένων», στο οποίο τα αντικείμενα του δυναμικά μεταβαλλόμενου πραγματικού κόσμου εκπροσωπούνται ως Εικονικά Αντικείμενα (Virtual Objects), και χρησιμοποιεί τη Γνωσιακές Τεχνολογίες (Cognitive Technologies) και τεχνικές εγγύτητας (proximity) για την επιλογή των πιο σχετικών αντικειμένων σύμφωνα με τις απαιτήσεις των χρηστών με έξυπνο και αυτόνομο τρόπο. Το Γνωσιακό Πλαίσιο αρχικοποιείται με ένα σύνολο αρχιτεκτονικών building blocks και μηχανισμών, καθώς και αποδεικνύεται και επικυρώνεται μέσα από ένα σενάριο εφαρμογής σε μια έξυπνη πόλη που οριζόντια εκτείνεται σε διάφορα πεδία εφαρμογών. Μέσω της μελέτης αποδεικνύεται ότι το IoT μπορεί να εφαρμοστεί και να επιτευχθεί στο πλαίσιο των έξυπνων πόλεων (Εικόνα 7).

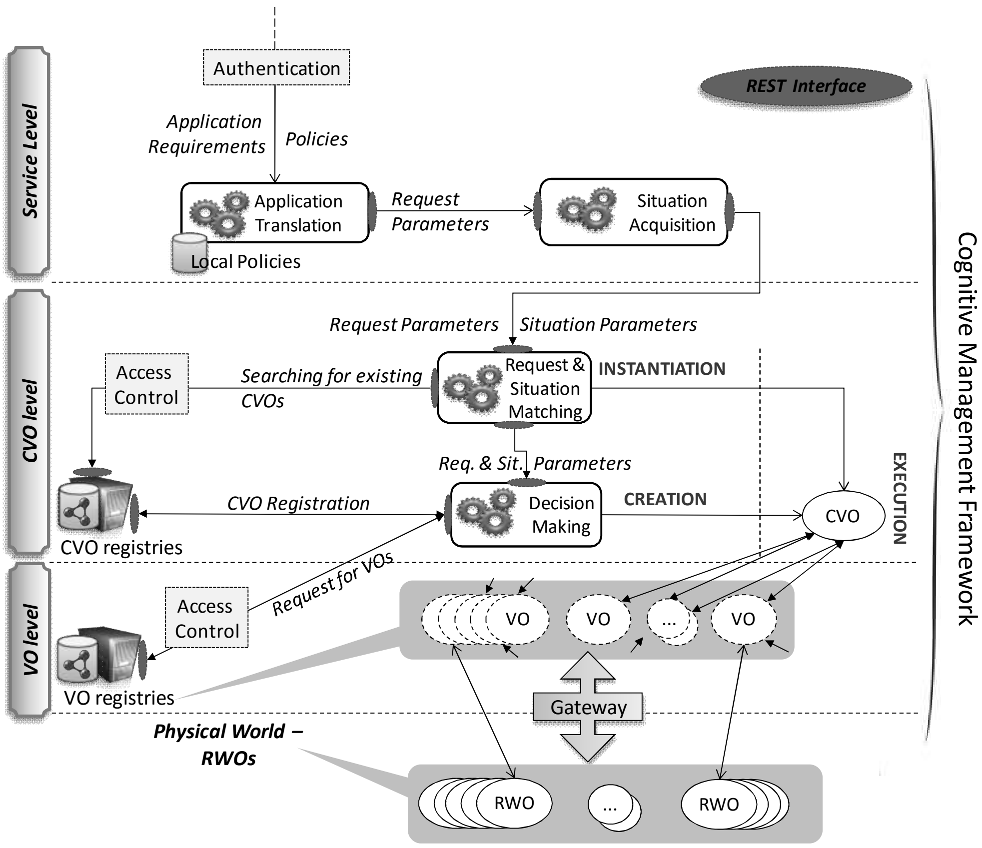


Εικόνα 7: Υψηλού επιπέδου αναπαράσταση της εφαρμογής του γνωστικού πλαισίου σε μια έξυπνη πόλη [121]

Λαμβάνοντας υπόψη τα παραπάνω, η συνεισφορά της διδακτορικής διατριβής εστιάζει στην αντιμετώπιση του παραπάνω προβλήματος με την παροχή μηχανισμών του Σημασιολογικού Πλαισίου, όπως το «Σημασιολογικό Σύστημα Αποθήκευσης». Οι μηχανισμοί του Σημασιολογικού Πλαισίου θα υποστηρίξουν την ανάπτυξη υποδομών για την έξυπνη και αυτόνομη διαχείριση των υποδομών, ενισχύοντας έτσι την αποτελεσματικότητα τόσο των υπηρεσιών όσο και των εικονικών αντικειμένων. Μέρος του γνωσιακού πλαισίου υλοποιείται, στα πλαίσια την προσπάθειας μας για την ανάπτυξη μιας ισχυρής γνωσιακής υποδομής που θα ενισχύεται από την εκμετάλλευση των Σημασιολογικών Τεχνολογιών (Semantic Technologies), και θα επικυρώνεται μέσα από ένα σενάριο ηλεκτρονικής υγείας. Μέσα από την επικύρωση των αποτελεσμάτων, προσδιορίζεται μια πρωταρχική απόδειξη των μεγάλων δυνατοτήτων που προκύπτουν σε ένα αυτό-αναδιαμορφώσιμο «Διαδίκτυο των Αντικειμένων» (self-reconfigurable IoT) εφαρμόσιμο στο πλαίσιο των έξυπνων πόλεων. Περαιτέρω, σε αυτή την κατεύθυνση η εφαρμογή και η επικύρωση των μηχανισμών του Σημασιολογικού Πλαισίου, καθώς και η προστιθέμενη αξία τους στο Διαδίκτυο των Αντικειμένων, πραγματοποιείται μέσα από ένα σύνολο δημοσιεύσεων, όπως οι [120][121].

8.6.2 Επίλυση Προβλήματος

Το Σημασιολογικό Πλαίσιο μπορεί να παρέχει απαραίτητους μηχανισμούς για την ανάπτυξη του Γνωσιακού Πλαισίου Διαχείρισης, ενισχύοντας τις λειτουργικές του δυνατότητες με την εφαρμογή Σημασιολογικών Τεχνολογιών και μηχανισμών ανάπτυξης εικονικών αναπαραστάσεων για τα ετερογενή αντικείμενα. Η διάρθρωση της αρχιτεκτονικής του Γνωσιακού Πλαισίου απεικονίζεται στην Εικόνα 8. Τα επίπεδα διάρθρωσης της αρχιτεκτονικής περιλαμβάνουν λειτουργικούς μηχανισμούς οι οποίοι μεταξύ άλλων συγκεντρώνουν τεχνικά χαρακτηριστικά από το πεδίο των Σημασιολογικών Τεχνολογιών (Semantic Technologies), της Τεχνίτης Νοημοσύνης (Artificial Intelligence) και των Γνωσιακών Τεχνολογιών (Cognitive Technologies). Πιο συγκεκριμένα, το επίπεδο υπηρεσιών (Service Level) συμπεριλαμβάνει όλους τους απαραίτητους μηχανισμούς που υποστηρίζουν την αλληλεπίδραση του τελικού χρήστη με το σύστημα. Συγκεκριμένα οι μηχανισμοί αναλαμβάνουν την ανάλυση των αιτημάτων των χρηστών, για την ανάπτυξη σύνθετων υπηρεσιών, σε παραμέτρους οι οποίες μπορούν να αξιοποιηθούν από τους υπόλοιπους γνωσιακούς μηχανισμούς τους συστήματος προκειμένου να παράγουν δυναμικά τις απαιτούμενες σύνθετες υπηρεσίες που προκύπτουν από τα αιτήματα του χρήστη. Τα αποτελέσματα της ανάλυσης αυτών των μηχανισμών διοχετεύονται στο επόμενο επίπεδο, αυτό των σύνθετων εικονικών δεδομένων.



Εικόνα 8: Αρχιτεκτονική Γνωστικού Πλαισίου Διαχείρισης με εφαρμογή στις έξυπνες πόλεις[121]

