UNIVERSITY OF PIRAEUS **ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ**

ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ

ΑΞΙΟΛΟΓΗΣΗ ΕΠΙΔΟΣΗΣ ΚΑΙ ΕΞΑΓΩΓΗ ΠΟΛΙΤΙΚΩΝ ΓΙΑ ΕΛΕΓΧΟΜΕΝΑ ΑΠΟ ΤΟΝ ΠΑΡΟΧΟ ΕΥΚΑΙΡΙΑΚΑ ΔΙΚΤΥΑ ΣΤΟ ΜΕΛΛΟΝΤΙΚΟ ΔΙΑΔΙΚΤΥΟ

Μάριος Μ. Λογοθέτης
Πτυχιούχος και Κάτοχος Μεταπτυχιακού τίτλου σπουδών
Τμήματος Ψηφιακών Συστημάτων Πανεπιστημίου Πειραιώς

Πειραιάς, 2012

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ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

PhD Dissertation

Performance Evaluation and Policy Derivation for Operator-governed Opportunistic Networks in the Future Internet

Marios M. Logothetis

B.Sc., M.Sc., University of Piraeus

Department of Digital Systems

Piraeus, 2012

ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

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Συμβουλευτική Επιτροπή: *Π. Δεμέστιχας, Καθηγητής Παν. Πειραιώς*
Μ. Θεολόγου, Καθηγητής ΕΜΠ
Γ. Ευθύμογλου, Αναπ. Καθηγητής Παν. Πειραιώς

Εγκρίθηκε από την επταμελή Εξεταστική Επιτροπή την 16η Οκτωβρίου 2013,

Π. Δεμέστιχας Καθηγητής Πανεπιστημίου Πειραιώς	**Μ. Θεολόγου** Καθηγητής ΕΜΠ	**Γ. Ευθύμογλου** Αναπληρωτής Καθηγητής Πανεπιστημίου Πειραιώς
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Γ. Βούρος Καθηγητής Πανεπιστημίου Πειραιώς		**Α. Ρούσκας** Αναπληρωτής Καθηγητής Πανεπιστημίου Πειραιώς

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Μάριος Μ. Λογοθέτης

Πτυχιούχος και Κάτοχος Μεταπτυχιακού τίτλου Σπουδών

Τμήματος Ψηφιακών Συστημάτων Πανεπιστημίου Πειραιώς

Μάριος Μ. Λογοθέτης, 2012.

Με επιφύλαξη παντός δικαιώματος.

Απαγορεύεται η αντιγραφή, αποθήκευση και διανομή της παρούσας εργασίας εξ' ολοκλήρου ή τμήματος αυτής, για εμπορικό σκοπό. Επιτρέπεται η ανατύπωση, αποθήκευση και διανομή για σκοπό μη κερδοσκοπικό, εκπαιδευτικής ή ερευνητικής φύσης, υπό την προϋπόθεση να αναφέρεται η πηγή προέλευσης και να διατηρείται το παρόν μήνυμα. Ερωτήματα που αφορούν τη χρήση της εργασίας για κερδοσκοπικό σκοπό πρέπει να απευθύνονται προς τον συγγραφέα.

Οι απόψεις και τα συμπεράσματα που περιέχονται σε αυτό το έγγραφο εκφράζουν τον συγγραφέα και δεν πρέπει να ερμηνευθεί ότι αντιπροσωπεύουν τις επίσημες θέσεις του Πανεπιστημίου Πειραιώς.

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....
Marios M. Logothetis
B.Sc., M.Sc., University of Piraeus,
Department of Digital Systems

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The concepts and conclusions included in this work express the author's personal opinion and should not be interpreted that they represent University of Piraeus official concepts.

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ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

ABSTRACT

Over the last 30 years the Internet has change radically our economy and society. Thereby from an academic network used by a few people in the early 1980s, the Internet became a truthfully worldwide open network for information, communication and commerce. In the light of the rapid spread of technology, particularly broadband networks and mobile communications, the Internet has become a central part of our lives in all sorts of ways and has also replaced traditional channels in many activities between people. The Internet has become a driver of 21st century society.

In the near future, the Internet will probably set the networks under stress for resources. In the scope of the Future Internet (FI), new applications, services and content will require a truly ubiquitous network capacity, capable of handling the amplified data traffic volumes transmitted by internet enabled devices. At the same time these new applications are going to be accessed at any time of a day, will be requested from all types of locations and environments and finally will have to be delivered meeting a set of QoS. On the other hand the number of broadband users around the world seems to explode dramatically, leading also to the increase of the total amount of energy consumption. Such a challenging landscape in the area of wireless/mobile networks motivates the quest for more flexible networking paradigms that will offer increased efficiency in resource utilization and application QoS provisioning and at the same time exhibit lower transmission powers and energy consumption, thus achieving “green” targets. Framed within above, this dissertation presents an approach for addressing and providing solutions for the aforementioned issues.