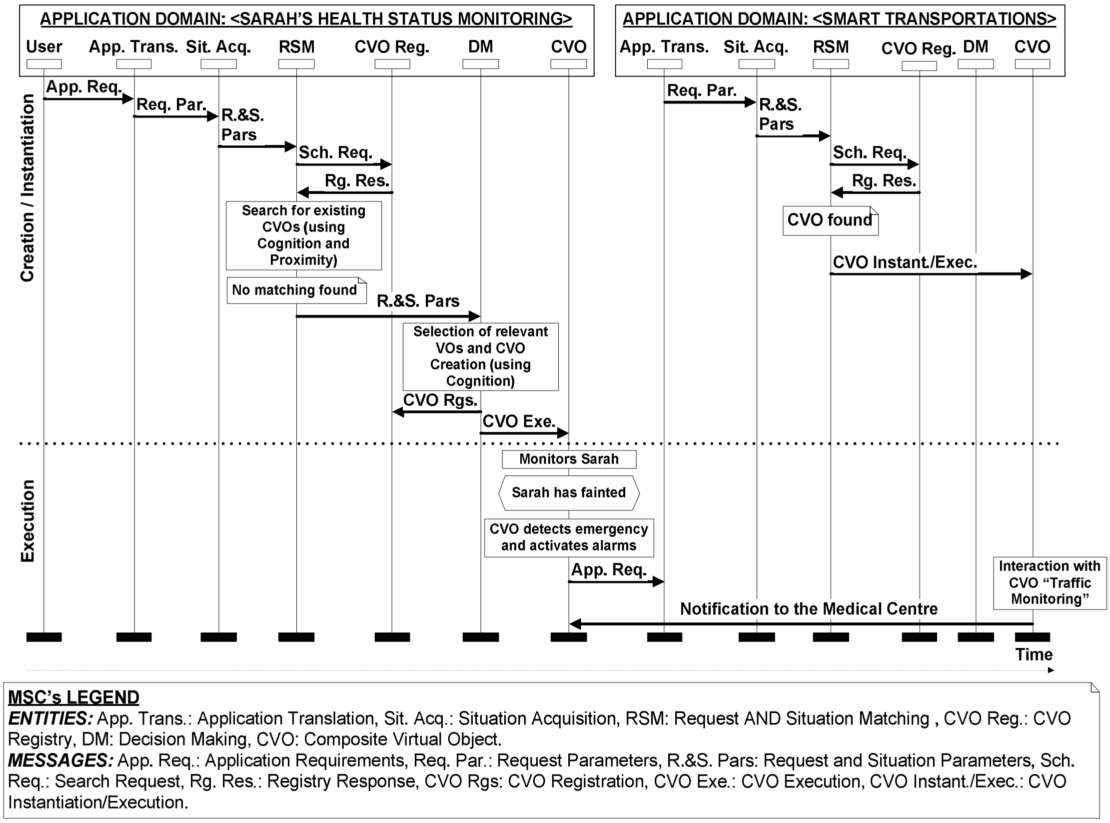
Το επίπεδο σύνθετων εικονικών αντικειμένων (Composite Virtual Object Level) περιέχει τα σύνθετα εικονικά αντικείμενα τα οποία αποτελούν μια σύνθετη υπηρεσία την οποία αιτείται ο χρήστης, ενώ τα ίδια αποτελούνται από πολλά ετερογενή εικονικά αντικείμενα. Επιπλέον ενσωματώνει ένα σύνολο γνωσιακών μηχανισμών οι οποίοι είναι υπεύθυνοι για την δυναμική ανάπτυξη σύνθετων εικονικών αντικειμένων, των οποίων η λειτουργικότητα βασίζεται στις παραμέτρους που προέκυψαν από την ανάλυση των αιτημάτων του χρήστη. Επιπλέον το επίπεδο αυτό συμπεριλαμβάνει μηχανισμούς που βασίζονται στις Σημασιολογικές Τεχνολογίες (Semantic Technologies) αναλαμβάνοντας τον σημασιολογικό εμπλουτισμό των διαθέσιμων πληροφοριών, σε επίπεδο επικοινωνίας, καθώς και σε επίπεδο περιγραφής των σύνθετων εικονικών αντικειμένων. Τέλος το επίπεδο εικονικών αντικειμένων (Virtual Object Level) περιλαμβάνει τα εικονικά αντικείμενα όπου κάθε ένα αποτελεί την σημασιολογικά εμπλουτισμένη αναπαράσταση ενός πραγματικού αντικειμένου στον εικονικό / ψηφιακό κόσμο. Επιπλέον το συγκεκριμένο επίπεδο συμπεριλαμβάνει μηχανισμούς που βασίζονται στις Σημασιολογικές Τεχνολογίες (Semantic Technologies) και υποστηρίζουν την δυναμική ανάπτυξη σημασιολογικών περιγραφών των εικονικών αντικειμένων βασιζόμενη σε προηγμένα, καλώς ορισμένα, σημασιολογικά μοντέλα (Semantic Models). Οντότητες λογισμικού (Software Modules) εισάγονται στο επίπεδο αυτό, προκειμένου να υποστηρίξουν την επικοινωνία / αλληλεπίδραση μεταξύ των εικονικών αντικειμένων με τα σύνθετα εικονικά αντικείμενα, καθώς και με τα αντικείμενα του πραγματικού κόσμου.

8.6.3 Αποτίμηση Επίδοσης

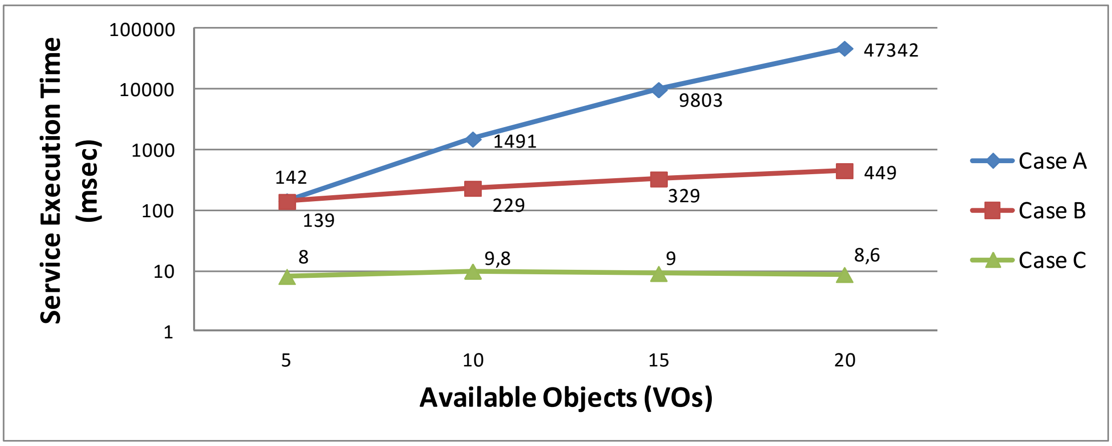
Για την επικύρωση του Γνωσιακού Πλαισίου Διαχείρισης εξετάζουμε ένα σενάριο το οποίο παρουσιάζει τρεις διαφορετικές εφαρμογές στους τομείς μιας έξυπνης πόλης (έξυπνη υγεία, τη δημόσια ασφάλεια, έξυπνες μεταφορές). Η κατάσταση σε κάθε τομέα απαιτεί την δυναμική ανάπτυξη των αντίστοιχων CVOs, δηλαδή (α) το CVO σε ιατρικό κέντρο για την παρακολούθηση της υγείας μίας ηλικιωμένης κυρίας, και των περιβαλλοντικών συνθηκών στο έξυπνο σπίτι όπου διαμένει η ηλικιωμένη κυρία, (β) το CVO σε ένα αστυνομικό τμήμα για την παρακολούθηση της κυκλοφοριακής συμφόρησης και (γ) το CVO σε ένα έξυπνο όχημα για την έξυπνη οδήγηση στους δρόμους της πόλης.

Η προτεινόμενη λύση μελετήθηκε και αξιολογήθηκε ως προς την αποδοτικότητα των μηχανισμών για την δυναμική ανάπτυξη υπηρεσιών σε αναλογία με το διαθέσιμο αριθμό των σημασιολογικά εμπλουτισμένων εικονικών αντικειμένων. Συγκεκριμένα, η Εικόνα 9 παρουσιάζει το διάγραμμα ροής εργασιών και ανταλλαγής μηνυμάτων μεταξύ των εμπλεκόμενων οντοτήτων στο σενάριο εφαρμογής του Γνωσιακού

Πλαισίου στην έξυπνη πόλη. Για την αξιολόγηση των επιδόσεων του πλαισίου, έχουμε πραγματοποιήσει μια σειρά ενδεικτικών πειραμάτων. Συγκεκριμένα, η εφαρμογή ζητά μια υπηρεσία η οποία αποτελείται από 4 λειτουργίες (που αντιπροσωπεύουν τις παραμέτρους αιτήματος). Ο χρόνος εκτέλεσης υπηρεσιών για διαφορετικό αριθμό των διαθέσιμων αντικειμένων που βρίσκονται στην περιοχή ενδιαφέροντος παρουσιάζεται στην Εικόνα 10 για 3 διαφορετικές περιπτώσεις. Η πρώτη περίπτωση αντιστοιχεί στην απουσία του πλαισίου σε σχέση με τις γνωστικές δυνατότητες στο επίπεδο CVO χρησιμοποιώντας μια εξαντλητική τεχνική έρευνα για την επιλογή των κατάλληλων αντικειμένων (περίπτωση Α), Η δεύτερη περίπτωση εξετάζει τη δημιουργία CVO μέσω της διαδικασίας Decision Making χρησιμοποιώντας των CPLEX αλγόριθμο (περίπτωση Β). Τέλος η τρίτη περίπτωση εξετάζει την συγκεκριμενοποίηση ενός υπαρκτού CVO (επαναχρησιμοποίηση των υφιστάμενων CVO) μέσω της εφαρμογής του μηχανισμού "Request and Situation Matching (RSM)" ο οποίος επεξεργάζεται τα σημασιολογικά δεδομένα περιγραφής των υπαρκτών CVO και προτείνει την επαναχρησιμοποίηση τους σε μια διαφορετική περίπτωση σύμφωνα με ένα βαθμό ομοιότητας που προκύπτει από τον αντίστοιχο αλγόριθμο του μηχανισμού RSM (περίπτωση Γ). Όπως απεικονίζεται, ο χρόνος εκτέλεσης υπηρεσίας μειώνεται μέσω της εφαρμογής του μηχανισμού Decision Making, ενώ περαιτέρω εξοικονόμηση χρόνου, επιτυγχάνεται μέσω της εφαρμογής του μηχανισμού RSM, δείχνοντας παράλληλα ότι η εφαρμογή τεχνικών της γνωστική τεχνολογίας όπως η εγγύτητα (proximity) μπορούν να οδηγήσουν σε μείωση των λειτουργικών δαπανών (OPEX).



Εικόνα 9: Διάγραμμα ροής εργασιών και ανταλλαγής μηνυμάτων μεταξύ των εμπλεκόμενων οντοτήτων στο σενάριο εφαρμογής του Γνωστικού Πλαισίου στην έξυπνη πόλη [121]



Εικόνα 10: Χρόνος εκτέλεσης υπηρεσίας (λογαριθμική κλίμακα). Case A: no cognition / proximity, Case B: CVO creation through DM, Case C: CVO instantiation (reuse) through RSM [121]

8.7 Cloud-IoT Υποδομές για το Μελλοντικό Διαδίκτυο

Η εισαγωγή του Σημασιολογικού Πλαισίου για το Διαδίκτυο των Αντικειμένων σε συνδυασμό με το προτεινόμενο Γνωσιακό Πλαίσιο Διαχείρισης, αποτελεί μια ισχυρή και αποδοτική λύση στον χώρο του «Μελλοντικού Διαδικτύου». Η αποδοτικότητα (performance) του συνδυαστικού πλαισίου, καθώς και η επεκτασιμότητα (scalability) των μηχανισμών και των λειτουργικών δυνατοτήτων τους, μπορεί να ενισχυθεί και να βελτιωθεί σε πολύ μεγάλο βαθμό με την ενσωμάτωση τους σε περιβάλλοντα του Υπολογιστικού Νέφους (Cloud Computing). Επιπλέον, με την εισαγωγή σε Cloud περιβάλλοντα αντιμετωπίζονται προβλήματα που αφορούν στην διάθεση υπολογιστικών πόρων (Computing Resources) και πόρων αποθήκευσης (Storage Resources) που απατούνται από τους επιμέρους μηχανισμούς. Ενδεικτικά οι μηχανισμοί λήψεως αποφάσεων (Decision Making) και σύνθεσης Εικονικών Αντικειμένων (CVO Composition engine), του Γνωσιακού Πλαισίου Διαχείρισης, θα ενισχυθούν σημαντικά από την άποψη επιτάχυνσης των υπολογιστικών διαδικασιών και των απαιτούμενων πόρων που χρειάζονται για να λειτουργήσουν με αξιοπιστία και υπολογιστική ακρίβεια. Οι προτεινόμενοι μηχανισμοί έχουν σχεδιαστεί ώστε να μπορούν να εφαρμοστούν σε κατανεμημένες Cloud υποδομές, προσφέροντας δυνατότητες ανάκτησης, επεξεργασίας και ανάλυσης δεδομένων, εικονικοποίηση πόρων υλικού και λογισμικού (Resource Virtualization, Virtual Objects, etc), καθώς και δυνατότητες κατανεμημένης υπολογιστικής επεξεργασίας και αποθήκευσης. Ειδικότερα, οι μηχανισμοί μπορούν να φιλοξενηθούν και να λειτουργήσουν σε Cloud υποδομές μικρής κλίμακας (Local Cloud), καθώς και σε Cloud υποδομές μεγάλης κλίμακας (Global Cloud). Επιπλέον, μέσω της ομαδοποίησης των λειτουργικών δυνατοτήτων των μηχανισμών καθίσταται δυνατή η παροχή ολοκληρωμένων υπηρεσιών Cloud (Integrated Cloud Services) μέσα από την σύνθεσή επιμέρους υπηρεσιών, που θα υλοποιούνται βάση του Γνωσιακού Πλαισίου Διαχείρισης που ενσωματώνεται και φιλοξενείται στο Cloud. Ενδεικτικά, με την ομαδοποίηση των λειτουργικών δυνατοτήτων των γνωστικών μηχανισμών που είναι υπεύθυνοι για την ανάλυση των αιτημάτων των χρηστών, καθώς και για την επεξεργασία των διαθέσιμων δεδομένων για τη δυναμική δημιουργία Σύνθετων Εικονικών Αντικειμένων (CVOs) και των υπηρεσιών / εφαρμογών, θα πρέπει να παρέχεται ένα σύνολο από δυνατότητες του Cloud Computing. Εκτός αυτού, μπορούν να παρέχονται διευρυμένες δυνατότητες αποθήκευσης στο Cloud, για την αποθήκευση μεγάλης κλίμακας ετερογενών σημασιολογικών δεδομένων, μέσω της ενοποίησης κατανεμημένων σημασιολογικών αποθετηρίων (Semantic Repositories), τα οποία περιέχουν δεδομένα περιγραφής για τα VOs, CVOs, Υπηρεσιών, κλπ. Στην κατεύθυνση αυτή η εισαγωγή τεχνολογιών δικτύωση 5G θα ενισχύσει σε μεγάλο βαθμό την αποδοτικότητα και την αξιοπιστία των διαδικασιών, (π.χ. μειώνοντας το χρόνο αλληλεπίδρασης των σημασιολογικών μηχανισμών).

8.7.1 Διατύπωση Προβλήματος – Συνεισφορά Διατριβής

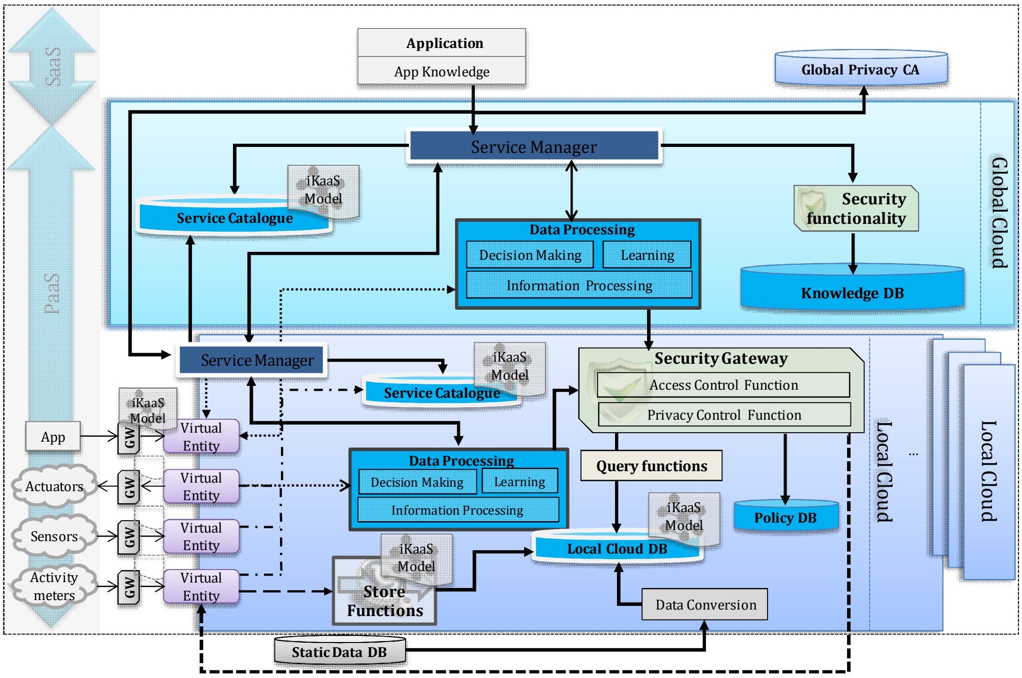
Στην παρούσα υποενότητα παρουσιάζεται μια επίσημη διατύπωση του προβλήματος που αφορά την εφαρμογή του προτεινόμενου πλαισίου σε Cloud υποδομές του «Μελλοντικού Διαδικτύου», συμπεριλαμβανομένων των δικτυακών υποδομών 5G. Τα τελευταία χρόνια, το «Διαδίκτυο των Αντικειμένων» εκκίνησε την υλοποίηση του οράματος ενός πιο διασυνδεδεμένου κόσμου οδηγώντας στην ανάπτυξη κολοσσιαίου όγκου δεδομένων και πολλών υπηρεσιών που παρέχονται μέσω ετερογενών δικτύων πρόσβασης. Ταυτόχρονα, το Cloud Computing ήρθε στο προσκήνιο για να προσφέρει υποστήριξη για τεράστιες αποθήκες δεδομένων, εγκαταστάσεις υπολογιστικών δυνατοτήτων και δυνατότητες μερισμού δεδομένων. Ωστόσο, η σύγκλιση του «Διαδικτύου των Αντικειμένων» και του Cloud μπορεί να προσφέρει νέες ευκαιρίες και για τις δύο τεχνολογίες. Μπορεί να ανοίξει ένα νέο ορίζοντα της πανταχού ανίχνευσης, της διασύνδεσης των συσκευών, της ανταλλαγής υπηρεσιών και προβλέψεων για την καλύτερη υποστήριξη της επικοινωνίας και της συνεργασίας μεταξύ των ανθρώπων, καθώς και την κατανομή των αντικειμένων με πιο δυναμικό τρόπο. Μπορεί επίσης να υποστηρίξει ισχυρές εγκαταστάσεις επεξεργασίας και αποθήκευσης τεράστιων ροών IoT δεδομένων πέρα από την ικανότητα των επιμέρους «αντικειμένων», καθώς και να παρέχει αυτοματοποιημένη λήψη αποφάσεων σε πραγματικό χρόνο. Συνεπώς, η σύγκλιση μπορεί να επιτρέψει την ανάπτυξη νέων καινοτόμων εφαρμογών σε διάφορες αναδυόμενες περιοχές, όπως έξυπνες πόλεις, ευφυή δίκτυα, υποδομές έξυπνης υγειονομικής περίθαλψης, κλπ, για να βελτιώσει όλες τις πτυχές της ζωής.

Η συνεισφορά της παρούσας διατριβής εστιάζει στην αξιοποίηση της σύγκλησης των Cloud και IoT τεχνολογιών, ενισχυμένων από τις σημασιολογικές τεχνολογίες για την ανάπτυξη προηγμένων λύσεων λογισμικού για διαχείριση σημασιολογικών δεδομένων για την περιγραφή και την δυναμική διαχείριση υπηρεσιών σε ετερογενή Cloud-IoT περιβάλλοντα μέσω των τεχνολογιών δικτύωσης 5G. Ειδικότερα, η εφαρμογή των μηχανισμών του «Σημασιολογικού Συστήματος Αποθήκευσης» για την αποθήκευση, διαχείριση (π.χ. ανακάλυψη, ενημέρωση) σημασιολογικών δεδομένων θα επιτρέψει την ενοποίηση σημασιολογικών δεδομένων περιγραφής κατανεμημένων υπηρεσιών σε Cloud περιβάλλοντα. Η ενοποίηση των κατανεμημένων σημασιολογικών δεδομένων θα επιτρέψει την ανάπτυξη σύνθετων υπηρεσιών οι οποίες θα βρίσκονται κατανεμημένες σε διαφορετικές Cloud υποδομές διασυνδεδεμένες μέσω 5G τεχνολογιών.