The proposed solution is based on dynamically created, operator-governed and coordinated, temporary infrastructure-less extensions of the infrastructure, called Opportunistic Networks (ONs). ONs are governed by operators through the provision of policies, e.g. upon resource usage, as well as context/profile information and knowledge, which is exploited for their creation and maintenance. They are dynamically created in places and at the time they are needed to deliver application flows to mobile users. Moreover, they comprise various devices/terminals, potentially organized in an ad hoc mode, as well as elements of the infrastructure itself. Due to the highly dynamic nature

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of the environment, including traffic and applications issues, as well as the potential complexity of the infrastructure, a solution that incorporates self-management and learning mechanisms are deemed essential. In this respect, Cognitive Management Systems (CMSs), rendering both self-management and learning capabilities seem appropriate for ensuring the fast and reliable establishment of ONs. In the context of this dissertation and in order to meet the requirements, for improved efficiency in resource provisioning and providing users with high quality services anytime, anywhere through the combination of ONs and CMSs, a new Functional Architecture (FA) for the management and control of the ONs is proposed.

Considering the above, in this dissertation is presented the performance evaluation of ONs as an extension to the infrastructure network in various scenarios. Particularly, the investigation under which circumstances (why, where and when) the creation of an ON will be beneficiary for the overall network is presented in certain scenarios. This is actually done by recognizing that the first step prior to proceeding with the establishment of an ON is to be able to judge the suitability of doing so. The study is mainly based on extensive network simulations, with the intention to cover a large gamut of cases in order to increase the validity of the finally extracted conclusions and recommendations. Eventually, it is presented the process of the properly exploitation of the extracted simulation results so as to derive policies that can be used by the operator of the wireless infrastructure to control the decision upon forming the ONs, while in operation or even in a proactive manner.

Keywords: Future Internet, Opportunistic Networks, Cognitive Management Systems, Functional Architecture, Network Simulations, Suitability Determination, Policy Derivation

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ΠΕΡΙΛΗΨΗ

Τα τελευταία 30 χρόνια το Διαδίκτυο έχει αλλάξει ριζικά την οικονομία και την κοινωνία μας. Έτσι από ένα ακαδημαϊκό δίκτυο που χρησιμοποιούταν από μερικούς ανθρώπους στις αρχές του 1980, το Διαδίκτυο έγινε ένα παγκόσμιο ανοικτό δίκτυο για την πληροφόρηση, την επικοινωνία και το εμπόριο. Υπό το πρίσμα της ταχείας εξάπλωσης της τεχνολογίας, ιδιαίτερα των ευρυζωνικών δικτύων και των κινητών επικοινωνιών, το Διαδίκτυο έγινε βασικό κομμάτι της ζωής μας με κάθε τρόπο και αντικατέστησε τα παραδοσιακά κανάλια επικοινωνίας των ανθρώπων σε πολλές δραστηριότητες. Το Διαδίκτυο έγινε η κινητήρια δύναμη της κοινωνίας του 21ου αιώνα.

Στο άμεσο μέλλον, το Διαδίκτυο θα πιέσει πιθανώς τα δίκτυα για επιπλέον πόρους. Στα πλαίσια του Μελλοντικού Διαδικτύου, νέες εφαρμογές, υπηρεσίες και περιεχόμενο θα απαιτήσουν ένα πραγματικά πανταχού παρόν δίκτυο, που θα είναι σε θέση να χειρίζεται τον μεγάλο όγκο της κίνησης των δεδομένων που μεταδίδονται από τις συσκευές που συνδέονται σε αυτό. Ταυτόχρονα, οι νέες αυτές εφαρμογές θα πρέπει να μπορούν να προσπελαστούν οποιαδήποτε στιγμή της ημέρας, να ζητηθούν από διαφορετικές τοποθεσίες και περιβάλλοντα και τέλος να εξασφαλίζεται η ποιότητα των παρεχόμενων αυτών υπηρεσιών. Από την άλλη πλευρά, ο αριθμός των ευρυζωνικών χρηστών σε όλο τον κόσμο φαίνεται να μεγαλώνει δραματικά, οδηγώντας στην αύξηση της συνολικής ποσότητας της κατανάλωσης της ενέργειας. Αυτή η όλο και πιο απαιτητική κατάσταση στο χώρο των ασύρματων/κινητών δικτύων ωθεί στην αναζήτηση πιο ευέλικτων προτύπων δικτύωσης που θα προσφέρουν μεγαλύτερη αποτελεσματικότητα στη χρησιμοποίηση των πόρων και στην παροχή υπηρεσιών υψηλής ποιότητας και την ίδια στιγμή να εμφανίζουν χαμηλότερη ισχύ μετάδοσης και μείωση στην κατανάλωση της ενέργειας, επιτυγχάνοντας έτσι «πράσινους» στόχους. Έχοντας υπόψη όλα τα παραπάνω, η διατριβή αυτή παρουσιάζει μια προσέγγιση για την αντιμετώπιση και την παροχή λύσεων για τα προαναφερθέντα θέματα.