8.7.2 Επίλυση Προβλήματος

Για την επίτευξη των παραπάνω θα μπορούσε να συνεισφέρει ιδανικά η συγχώνευση μεταξύ Cloud Computing και Internet of Things υποδομών και τεχνολογιών, σε συνδυασμό με διεπαφές επικοινωνίας (Communication Interfaces), μονάδες αποθήκευσης (Storage Volumes) και εφαρμογές για την υλοποίηση μια κατανεμημένης multi-Cloud αρχιτεκτονικής με υποδομές επικοινωνίας που βασίζονται στο 5G. Η εισαγωγή των γνωσιακών τεχνολογιών (Cognitive Technologies) αποτέλεσε το πρώτο βήμα για την επιτυχημένη εφαρμογή και καθιέρωση των IoT τεχνολογιών, συνεισφέροντας στην αυτοδιαχείριση και την λειτουργική διαχείρισης των δεδομένων που αφορούν τις παρεχόμενες υπηρεσίες. Η Εικόνα 11 παρουσιάζει την αρχιτεκτονικής ενός τέτοιου συστήματος. Η προτεινόμενη αρχιτεκτονική στοχεύει στην ενοποίηση κατανεμημένων IoT Cloud συστημάτων για την παροχή ενοποιημένων υπηρεσιών προς τους τελικούς χρήστες του «Μελλοντικού Διαδικτύου». Η αρχιτεκτονική περιλαμβάνει την εισαγωγή των Local Clouds (εναλλακτικά Edge Clouds) και του Global/Federated Cloud τα οποία συνθέτουν ένα multi-Cloud περιβάλλον, διαχείρισης και παροχής Cloud υπηρεσιών.

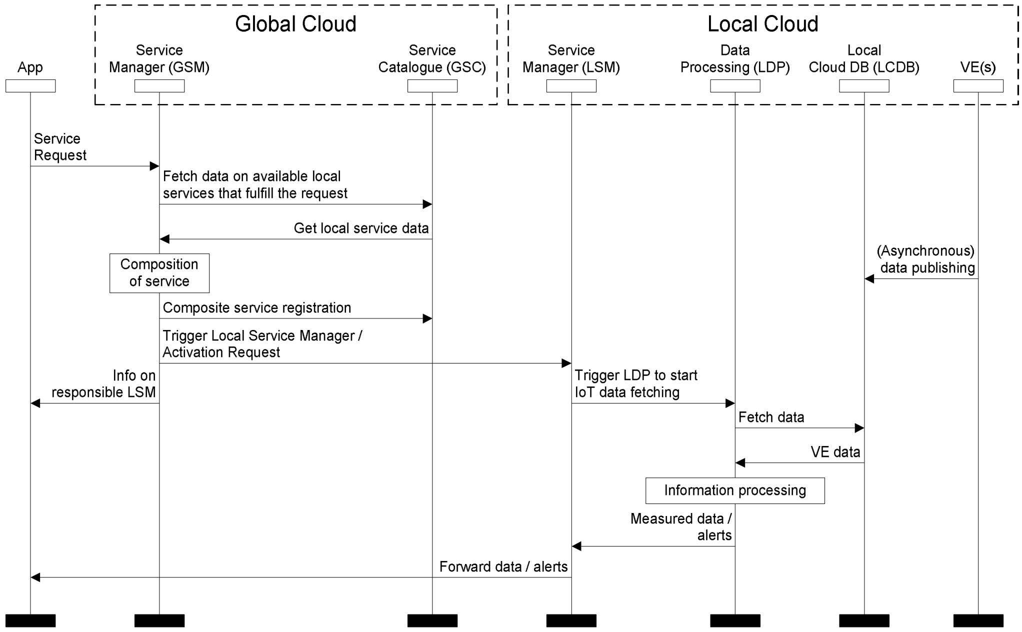
Κατανεμημένες συνιστώσες του «Σημασιολογικού Συστήματος Αποθήκευσης» (ενδεικτικά στην εικόνα Service Catalogues) θα αποθηκεύουν και θα διαχειρίζονται τα σημασιολογικά δεδομένα που θα περιγράφουν τις διαθέσιμες υπηρεσίες σε κάθε Cloud υποδομή. Για την ανάπτυξη σύνθετων υπηρεσιών που θα συνδυάζουν τις κατανεμημένες υπηρεσίες, κατάλληλοι γνωσιακή μηχανισμοί (όπως ο Service Manager στο Federated/Global Cloud) θα χρησιμοποιούν τα σημασιολογικά δεδομένα (από τα κατανεμημένα συστήματα αποθήκευσης σημασιολογικών δεδομένων στα Edge Clouds) προκειμένου να δημιουργήσουν δυναμικά αποφάσεις σχετικά με την σύνθεση. Επειδή απαιτείται η ενοποίηση και επεξεργασία των κατανεμημένων σημασιολογικών δεδομένων, θα πρέπει να εφαρμοστούν καινοτόμες τεχνολογίες δικτύωσης από τον τομέα του 5G προκειμένου να διασύνδεουν τις κατανεμημένες σημασιολογικές βάσεις δεδομένων. Συνεπώς, η διακίνηση των δεδομένων θα εκτελείται πάνω από προηγμένες υποδομές 5G δικτύωσης προκειμένου να επιτευχτεί υψηλή απόδοση σε ταχύτητα και χρόνο μετάδοσης στοχεύοντας στη μείωση του χρόνου διεκπεραίωσης της συνολικής διαδικασίας. Τέλος, η επίλυση του προβλήματος εστιάζει και σε περαιτέρω παράγοντες βελτίωσης του συστήματος, όπως η μετακίνηση των σημασιολογικών δεδομένων από απομακρυσμένες σημασιολογικές αποθήκες. Η μετακίνηση των σημασιολογικών δεδομένων μπορεί να αποφασίζεται δυναμικά λαμβάνοντας υπόψη το κόστος δικτύωσης (π.χ. latency) σε σχέση με την απόδοση του συστήματος. Στην περίπτωση αυτή θα εφαρμοστούν τεχνικές ανάπτυξης Federated Σημασιολογικών Βάσεων Δεδομένων οι οποίες θα επιτρέπουν την εκτέλεση Federated SPARQL ερωτημάτων σε σημασιολογικά δεδομένα που βρίσκονται «πιο κοντά» στο μηχανισμό λήψης αποφάσεων για την σύνθεση των υπηρεσιών (π.χ. τον Service Manager).



Εικόνα 11: multi-Cloud αρχιτεκτονική για το Μελλοντικό Διαδίκτυο[127]

8.7.3 Αποτίμηση Επίδοσης

Για την αξιολόγηση της προτιμώμενης λύσης, καθώς και για την επικύρωση της προτεινόμενης αρχιτεκτονικής μελετάται η εφαρμογή σεναρίου που αφορά την δυναμική ανάπτυξη συνθετών υπηρεσιών σε multi-Cloud περιβάλλον με κατανεμημένες σημασιολογικές αποθήκες οι οποίες επικοινωνούν μέσω παραδοσιακών δικτυακών υποδομών αλλά και μέσω δικτυακών υποδομών 5G. Η Εικόνα 12 παρακάτω, παρουσιάζει το διάγραμμα ανταλλαγής μηνυμάτων μεταξύ των εμπλεκόμενων οντοτήτων στη παραπάνω διαδικασία.



Εικόνα 12: Service composition over multi-Cloud IoT environments[127]

Συγκριμένα, ακολουθείται η θεώρηση ότι το Global Cloud αναλαμβάνει την ανάπτυξη μιας σύνθετης υπηρεσίας βάση κατάλληλου αιτήματος που λαμβάνει από κάποιον τελικό χρήστη. Τα απαιτούμενα δεδομένα για τον μηχανισμό λήψης αποφάσεων σχετικά με την σύνθεση, βρίσκονται κατανεμημένα σε διαφορετικά Local Cloud περιβάλλοντα. Η αξιολόγηση μας εστιάζει στην μελέτη του χρόνου ολοκλήρωση των διαδικασιών σύνθεσης της υπηρεσίας, λαμβάνοντας υπόψη τον όγκο των διακινούμενων σημασιολογικών δεδομένων που περιγράφουν τις επιμέρους υπηρεσίες, καθώς και τις τεχνολογίες δικτύωσης μεταξύ των κατανεμημένων Cloud περιβαλλόντων. Ο Πίνακας 1 παρουσιάζει μια ενδεικτική απεικόνιση της αναλογίας χρόνου ολοκλήρωσης της διαδικασίας σύνθεσης υπηρεσίας σε σχέση με τον αριθμό των διαθέσιμων υπηρεσιών στα επιμέρους κατανεμημένα περιβάλλοντα.

Available Services	Service Discovery & Data fetch Time	Overall Service Instantiation Time	Ratio of Service Discovery & Data fetch Time
10	350 ms	874.2 ms	40 %
20	420 ms	963.6 ms	43.5 %
30	510 ms	1116.6 ms	45.6 %
40	585 ms	1264 ms	46.2 %
50	673 ms	1489.6 ms	45.1 %
60	750 ms	1809 ms	41.4 %
70	892 ms	1999 ms	44.6 %
80	976 ms	2321.6 ms	42 %

Πίνακας 1: Απαιτούμενος χρόνος ανάπτυξης υπηρεσίας vs. χρόνος ανακάλυψης υπηρεσία και λήψη σημασιολογικών δεδομένων[129]

8.8 Συμπεράσματα και Επόμενα Βήματα

Το «Διαδίκτυο των Αντικειμένων» (Internet of Things) συμπεριλαμβάνει, και προβλέπεται να συμπεριλάβει, τεράστιο αριθμό συσκευών, υποδομών επικοινωνίας και εφαρμογών. Το παραπάνω οδηγεί σε τεχνολογική ετερογένεια η οποία θα πρέπει να αντιμετωπιστεί αποτελεσματικά προκειμένου να επιτρέψει την σύνθεση λειτουργικών δυνατοτήτων για την παροχή καινοτόμων ποιοτικών και αξιόπιστων σύνθετων τεχνολογικών λύσεων και υπηρεσιών προς τους τελικούς χρήστες. Το «Διαδίκτυο των Αντικειμένων» συμπεριλαμβάνει τόσο την παροχή των αντικειμένων με υποδομές για την υποστήριξη της φυσικής επικοινωνίας, καθώς και στην ανταλλαγή των δεδομένων που μπορούν να (επανα-)χρησιμοποιηθούν από άλλα αντικείμενα, καθιστώντας δυνατή την ανάπτυξη νέων ή την εξέλιξη υπαρχόντων εφαρμογών με περισσότερες δυνατότητες.