Η προτεινόμενη λύση βασίζεται σε δίκτυα που δημιουργούνται δυναμικά, ελέγχονται και συντονίζονται από τον πάροχο, είναι προσωρινές επεκτάσεις της υποδομής και ονομάζονται Ευκαιριακά Δίκτυα (Opportunistic Networks). Τα Ευκαιριακά Δίκτυα ελέγχονται από τους παρόχους μέσω της διάθεσης πολιτικών (policies), π.χ. για την

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χρήση των πόρων, καθώς και από την πληροφορία του πλαισίου λειτουργίας (context), του προφίλ και της γνώσης, τα οποία αξιοποιούνται για τη δημιουργία και τη συντήρηση τους. Δημιουργούνται δυναμικά σε τοποθεσίες και όταν χρονικά απαιτούνται, για να παρέχουν τις υπηρεσίες στους χρήστες. Επιπλέον, αποτελούνται από διάφορες συσκευές/τερματικά, συνδεδεμένα ενδεχομένως με ad-hoc τρόπο μεταξύ τους, καθώς και με στοιχεία της ίδιας της υποδομής. Λόγω του ιδιαίτερα δυναμικού χαρακτήρα του περιβάλλοντος, συμπεριλαμβανομένων ζητημάτων κίνησης και εφαρμογών, καθώς και την πιθανή πολυπλοκότητα της υποδομής, μια λύση που ενσωματώνει μηχανισμούς αυτοδιαχείρισης και μάθησης κρίνεται απαραίτητη. Από αυτή την άποψη, τα Γνωσιακά Συστήματα Διαχείρισης (Cognitive Management Systems), προσφέροντας δυνατότητες αυτοδιαχείρισης και μάθησης θεωρούνται κατάλληλα για να εξασφαλίσουν μια γρήγορη και αξιόπιστη εγκατάσταση των Ευκαιριακών Δικτύων. Στο πλαίσιο αυτής της διατριβής και προκειμένου να ικανοποιηθούν οι απαιτήσεις για βελτιωμένη αποδοτικότητα στην παροχή πόρων και παροχή υπηρεσιών υψηλής ποιότητας στους χρήστες ανά πάσα στιγμή και οπουδήποτε, μέσω του συνδυασμού των Ευκαιριακών Δικτύων και των Γνωσιακών Συστημάτων Διαχείρισης προτείνεται μια νέα Αρχιτεκτονική Λειτουργιών (Functional Architecture) για τη διαχείριση και τον έλεγχο των δικτύων αυτών.

Λαμβάνοντας υπόψη τα παραπάνω, σε αυτή την διατριβή παρουσιάζεται η αξιολόγηση της απόδοσης των Ευκαιριακών Δικτύων ως επέκταση του δικτύου υποδομής σε διάφορα σενάρια. Συγκεκριμένα, γίνεται μελέτη για τις συνθήκες (γιατί, που και πότε) κάτω από τις οποίες μπορούν να δημιουργηθούν τα Ευκαιριακά Δίκτυα ώστε να υπάρχει γενικό όφελος για το σύνολο του δικτύου. Αυτό στην πραγματικότητα γίνεται αναγνωρίζοντας ότι το πρώτο βήμα πριν από τη διαδικασία της δημιουργίας ενός Ευκαιριακού Δικτύου είναι ο προσδιορισμός της καταλληλότητας. Η έρευνα βασίζεται κυρίως σε εκτεταμένες προσομοιώσεις του δικτύου, με σκοπό να καλύψει ένα μεγάλο φάσμα των περιπτώσεων, προκειμένου να αυξηθεί η εγκυρότητα των τελικών εξαγόμενων συμπερασμάτων και συστάσεων. Τέλος, παρουσιάζεται η διαδικασία της κατάλληλης εκμετάλλευσης των αποτελεσμάτων της προσομοίωσης, για την εξαγωγή των πολιτικών που θα χρησιμοποιηθούν από τον πάροχο της ασύρματης υποδομής για να ελέγξει την απόφαση για την δημιουργία των Ευκαιριακών Δικτύων, την ώρα της λειτουργίας ή και εκ των προτέρων.

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Λέξεις – Κλειδιά: Μελλοντικό Διαδίκτυο, Ευκαιριακά Δίκτυα, Γνωσιακά Συστήματα Διαχείρισης, Αρχιτεκτονική Λειτουργιών, Προσομοιώσεις Δικτύων, Προσδιορισμός Καταλληλότητας, Εξαγωγή Πολιτικών

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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 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 supervisor, Professor Panagiotis Demestichas, whose dedication to this dissertation and my research work, as well as his academic experience have been invaluable to me during the accomplishment of this effort. He also encouraged me psychologically in difficult and challenging moments during the implementation of this project. In every sense, none of this work would have been possible without his presence. Moreover, I would like to thank co-supervisors and all my professors of the Department who supported me and advised me at every stage of my studies.

I am also grateful for the support of Assistant Professor Vera Stavroulaki and Adjunct Lecturer Kostas Tsagkaris, whose excellent cooperation was invaluable to the completion of this dissertation. As well as Dr. George Dimitrakopoulos, Dr. Aggelos Saatsakis, Dr. Apostolos Katidiotis and Dr. Yiouli Kritikou, 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

Marios M. Logothetis

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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 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 στον επιβλέποντα μου, Καθηγητή Παναγιώτη Δεμέστιχα, του οποίου η αφοσίωση του στη παρούσα διατριβή και το ερευνητικό μου έργο, καθώς και η ακαδημαϊκή του εμπειρία του ήταν πολύτιμη για μένα κατά τη διάρκεια της υλοποίησης αυτής της προσπάθειας. Εκείνος με ενθάρρυνε επίσης ψυχολογικά σε δύσκολες και απαιτητικές στιγμές κατά τη διάρκεια της υλοποίησης του έργου αυτού. Τίποτα δε θα ήταν δυνατό χωρίς την παρουσία του. Επιπλέον, θα ήθελα να ευχαριστήσω τους συνεπιβλέποντες και όλους τους καθηγητές του Τμήματός μου, οι οποίοι με στήριξαν και με συμβούλεψαν σε κάθε στάδιο των σπουδών μου.

Είμαι επίσης ευγνώμων για την υποστήριξη και θα ήθελα να ευχαριστήσω τους Βέρα Σταυρουλάκη και Κώστα Τσαγκάρη, των οποίων η εξαιρετική συνεργασία μας υπήρξε πολύτιμη για την ολοκλήρωση αυτής της διατριβής. Καθώς και τους Δρ. Γιώργο Δημητρακόπουλο, Δρ. Άγγελο Σαατσάκη, Δρ. Απόστολο Κατιδιώτη και Δρ. Γιούλη Κρητικού, 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

Μάριος Μ. Λογοθέτης

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"Λες: Πολύ καιρό αγωνίστηκες. Δεν μπορείς άλλο πια ν' αγωνιστείς.

Άκου λοιπόν: Είτε φταις είτε όχι: Σαν δε μπορείς άλλο να παλέψεις, θα πεθάνεις.

Λες: Πολύ καιρό έλπιζες. Δεν μπορείς άλλο πια να ελπίσεις.

Έλπιζες τι; Πως ο αγώνας θαν' εύκολος;

Δεν είν' έτσι. Η θέση μας είναι χειρότερη απ' όσο νόμιζες.
Είναι τέτοια που: Αν δεν καταφέρουμε το αδύνατο Δεν έχουμε ελπίδα.
Αν δεν κάνουμε αυτό που κανείς δεν μπορεί να μας ζητήσει Θα χαθούμε.

Οι εχθροί μας περιμένουν να κουραστούμε.

Όταν ο αγώνας είναι στην πιο σκληρή καμπή του.
Οι αγωνιστές έχουν την πιο μεγάλη κούραση.
Οι κουρασμένοι, χάνουν τη μάχη."

Μπέρτολτ Μπρεχτ

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1. INTRODUCTION

1.1. Research Area

1.1.1. Motivation

Undoubtedly, the vision of Future Internet (FI) seems to drive the research in many aspects of today's Information and Communication Technologies (ICT) [1]. One of the great promises that FI needs to fulfil so as to live up to its potential, is the efficient provisioning of modern types of applications. Current Internet seems to strain under the advent of rich multimedia content and new mobile applications. Traditional applications such as file-transfer, e-mail, media streaming etc. will be extended by far richer and bandwidth "hungrier" multimedia content applications.