Η εφαρμογή του Σημασιολογικού Πλαισίου θα πρέπει να υποστηρίζει και να διασφαλίζει την ορθή εκτέλεση των διαδικασιών που αφορούν στην διαχείριση της τεχνολογικής ετερογένειας και την απόκρυψη της πολυπλοκότητας των διαδικασιών ενοποίησης, μέσω των μηχανισμών που ενσωματώνει. Για την κάλυψη των αναγκών μοντελοποίησης των δεδομένων και των πληροφοριών που συνδέονται με τους διαφορετικούς τύπους συσκευών, εφαρμογών, υπηρεσιών, καθώς και με την ανάπτυξη σχετιζόμενης γνώσης, θα πρέπει να εφαρμοστεί η παρεχόμενη λειτουργία του δομικού τμήματος «Σημασιολογικό Σύστημα Αποθήκευσης» (Semantic Storage System) του Σημασιολογικού Πλαισίου. Επιπλέον, οι λειτουργικές δυνατότητες αυτού του δομικού τμήματος μπορούν να εφαρμοστούν για την κατανεμημένη αποθήκευση και διαχείριση μεγάλης κλίμακας σημασιολογικών δεδομένων που εμπεριέχονται σε περιβάλλοντα του «Διαδικτύου των Αντικειμένων». Η κατανεμημένη αποθήκευση και διαχείριση των σημασιολογικών δεδομένων μπορεί να εφαρμοστεί και να πραγματοποιηθεί με την ενσωμάτωση των μηχανισμών του Σημασιολογικού Πλαισίου σε περιβάλλοντα Cloud. Μπορεί να εφαρμοστεί σε διάφορες περιπτώσεις, όπως ενδεικτικά η επεξεργασία και ενοποίηση σημασιολογικών δεδομένων για την αναπαράσταση γνώσης (knowledge representation).

Επιπλέον, το Σημασιολογικό Πλαίσιο αποτελεί την βάση πάνω στην οποία θα καταστεί δυνατή η ανάπτυξη επιπλέον μηχανισμών, εφαρμογών και υπηρεσιών που θα χρησιμοποιούν τις λειτουργικές δυνατότητες των δομικών τμημάτων «Γνωσιακής Διαχείρισης και Σύνθεση Εικονικών Αντικειμένων» και «Γνωσιακής Διαχείρισης Υπηρεσιών». Στόχος, η επέκταση των παρεχόμενων λειτουργικών δυνατοτήτων του πλαισίου για την κάλυψη των διαρκώς αυξανόμενων απαιτήσεων στον τομέα του «Μελλοντικού Διαδικτύου» (Future Internet). Τέτοιου είδους απαιτήσεις μπορεί να αφορούν τον τομέα των Wearables ο οποίος αφορά τις συσκευές που μπορεί ένας άνθρωπος να φέρει πάνω του για την υποστήριξη διάφορων λειτουργιών, όπως η παρακολούθηση ζωτικών λειτουργιών (π.χ. οι παλμοί της καρδιάς).

Κλείνοντας, θα πρέπει να τονιστεί, πως η διατριβή εστίασε στην ενδελεχή επιστημονική μελέτη των παραπάνω και κάθε ενότητα της, συνδέεται με ένα σύνολο επιστημονικών αποτελεσμάτων ή/και συμπερασμάτων που έχουν δημοσιευτεί σε επιστημονικά περιοδικά και συμπεριλαμβάνονται στην μέχρι στιγμής καταγεγραμμένη βιβλιογραφία.

8.9 Βιβλιογραφία Κεφαλαίου

[1].Atzori L., Iera A., Morabito G. (2010). The Internet of Things: A survey. J. Computer Networks, 54, 2787-2805.

[2].Fürber, C. (2016). Semantic Technologies. In Data Quality Management with Semantic Technologies (pp. 56-68). Springer Fachmedien Wiesbaden.

[3].W3C Standards – Semantic Web. (2016). http://www.w3.org/standards/semanticweb/.

[4].Kephart, J. O., Chess, D. M. (2003). The Vision of Autonomic Computing. IEEE Computer, 36(1). 41-50.

[5].Babar, S., Mahalle, P., Stango, A., Prasad, N., & Prasad, R. (2010). Proposed security model and threat taxonomy for the internet of things (IoT). In Recent Trends in Network Security and Applications (pp. 420-429). Springer Berlin Heidelberg.

[6].Miorandi, D., Sicari, S., De Pellegrini F., Chlamtac I. (2012) Internet of things: Vision, applications and research challenges. Ad Hoc Networks, 10(7), 1497-1516.

[7].Brian, M. (2005). Semantic Web Technologies. Semantic Web Interest Group World Wide Web Consortium (W3C). Technical Report.

[8].Semantic Web Activity. (2016). [Online]: http://www.w3.org/2001/sw/.

[9].M-R. Koivunen, E. Miller. W3C Semantic Web Activity. Proceedings of the Semantic Web Kick-off Seminar in Finland. (2016). [Online]: http://www.w3.org/2001/12/semweb-fin/w3csw.

[10]. Michael Armbrust, et al. (2010). A view of cloud computing. Magazine Communications of the ACM. 53(4). 50-58.

[11]. Mcgrath, Michael P., et al. (2015). "Controlling Capacity in a Multi-Tenant Platform-as-a-Service Environment in a Cloud Computing System". U.S. Patent No. 20,150,081,916. 19.

[12]. Alcaraz Calero, J., and J. Gutierrez Aguado. (2014). "Monpaas: An adaptive monitoring platform as a service for cloud computing infrastructures and services".

[13]. Manvi, Sunilkumar S., and Gopal Krishna Shyam. "Resource management for Infrastructure as a Service (IaaS) in cloud computing: A survey". (2014). Journal of Network and Computer Applications 41: 424-440.

[14]. Serrano, Nicolas, Gorka Gallardo, and Josune Hernantes. "Infrastructure as a Service and Cloud Technologies". IEEE Software 2 (2015): 30-36.

[15]. Agrawal, Divyakant, Sudipto Das, and Amr El Abbadi. "Big data and cloud computing: current state and future opportunities". (2011) . Proceedings of the 14th International Conference on Extending Database Technology. ACM.

[16]. Chaudhuri, Surajit. (2012). "What next?: a half-dozen data management research goals for big data and the cloud". Proceedings of the 31st symposium on Principles of Database Systems. ACM.

[17]. Berners-Lee, T. (2001). "The Semantic Web". Scientific American.

[18]. Shadbolt, N., Hall, W., Berners-Lee, T. (2006). "The Semantic Web Revisited". IEEE Intelligent Systems.

[19]. OpenStack Open Source Cloud Computing Software. (2016). [Online]: https://www.openstack.org/.

[20]. Apache CloudStack: Open Source Cloud Computing. (2016). [Online]: https://cloudstack.apache.org/.

[21]. Docker - Build, Ship, and Run Any App, Anywhere. (2016). [Online]: https://www.docker.com/.

[22]. FIA Website. (2016). [Online]: http://www.future-internet.eu/.

[23]. IERC Website. (2016). [Online]: http://www.internet-of-things-research.eu/.

[24]. IoT-I Website. (2016). [Online]: http://www.iot-i.eu/.

[25]. Open Geospatial Consortium (OGC). (2016). [Online]: http://www.opengeospatial.org/.

[26]. World Wide Web Consortium (W3C). (2016). [Online]: http://www.w3.org/ .

[27]. W3C and OGC to Collaborate to Integrate Spatial Data on the Web. (2016). [Online]: http://www.opengeospatial.org/pressroom/pressreleases/2149.

[28]. Standards - W3C. (2016). [Online]: www.w3.org/standards/.

[29]. Catalogue Service. (2016). [Online]: http://www.opengeospatial.org/standards/cat.

[30]. Observations and Measurements. (2016). [Online]: http://www.opengeospatial.org/standards/om.

[31]. SensorML. (2016). [Online]: http://www.ogcnetwork.net/SensorML.

[32]. Sensor Observation Service. (2016). [Online]: http://www.opengeospatial.org/standards/sos.

[33]. Transducer Markup Language (TML). (2016). [Online]: http://www.ogcnetwork.net/infomodels/tml.

[34]. Web Processing Service. (2016). [Online]: http://www.opengeospatial.org/standards/wps.

[35]. Web Registry Service Research Document. (2016). [Online]: http://udig.refractions.net/files/docs/WRS.pdf.

[36]. De, Suparna, et al. (2011). "Service modelling for the Internet of Things". Computer Science and Information Systems (FedCSIS), 2011 Federated Conference on. IEEE.

[37]. Geography Markup Language (GML). (2016). [Online]: http://www.opengeospatial.org/standards/gml.

[38]. CityGML. (2016). [Online]: http://www.opengeospatial.org/standards/citygml.

[39]. GeoRSS :: Geographically Encoded Objects for RSS feeds. (2016). [Online]: http://www.georss.org/.

[40]. GeoSPARQL - A Geographic Query Language for RDF Data. (2016). [Online]: http://www.opengeospatial.org/standards/geosparql.

[41]. OGC® WaterML. (2016). [Online]: http://www.opengeospatial.org/standards/waterml.

[42]. W3C Semantic Web. (2016). [Online]: http://www.w3.org/standards/semanticweb/.

[43]. W3C Standards, Semantic Web, Linked Data. (2016). [Online]: http://www.w3.org/standards/semanticweb/data.

[44]. Linked Data - Connect Distributed Data across the Web. (2016). [Online]: http://linkeddata.org/.

[45]. The Linking Open Data cloud diagram. [Online] http://lod-cloud.net/.

[46]. W3C Standards, Semantic Web, Vocabularies. (2016). [Online]: http://www.w3.org/standards/semanticweb/ontology.

[47]. OWL Web Ontology Language Overview. (2016). [Online]: http://www.w3.org/TR/owl-features/.

[48]. OWL WEB ONTOLOGY LANGUAGE CURRENT STATUS. (2016). [Online]: http://www.w3.org/standards/techs/owl#w3c_all.

[49]. RDF Vocabulary Description Language 1.0: RDF Schema (RDFS). (2016). [Online]: http://www.w3.org/TR/rdf-schema/.

[50]. RDF Schema 1.1. (2016). [Online]: https://www.w3.org/2001/sw/wiki/RDFS.

[51]. W3C Standards, Semantic Web, Inference. (2016). [Online]: http://www.w3.org/standards/semanticweb/inference.