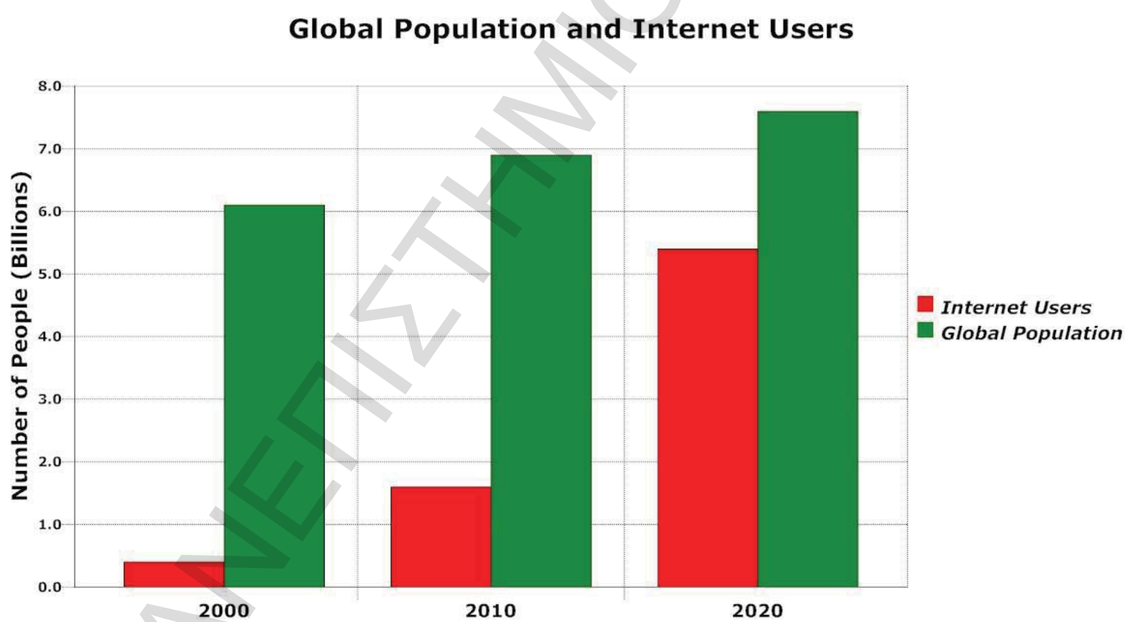

Figure 1-1: Global population and Internet Users, [2000-2020]

At the same time all these applications are going to be accessed at any time of a day, will be requested from all types of locations/environments (e.g., home, public, work, urban, rural, etc.) or by all types of communication end-points (e.g., machines, humans acting in different roles, namely in-work or private life), and will involve all various information flows (voice, audio, data, images, video) and communication types (uni-cast, multicast, broadcast, peer-to-peer).

Moreover, these will have to be delivered meeting a set of Quality of Service (QoS) levels, or at least guaranteeing a certain Quality of Experience (QoE), thus opposing to the well-known “Best Effort” delivery model of the Internet. Furthermore, the above applications will be used by far more people and from more dispersed geographical areas according to expectations for the Internet usage by 2020.

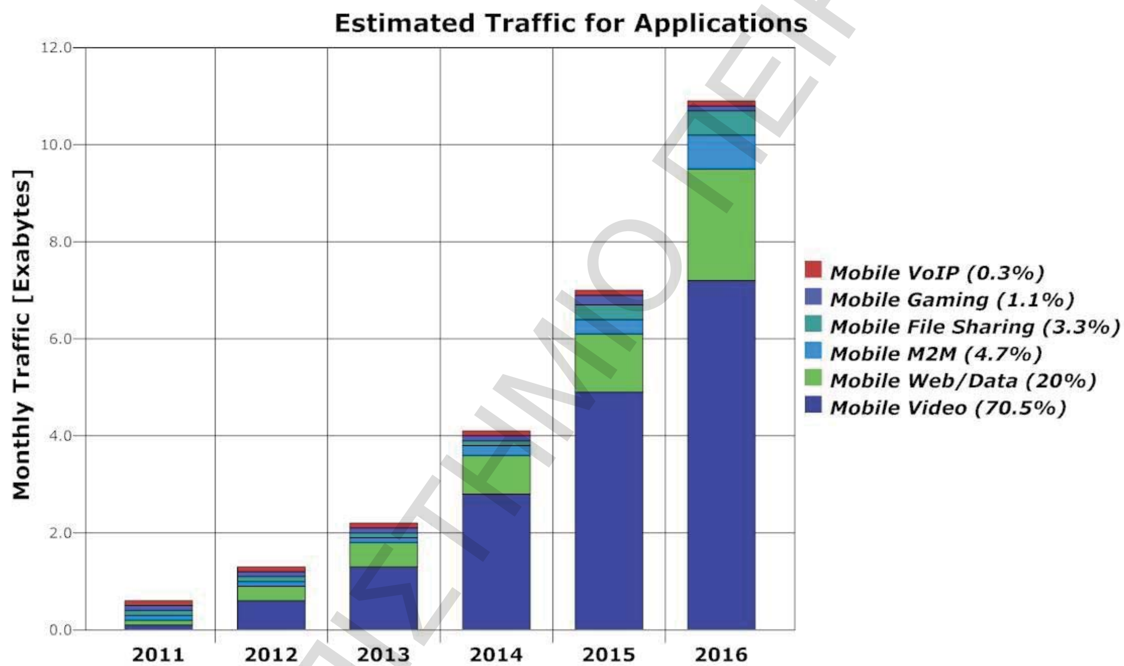

Figure 1-2: Estimated Traffic and Applications, [2011-2016]

Specifically and considering the above statements, the prediction is that the Internet will have nearly 5 billion users by 2020, as also depicted in Figure 1-1 [2],[3]. This will result in more application (deployment) areas, wherein the FI will penetrate and provide increasingly modern information and communication services e.g. services built around social network concepts. Moreover the growth of applications that need more data, more connectivity and more bandwidth show no signs of slowing, as also depicted in Figure 1-2. For the first time, due to the increase in connectivity and phones capable of

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video viewing, video accounted for over half of all traffic (52%) in 2012. By 2016, video will be over 70% of traffic [4].