[52]. W3C Uncertainty Reasoning for the World Wide Web Incubator Group. (2016). [Online]: http://www.w3.org/2005/Incubator/urw3/.

[53]. RIF RULE INTERCHANGE FORMAT CURRENT STATUS. (2016). [Online]: http://www.w3.org/standards/techs/rif#w3c_all.

[54]. SWI Prolog. [Online] http://www.swi-prolog.org/.

[55]. W3C Semantic Web - Resource Description Framework (RDF). (2016). [Online]: http://www.w3.org/RDF/.

[56]. SPARQL Query Language for RDF. (2016). [Online]: http://www.w3.org/TR/rdf-sparql-query/.

[57]. W3C WiKi - LargeTripleStores. (2016). [Online]: http://www.w3.org/wiki/LargeTripleStores.

[58]. Franz Inc. AllegroGraph. (2016). [Online]: http://franz.com/agraph/allegrograph/.

[59]. OpenLink Software - Virtuoso Server. [Online] http://virtuoso.openlinksw.com/.

[60]. Information Systems Group - RDFox. (2016). [Online]: http://www.cs.ox.ac.uk/isg/tools/RDFox/.

[61]. openRDF Sesame Framework. (2016). [Online]: http://rdf4j.org/.

[62]. Apache Jena Fuseki - Fuseki: serving RDF data over HTTP. (2016). [Online]: http://jena.apache.org/documentation/serving_data/.

[63]. Systap - Blazegraph. (2016). [Online]: http://www.blazegraph.com/.

[64]. Jena Ontology API. (2016). [Online]: https://jena.apache.org/documentation/ontology/.

[65]. EBBITS project Website. (2016). [Online]: http://www.ebbits-project.eu/.

[66]. SPITFIRE project Website. (2016). [Online]: http://spitfire-project.eu/.

[67]. SOFIA project Website. (2016). [Online]: http://www.sofia-project.eu/.

[68]. SENSEI project Website. (2016). [Online]: http://www.sensei-project.eu/.

[69]. DIEM project Website. (2016). [Online]: http://www.cs.tut.fi/ihte/projects/DIEM/index.html.

[70]. OPUTE (Open Ubiquitous Technologies) project information, http://www.tekes.fi/programmes/Ubicom/Projects?id=9822957.

[71]. Internet of Things Architecture (IoT-A) EU Project Website. (2016). [Online]: http://www.iot-a.eu/.

[72]. EU/FP7 project IoT-A (The Internet-of-Things Architecture – IoT-A, 257521), Sep. 2010 – Aug. 2013, Deliverable 1.2 (D1.2), "Initial Architectural Reference Model for IoT.

[73]. EU/FP7 project IoT-i (Internet-of-Things Initiative – IoT-i, 257565), Sep. 2010 – Aug. 2012, Deliverable 1.2 (D1.2), "Final Reference Model".

[74]. Aberer, K., Hauswirth, M., Salehi, A. (2007). Infrastructure for Data Processing in Large-Scale Interconnected Sensor Networks. In: Proceedings of the International Conference on Mobile Data Management (MDM '07), 198-205.

[75]. Mattern, F. (2003). From Smart Devices to Smart Everyday Objects. In: Proceedings of the Smart Objects Conference (SOC 03), 15–16.

[76]. Beigl, M., Gellersen, H.-W. (2001). Schmidt, A.: MediaCups: Experience with Design and Use of Computer-Augmented Everyday Objects. J. Computer Networks 35(4), 401–409.

[77]. Zhang L., Mitton N. (2011). "Advanced Internet of Things", Université des Sciences et Technologies de Lille, France. iThings-2011.

[78]. Lambros Sarakis, Theodore Zahariadis, Helen-Catherine Leligou, Mischa Dohler. (2012). "A Framework for Service Provisioning in Virtual Sensor Networks", Eurasip Journal on Wireless Communications and Networking,.

[79]. S. Alam, Mohammad M. R. Chowdhury, J. Noll, "SenaaS:An Event-driven Sensor Virtualization approach for Internet of Things Cloud", Networked Embedded Systems for Enterprise Applications(NESEA). (2010) IEEE International Conference.

[80]. Melazzi N. B. (2010). "CONVERGENCE: Extending the Media Concept to Include Representations on Real World Objects", The Internet of Things: 20th Tyrrhenian Workshop on Digital Communications, 129-140.

[81]. FP7/ICT- 257123 project CONVERGENCE, Jun. 2010 - Feb. 2013, Website, http://www.ict-convergence.eu/.

[82]. Every Thing Connected: How Web Object Technology is Putting Every Physical Thing on the Web. (2012). EvryThng Ltd..

[83]. A. Pintus, D. Carboni, A. Piras. (2012). "Paraimpu:a Platform for a Social Web of Things", WWW, Lyon, France.

[84]. D. Guinard, V. Trifa, T. Pham, O. Liechti. (2009)."Towards Physical Mashups in the Web of Things". Proc. of the 6th International Conference on Networked Sensing Systems (INSS), Pittsburgh, USA.

[85]. M. Marin-Perianu, N. Meratnia, P. Havinga, L. de Souza, J. Muller, P. Spiess, S. Haller, T. Riedel, C. Decker, G. Stromberg. (2007). "Decentralized enterprise systems: a multiplatform wireless sensor network approach," IEEE Wireless Communications.

[86]. L. M. S. de Souza, P. Spiess, D. Guinard, M. Koehler, S. Karnouskos, D. Savio, "Socrades: A web service based shop floor integration infrastructure," in Proc. of the Internet of Things Conference (IOT 2008), Springer.

[87]. P. Liuha, A. Lappeteläinen, J-P, Soininen. (2009). "Smart Objects for Intelligent Applications - first results made open", ARTEMIS Magazine, No. 5, pp. 27-29.

[88]. Wu, D., Rosen, D. W., Wang, L., & Schaefer, D. (2015). Cloud-based design and manufacturing: A new paradigm in digital manufacturing and design innovation. Computer-Aided Design, 59, 1-14.

[89]. Wang, T., Guo, S., & Lee, C. G. (2014). Manufacturing task semantic modeling and description in cloud manufacturing system. The International Journal of Advanced Manufacturing Technology, 71(9-12), 2017-2031.

[90]. Abolfazli, S., Sanaei, Z., Ahmed, E., Gani, A., & Buyya, R. (2014). Cloud-based augmentation for mobile devices: motivation, taxonomies, and open challenges. Communications Surveys & Tutorials, IEEE, 16(1), 337-368.

[91]. Joshi, K. P., Yesha, Y., & Finin, T. (2014). Automating cloud services life cycle through semantic technologies. Services Computing, IEEE Transactions on, 7(1), 109-122.

[92]. Verlaine, B., Jureta, I., & Faulkner, S. (2015). Towards the Alignment of a Detailed Service-Oriented Design and Development Methodology with ITIL v. 3. In Exploring Services Science (pp. 123-138). Springer International Publishing.

[93]. Ma, H., Bastani, F., Yen, I. L., & Mei, H. (2013). QoS-driven service composition with reconfigurable services. Services Computing, IEEE Transactions on, 6(1), 20-34.

[94]. M. Hepp , GoodRelations: An Ontology for Describing Products and Services Offers on the Web, Proceedings of the 16th International Conference on Knowledge Engineering and Knowledge Management (EKAW2008). (2008). Italy, Springer LNCS, Vol 5268, pp. 332-347

[95]. K. Ren, N. Xiao, J. Chen, "Building Quick Service Query List Using WordNet and Multiple Heterogeneous Ontologies toward More Realistic Service Composition". (2011). IEEE Transactions on Services Computing, vol. 4, no. 3, pp. 216-229.

[96]. D. De Roure et. al., The Semantic Grid: Past, Present, and Future. (2005). Proceedings of the IEEE, vol. 93, No. 3.

[97]. T Dornemann, E Juhnke, B Freisleben. (2009). On-Demand Resource Provisioning for BPEL Workflows Using Amazon's Elastic Compute Cloud, proc. of CCGrid.

[98]. Quan Z. Sheng, et al, , Configurable Composition and Adaptive

[99]. Provisioning of Web Services. (2009). IEEE Transactions on Services Computing, Vol. 2, No. 1.

[100]. Mike Boniface, et al. (2007). Dynamic Service Provisioning Using GRIA SLAs Service-Oriented Computing - ICSOC.

[101]. Ana Juan Ferrer, et al, (2011). OPTIMIS: A holistic approach to cloud service provisioning, FGCS.

[102]. Kourtesis, D., Alvarez-Rodríguez, J. M., & Paraskakis, I. (2014). Semantic-based QoS management in cloud systems: Current status and future challenges. Future Generation Computer Systems, 32, 307-323.

[103]. Singh, D., Tripathi, G., & Jara, A. J. (2014, March). A survey of Internet-of-Things: Future vision, architecture, challenges and services. In Internet of Things (WF-IoT), 2014 IEEE World Forum on (pp. 287-292). IEEE.

[104]. Elgazzar, K., Hassanein, H. S., & Martin, P. (2014). DaaS: Cloud-based mobile Web service discovery. Pervasive and Mobile Computing, 13, 67-84.

[105]. Husain, Mohammad Farhan, et al. "Storage and retrieval of large rdf graph using hadoop and mapreduce." Cloud Computing. Springer Berlin Heidelberg, 2009. 680-686.

[106]. Huang, Jiewen, Daniel J. Abadi, and Kun Ren. (2011). "Scalable SPARQL querying of large RDF graphs". Proceedings of the VLDB Endowment 4.11: 1123-1134.

[107]. Husain, Mohammad, et al. (2011) "Heuristics-based query processing for large rdf graphs using cloud computing". Knowledge and Data Engineering, IEEE Transactions on 23.9: 1312-1327.

[108]. Sun, Jianling, and Qiang Jin. "Scalable rdf store based on hbase and mapreduce." Advanced Computer Theory and Engineering (ICACTE). (2010). 3rd International Conference on. Vol. 1. IEEE.

[109]. Apache Hbase. (2016) [Online]: http://hbase.apache.org/.