Furthermore the internet operations/applications will affect the data/control traffic load, leading to the increase of the total amount of energy consumption, which is escalating rapidly. Specifically, due to the increased energy prices, the growth of costumer population and the expanding number of services being offered by operators and Internet Service Providers (ISPs), the energy efficiency issue has become a high-priority objective for the future networks. The continuously rising demands in network energy consumption essentially depend on new services that must be supported by the future infrastructures.

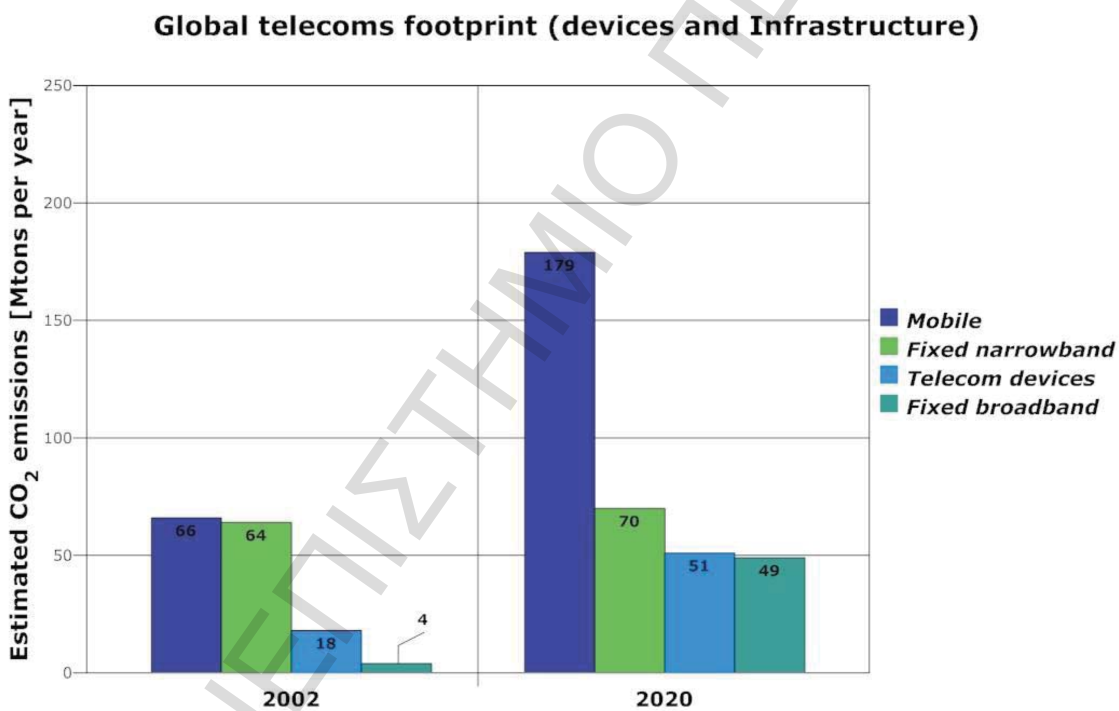

Figure 1-3: Global telecoms footprint [2002 & 2020]

Figure 1-3 depicts the Global e-Sustainability Initiative (GeSI) report [5], for the estimated CO_2 emissions. Particularly, in 2002, network infrastructures for mobile communication and for wired narrowband access caused the most considerable greenhouse contributions, since each of them weighs for more than 40% upon the

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overall network carbon footprint. The estimation for 2020 depicts that mobile communication infrastructures will represent more than 50% of network CO_2 emissions.

On the other hand, the newly coming applications are more likely to be provided in their mobile/wireless manifestation. This has mainly aroused as a result of the expansion in using wireless internet access, and accordingly of the increase of data traffic volumes received/sent by internet enabled mobile devices. In addition, the number of mobile broadband users around the world who are subscribing to 3G, WiMAX and other higher speed data networking technologies (altogether constituting the Beyond-3G (B3G) and 4G wireless networks), seems to explode, and as also predicted and depicted in Figure 1-4, it will reach the remarkable number of 2.5 billion people by 2014. All in all, it is now a quite a common percipience that the "Future Internet will be wireless" [3].