[110]. Weiss, Cathrin, Panagiotis Karras, and Abraham Bernstein. "Hexastore: sextuple indexing for semantic web data management". (2008). Proceedings of the VLDB Endowment 1.1: 1008-1019.

[111]. Um, Jung-Ho, et al. (2015). "MapReduce-based Bulk-Loading Algorithm for Fast Search for Billions of Triples". Computer Science and its Applications. Springer Berlin Heidelberg, 2015. 1139-1145.

[112]. Mori, Pravinsinh, A. R. Kazi, and Sandip Chauhan. (2015). "A Survey on an Efficient Query Processing and Analysis on Big Data (RDF) Using Map Reduce". International Journal for Scientific Research and Development 1.7: 142-146.

[113]. Park, Seong-hun, Sung-min Kim, and Young-guk Ha. (2015). "Scalable visualization for DBpedia ontology analysis using Hadoop". Software: Practice and Experience.

[114]. FP7/ICT project iCore (Internet Connected Objects for Reconfigurable Eco-systems, ICT-287708), Oct. 2011 – Sept. 2014, Website: http://www.iot-icore.eu.

[115]. Kelaidonis, Dimitris, et al. (2012). "Virtualization and cognitive management of real world objects in the internet of things." Green Computing and Communications (GreenCom), 2012 IEEE International Conference on. IEEE.

[116]. P. Tilanus, B. Ran, M. Faeth, D. Kelaidonis, V. Stavroulaki, "Virtual Object Access Rights to Enable Multi-Party Use of Sensors", (WoWMoM 2013), Second Workshop on the Internet of Things: Smart Objects and Services, IoT-SoS 2013, Spain, June 4 2013.

[117]. Dimitris Kelaidonis, Panagiotis Vlacheas, Vasilis Foteinos, Antonis Moustakos, Theodoros Michalareas, Zhiyong Feng, Meng Dexiang, Panagiotis Demestichas. (2014). "Smart energy management of wireless technologies and mobile applications". Submitted to the workshop on Cognitive Radio Advances, Applications and Future Emerging Technologies (CRAFT), May 2014.

[118]. V. Foteinos, D. Kelaidonis, G. Poulios, V, Stavroulaki, P. Vlacheas, P. Demestichas, R. Giaffreda, A. R. Biswas, S. Menoret, G. Nguengang, M.

Etelapera, N. Septimiu-Cosmin, M. Roelands, F. Visintainer, and K. Moessner, "A Cognitive Management Framework for Empowering the Internet of Things", Future Internet Assembly 2013: Validated Results and New Horizons, A. Galis and A. Gavras (Eds.): FIA 2013, LNCS 7858, pp. 187-199, 2013, Book Chapters.

[119]. Foteinos, V., Kelaidonis, D., Poulios, G., Vlacheas, P., Stavroulaki, V., & Demestichas, P. (2013). "A Cognitive Management Framework for Service Provisioning in the Internet of Things". Future Networks and Mobile Summit 2013, Portugal, Lisbon.

[120]. Foteinos, V., Kelaidonis, D., Poulios, G., Vlacheas, P., Stavroulaki, V., & Demestichas, P. (2013). Cognitive Management for the Internet of Things: A Framework for Enabling Autonomous Applications. Vehicular Technology Magazine, IEEE, 8(4), 90-99.

[121]. P. Vlacheas, R. Giaffreda, V. Stavroulaki, D. Kelaidonis, A. Somov, V. Foteinos, G. Poulios, A.-R. Biswas, K. Moessner, P. Demestichas, "Enabling smart cities through a cognitive management framework for the Internet of Things", IEEE Communications Magazine, vol.51, no.6, 2013, Journal Papers.

[122]. FP7/ICT-287708 iCore Project. Deliverable Document 3.1 "Virtual Object Requirements and Dependencies".

[123]. ARTEMIS Project "A cognitive ecosystem for smART Energy Management of wIreless technologieS and mobile applications". "Greece-China bilateral collaboration" Action of the General Secretariat for Research and Technology (GSRT) in Greece. Project duration April 2013 to September 2015.

[124]. ARTEMIS Project "A cognitive ecosystem for smART Energy Management of wIreless technologieS and mobile applications". "Greece-China bilateral collaboration" Action of the General Secretariat for Research and Technology (GSRT) in Greece. Deliverable Document 2.1. "Requirements and Dependencies for device level". April 2013 to September 2015.

[125]. ARTEMIS Project "A cognitive ecosystem for smART Energy Management of wIreless technologieS and mobile applications". "Greece-China bilateral collaboration" Action of the General Secretariat for Research and Technology (GSRT) in Greece. Deliverable Document 5.1. "Requirements and Dependencies for application level". April 2013 to September 2015.

[126]. Intelligent Platform as a Service – iKaaS Project. EU – Japan Collaborative R&D project, Duration: 2014-2017. Deliverable document 2.1 – "Foundations of

Semantic Data Models and Tools, IoT and Big Data Integration in Multi-Cloud Environments”.

[127]. Dimitrios Kelaidonis, Panagiotis Vlacheas, Vera Stavroulaki, Stylianos Georgoulas, Klaus Moessner, Yuichi Hashi, Kazuo Hashimoto, Yutaka Miyake, Keiji Yamada, Panagiotis Demestichas. (2016). “Cloud Internet of Things framework for enabling services in Smart Cities”. Accepted for publication, Springer Book.

[128]. Dimitrios Kelaidonis, Angelos Rouskas, Panagiotis Vlacheas, Vera Stavroulaki, Panagiotis Demestichas. (2016). “A Federated Edge Cloud-IoT Architecture – Enabling semantic-based service provisioning in Future Internet”. Accepted. EUCNC June, 2016, Athens Greece.

[129]. Dimitrios Kelaidonis, Angelos Rouskas, Panagiotis Vlacheas, Vera Stavroulaki, Panagiotis Demestichas. (2016). “Federated Edge Cloud Internet of Things Architecture over 5G infrastructures”. Submitted to Communications Magazine, IEEE, Feature Topic: Impact of next-generation mobile technologies on IoT-Cloud convergence, April, 2016.

[130]. P. Vlacheas, V. Stavroulaki, A. Georgakopoulos, D. Kelaidonis, K. Moessner, A. Rahim, Y. Miyake, S. Kiyomoto, K. Yamada, K. Hashimoto. "An overview and main benefits of an Intelligent Knowledge-as-a-Service Platform". (2015). Accepted. 34th WWRF meeting. Santa Clara, California, US.

[131]. P. Vlacheas, V. Stavroulaki, A. Georgakopoulos, D. Kelaidonis, K. Moessner, A. Rahim, Y. Miyake, S. Kiyomoto, K. Yamada, K. Hashimoto. "An overview and main benefits of an Intelligent Knowledge-as-a-Service Platform". (2015). Submitted to IEEE VTM Journal 2015.

[132]. K. Hashimoto, K. Yamada, K. Tabata, M. Oda, T. Suganuma, A. Rahim, P. Vlacheas, V. Stavroulaki, D. Kelaidonis, A. Georgakopoulos. "iKaaS Data Modeling: A Data Model for Community Services and Environment Monitoring in Smart City". (2015). Accepted. 3rd International Workshop On Self-Aware Internet-of-Things 2015 (Self-IoT 2015). Grenoble, France.

[133]. K. Hashimoto, K. Yamada, K. Tabata, M. Oda, T. Suganuma, A R. Biswas, P. Vlacheas, V. Stavroulaki, D. Kelaidonis, A. Georgakopoulos. (2015). “3D Geospatial Definition of Smart City and its Data Model for Community Services”, submitted to IEEE BIOT 2015.

[134]. FP7 EU Project. eXperimental Infrastructures for the Future Internet – FI-XiFi. Grant Agreement No.: 604590. [Online]: https://www.fi-xifi.eu/.

[135]. Dimitris Kelaidonis, Kostas Tsagkaris, Panagiotis Demestichas. (December, 2014). "Enabling experimentation on building and traffic management through the XiFi node of the University of Piraeus". Available online at: https://blog.fi-xifi.eu/wp-content/uploads/2014/09/TNS_XiFi_Node.pdf.

[136]. P. Demestichas, K. Tsagkaris, D. Kelaidonis, A. Georgakopoulos. (2015). "Leveraging XIFI for conducting experimentally-driven research on 5G". Newsletter. Available online at: https://blog.fi-xifi.eu/wp-content/uploads/2015/01/XIFI-Newsletter-UPRC-20150112a.pdf.

[137]. Dimitris Kelaidonis, Aristi Galani, Marios Logothetis, Panagiotis Demestichas. (2015). Presentation. Title: "Towards a Cognitive Internet of Things: From lab experiments to small scale pilots; Experience from the iCore and XiFi projects". Event: "Telecommunication Networks & integrated Services (TNS) Node in Piraeus: Capabilities & Prospects". University of Piraeus. Event Programme: http://tns.ds.unipi.gr/tns/multi/ProgrammeXIFIevent_eng.pdf.

[138]. Dimitris Kelaidonis. (2015). "Towards a Cognitive Internet of Things: From lab experiments to small scale pilots; Experience from the iCore and XiFi projects". Event: «RFID και Internet of Things - Παραδείγματα και Επιχειρηματική Αξιοποίησης». Organized by: Εργαστήριο Ηλεκτρονικού Επιχειρείν και Εμπορίου (ELTRUN) – Οικονομικό Πανεπιστήμιο Αθηνών. Event Programme: http://www.eltrun.gr/wp-content/uploads/2015/03/%CE%95%CE%BA%CE%B4%CE%AE%CE%BB%CF%89%CF%83%CE%B7-RFID-IOT-31-March-2015-Final-Program-2.pdf.

[139]. Web Server Load-Balancing with HAProxy on Ubuntu 14.04. (2016). [Online]: https://www.howtoforge.com/tutorial/ubuntu-load-balancer-haproxy/.

9 APPENDIX B - ACRONYMS

Acronym	Explanation
A	
AAI	Ambient Assisted Intelligence
ACK	Acknowledgement
ADI	Active Digital Identities
API	Application Programming Interface
B	
BE	Back-End
BGP	Basic Graph Pattern
C	
CBDM	Cloud-based design manufacturing
CMA	Cloud-based Mobile Augmentation
CMfg	Cloud manufacturing
CoT	Cloud of Things
CRAN	Cloud-RAN
CRUD	Create Read Update Delete
CVO	Composite Virtual Object
D	
DaaS	Discovery-as-a-Service

E	
-	
F	
FE	Front-End
G	
GC	Global Cloud
GSC	Global Service Catalogue
H	
H2M	Human-to-Machine
HA	High Availability
HDFS	Hadoop Distributed File System
HTTP	Hypertext Transfer Protocol
I	
ICT	Information and Communication Technology
IETF	Internet Engineering Task Force
IoT	Internet of Things
IP	Internet Protocol
IT	Information Technology
J	
JSON	JavaScript Object Notation
K	

KW	Knowledge
L	
LC	Local Cloud
LSC	Local Service Catalogue
M	
M2M	Machine-to-Machine
MSC	Message Sequence Chart
N	
-	
O	
OWL	Web Ontology Language
P	
-	
Q	
QoE	Quality-of-Experience
QoS	Quality-of-Service
R	
RAN	Radio Access Network
RBAC	Role Based Access Control
REST	Representational State Transfer
RFID	Radio Frequency Identification

RDF	Resource Description Framework
RDFS	Resource Description Framework Schema
S	
SoA	Service Oriented Architecture
SPO	Subject-Object-Predicate
SW	Software
T	
-	
U	
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
V	
VD	Virtual Device
VDI	Versatile Digital Item
VE	Virtual Entity
VIDs	Virtual Identities
VO	Virtual Object
VODB	Virtual Object Data Base
VSN	Virtual Sensor Networks
VT	Virtual Thing
W	

WS	Web Service
WSN	Wireless Sensor Network
X	
XML	eXtensible Markup Language
Y	
-	
Z	
-	

10 APPENDIX C – LIST OF PUBLICATIONS

Short CV	
Mr. Dimitris Kelaidonis was born in Sykea Fokidos, Greece in 1986. He has received the Diploma and Master Degree in Digital Systems, from the University of Piraeus in 2008 and 2010, respectively. Since September 2011 he is research engineer at the University of Piraeus, Laboratory of Telecommunication Networks and Services, in the area of Semantic Technologies for Future Networks. He has been involved in different research EU-funded FP7/ICT Projects, including "Internet Connected Objects for Reconfigurable Ecosystems" (iCore) and "eXperimental Infrastructures for the Future Internet" (XiFi). Moreover, he was involved in "smART Energy Management of wIreless technologies" (ARTEMIS) Greece-China Collaborative Project, as well as in eScience Project funded by GRNET. His main interests include the design and the development of Cloud-based Internet of Things infrastructures with particular focus on the semantics and storage management systems for the enhancement of machine-to-machine communications in the Future Internet era.	
Book Chapters	
1.	Dimitrios Kelaidonis, Panagiotis Vlacheas, Vera Stavroulaki, Stylianos Georgoulas, Klaus Moessner, Yuichi Hashi, Kazuo Hashimoto, Yutaka Miyake, Keiji Yamada, Panagiotis Demestichas. (2016). "Cloud Internet of Things framework for enabling services in Smart Cities". Springer Book.
2.	V. Foteinos, D. Kelaidonis, G. Poulios, V, Stavroulaki, P. Vlacheas, P. Demestichas, R. Giaffreda, A. R. Biswas, S. Menoret, G. Nguengang, M. Etelapera, N. Septimiu-Cosmin, M. Roelands, F. Visintainer, and K. Moessner, "A Cognitive Management Framework for Empowering the Internet of Things", Future Internet Assembly 2013: Validated Results and New Horizons, A. Galis and A. Gavras (Eds.): FIA 2013, LNCS 7858, pp. 187-199, 2013, Book Chapters.
Journal Publications	
1.	Dimitrios Kelaidonis, Angelos Rouskas, Panagiotis Vlacheas, Vera Stavroulaki,

	Panagiotis Demestichas. (2016). "Federated Edge Cloud Internet of Things Architecture over 5G infrastructures". Submitted to Communications Magazine, IEEE, Feature Topic: Impact of next-generation mobile technologies on IoT-Cloud convergence, April, 2016.
2.	Vassilis Foteinos, Dimitris Kelaidonis, George Poulios, Panagiotis Vlacheas, Vera Stavroulaki, and Panagiotis Demestichas. (2013). "Cognitive management for the Internet of things: A framework for enabling autonomous applications". Vehicular Technology Magazine, IEEE, 8(4), 90-99.
3.	Panagiotis Vlacheas, Raffaele Giaffreda, Vera Stavroulaki, Dimitris Kelaidonis, Vassilis Foteinos, George Poulios, Panagiotis Demestichas, Andrey Somov, Abdur R. Biswas, and Klaus Moessner. (2013). "Enabling smart cities through a cognitive management framework for the internet of things". Communications Magazine, IEEE, 51(6), 102-111.
Conference Publications	
1.	Dimitrios Kelaidonis, Angelos Rouskas, Panagiotis Vlacheas, Vera Stavroulaki, Panagiotis Demestichas. (2016). "A Federated Edge Cloud-IoT Architecture – Enabling semantic-based service provisioning in Future Internet". Accepted. EUCNC June, 2016, Athens Greece.
2.	Dimitris Kelaidonis, et al. (2016). "Self-Organizing Virtual Devices in the Internet of Things Networks". Accepted. IISA 2016, 13-15 July, 2016, Chalkidiki Greece.
3.	Panagiotis Vlacheas, Vera Stavroulaki, Andreas Georgakopoulos, Dimitrios Kelaidonis, Panagiotis Demestichas, Klaus Moessner, Stylianos Georgoulas, Yuichi Hashi, Yutaka Miyake, Shinsaku Kiyomoto, Keiji Yamada, Kazuo Hashimoto. (October 2015). "Enhanced Architecture of an Intelligent Knowledge-as-a-Service Platform", paper and presentation at WWRF 35th Meeting, 14-16, Copenhagen, Denmark.
4.	P. Vlacheas, V. Stavroulaki, A. Georgakopoulos, D.Kelaidonis, A. R. Biswas, K. Moessner, Y. Miyake, S. Kiyomoto, K. Yamada, K. Hashimoto. (2015). "An

	overview and main benefits of an Intelligent Knowledge-as-a-Service Platform", paper and presentation at WWRF 34th Meeting 21st – 23rd April 2015 Santa Clara, California, USA.
5.	Fujiwara, Y., Yamada, K., Tabata, K., Oda, M., Hashimoto, K., Suganuma, T., Rahim, A., Vlacheas, P., Stavroulaki, V., Kelaidonis, D. and Georgakopoulos, A. (July, 2015). "Context Aware Services: A Novel Trend in IoT Based Research in Smart City Project". In Computer Software and Applications Conference (BIoT2015 COMPSAC), 2015 IEEE 39th Annual (Vol. 3, pp. 479-480). IEEE.
6.	Kelaidonis, Dimitris, et al. (2014, August). "Smart energy management of wireless technologies and mobile applications". In Wireless Communications Systems (ISWCS), 2014 11th International Symposium on (pp. 848-852). IEEE.
7.	V. Foteinos, D. Kelaidonis, G. Poulios, P. Vlacheas, V. Stavroulaki, P. Demestichas, "A Cognitive Management Framework for Service Provisioning in the Internet of Things", in Proc. 22nd Future Network and Mobile Summit (FNMS) 2013, Lisbon, Portugal, 03-05 July, 2013, (Runner-up Paper Award), International Conference Papers.
8.	Kelaidonis, Dimitris, et al. (2013). "A cognitive management framework for smart objects and applications in the internet of things". In Mobile Networks and Management (pp. 196-206). Springer Berlin Heidelberg.
9.	Kelaidonis, Dimitris, et al. (2012, November). "Virtualization and cognitive management of real world objects in the internet of things". In Green Computing and Communications (GreenCom), 2012 IEEE International Conference on the Internet of Things (pp. 187-194). IEEE.
Workshop Publications	
1.	K. Hashimoto, K. Yamada, K. Tabata, M. Oda, T. Suganuma, A. Rahim, P. Vlacheas, V. Stavroulaki, D. Kelaidonis, A. Georgakopoulos. "iKaaS Data Modeling: A Data Model for Community Services and Environment Monitoring in Smart City". (2015). Accepted. 3rd International Workshop On

	Self-Aware Internet-of-Things 2015. Grenoble, France.
2.	Ayaka Nishiwaki, Kazuo Hashimoto, Keiji Yamada, Kenichi Tabata, Michio Oda, Abdur Rahim, Panagiotis Vlacheas, Vera Stavroulaki, Dimitrios Kelaidonis, Andreas Georgakopoulos. (2015). "3D Geospatial Definition of Smart City and its Data Model for Community Services (in Japanese)", Proc. of the 14th Forum on Information Technology, September 2015, Ehime, Japan.
3.	Tilanus, Paul, Ran, Bob, Faeth, Matthias, Kelaidonis, Dimitris, & Stavroulaki, Vera. (2013, June). "Virtual object access rights to enable multi-party use of sensors". In World of Wireless, Mobile and Multimedia Networks (WoWMoM), 2013 IEEE 14th International Symposium and Workshops on a (pp. 1-7). IEEE.
Newsletter Publications	
1.	P. Demestichas, K. Tsagkaris, D. Kelaidonis, A. Georgakopoulos. (2015). "Leveraging XIFI for conducting experimentally-driven research on 5G". Newsletter. [Online]: https://blog.fi-xifi.eu/wp-content/uploads/2015/01/XIFI-Newsletter-UPRC-20150112a.pdf.
2.	Dimitris Kelaidonis, Kostas Tsagkaris, Panagiotis Demestichas. (2014, December). "Enabling experimentation on building and traffic management through the XiFi node of the University of Piraeus". [Online]: https://blog.fi-xifi.eu/wp-content/uploads/2014/09/TNS_XiFi_Node.pdf.
Software Prototypes	
1.	Dimitris Kelaidonis, Vera Stavroulaki, Panagiotis Vlacheas. (2014, November). Software Prototype. IoT Open Platforms. iCore – Virtual Object Registry API. [Online]: http://open-platforms.eu/standard_protocol/icore-virtual-object-registry-api/.