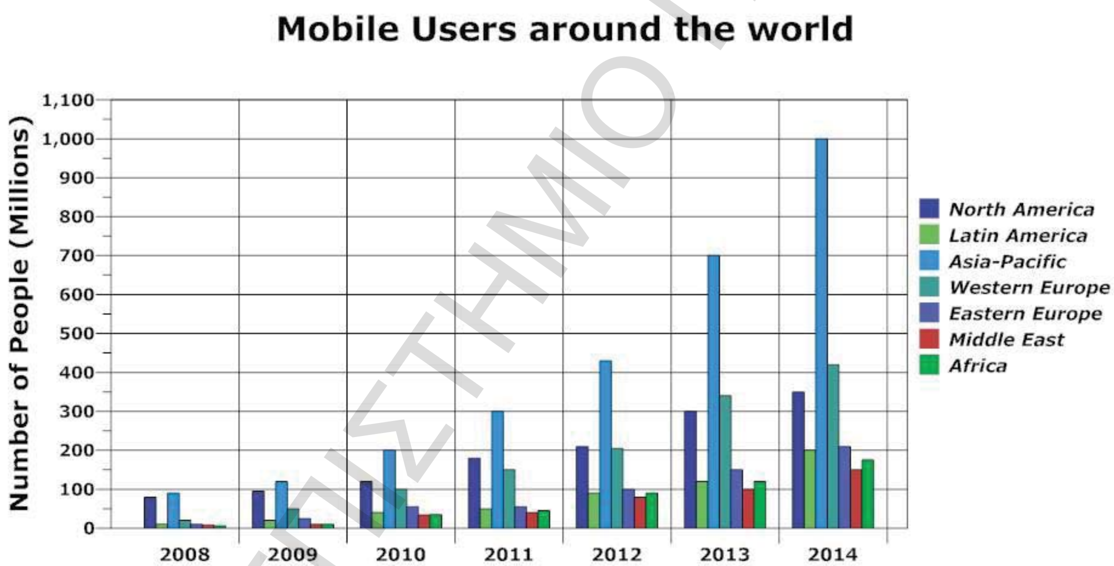

Figure 1-4: Mobile Broadband Users around the World, [2008-2014]

Considering all the above, such an increasingly demanding landscape motivates the quest for technological solutions that will offer increased efficiency in resource provisioning and utilization anywhere and anytime. Efficiency can be generally coupled with targets like:

(i) the higher utilization of resources,

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(ii) the reduction of transmission powers and energy consumption (in general, having decisions with a “green” footprint) or

(iii) the reduction of the total cost of ownership, which will be assumed to comprise the OPerational EXpenditures (OPEX), CApital EXpenditures (CAPEX), and costs associated with the management of customer relations.

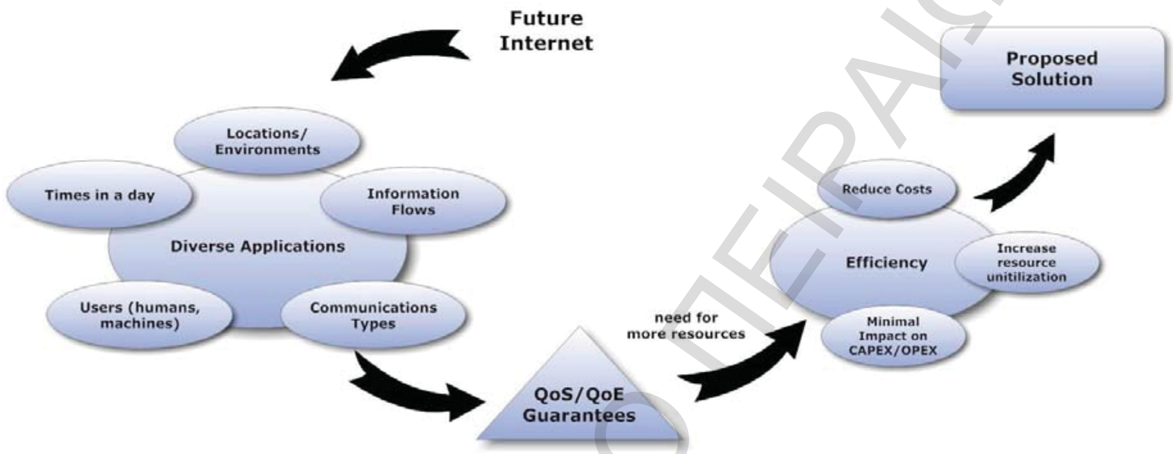

Figure 1-5: Motivation and rationale for Solution

In order to address such stringent requirements for the FI and meet the objectives for increased efficiency in resource provisioning and utilization, a solution is proposed and presented with details in Section 2.2, which is one of the main goals of this dissertation. Figure 1-5 depicts exactly the motivation and rationale for a new solution, considering all the above statements.

1.1.2. Opportunistic Networks and Cognitive Management Systems

Considering the above facts, this demanding landscape motivates the quest for flexible networking paradigms that will offer improved efficiency in resource provisioning and provide user with high Quality of Services (QoS) and at the same time achieving green targets.

Operator-governed Opportunistic Networks (ONs), which are dynamically created, temporary, coordinated extensions of the infrastructure, is a first ingredient for the proposed solution depicted in Figure 1-6. Particularly, ONs are governed by operators through the provision of policies, e.g. upon resource usage, as well as context/profile

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information and knowledge, which is exploited for their creation and maintenance. They are dynamically created in places and at the time they are needed to deliver application flows to mobile users. Moreover, they comprise various devices/terminals, potentially organized in an ad hoc mode, as well as elements of the infrastructure itself. Furthermore the policies are provided by the advanced management plane traversing the infrastructure-based and infrastructure-less segments and are used to decide on the feasibility of the creation of the latter when required, while in operation or even in a proactive manner.

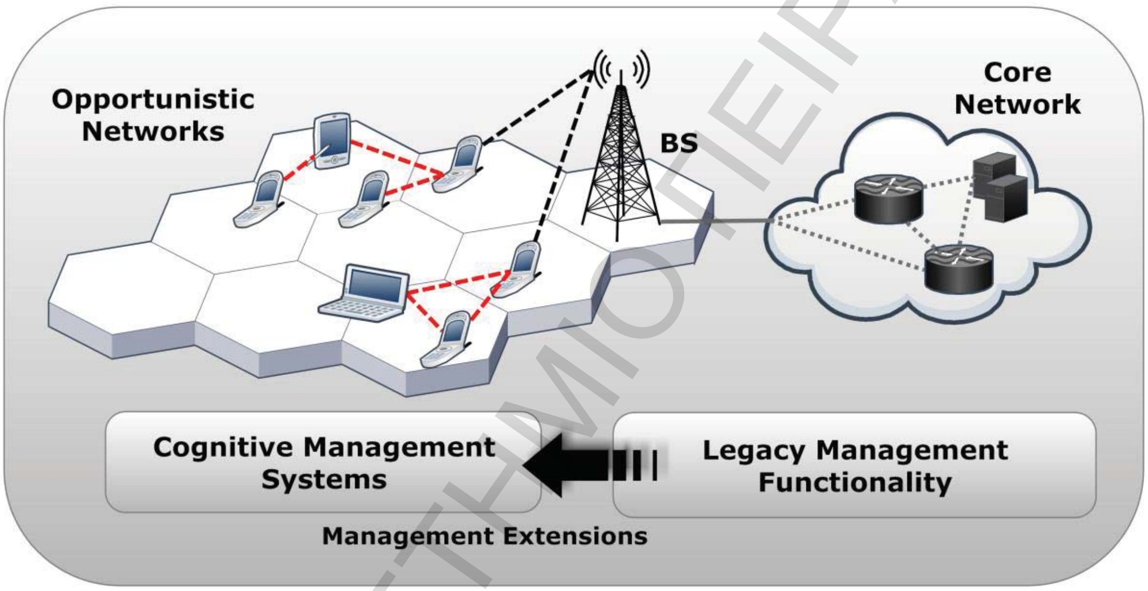

Figure 1-6: Opportunistic Networks and Cognitive Management Systems

Furthermore, because of this dynamic landscape, including traffic and applications issues, as well as the potential complexity of the infrastructure, a network management system which incorporates self-management and learning mechanisms is deemed essential. Self-management enables a system to identify opportunities for improving its performance and adapting its operation without the need for human intervention. Learning mechanisms are important so as to increase the reliability of decision making. Learning mechanisms also enable proactive handling of problematic situations, i.e. identifying and handling issues that could undermine the performance of the system before these actually occur. Moreover the management system should exploit this versatile landscape and should also be performed in a distributed manner, so as to be fast, scalable and reliable.

In this respect, Cognitive Management Systems (CMSs), which comprise self-management and learning capabilities can be exploited for ensuring the fast and reliable establishment of ONs. CMSs can be located in both the network infrastructure and the terminals/devices. Moreover, it is envisaged that control channels will be used for the coordination between CMSs and the exchange of information, knowledge and commands.

1.1.3. Suitability Determination

In the context of the proposed solution, it is advocated that an operator, owning a wireless network infrastructure, can exploit ONs for complementing the infrastructure, e.g., for expanding its coverage or for achieving green targets (less power consumption). Given the existence of opportunities in terms of available nodes and spectrum, the suitability of extending the wireless network infrastructure with an ON can be determined based on parameters such as the involved applications or mobility levels as well as on the anticipated benefits in terms of adequate QoS level provisioning and energy (power) consumption.

Considering the above, in this dissertation is presented the suitability determination of ONs as an extension to the infrastructure network in various scenarios. In particular, the investigation under which circumstances (why, where and when) the creation of an ON will be beneficiary for the overall network is presented in certain scenarios. This is actually done by recognizing that the first step prior to proceeding with the establishment of an ON is to be able to judge the suitability of doing so. The study is mainly based on extensive network simulations, with the intention to cover a large gamut of cases in order to increase the validity of the finally extracted conclusions and recommendations.

Eventually, those recommendations should be used to set up an advanced management plane, to comprise the set of management functions and/or signalling procedures and channels, which are necessary for the integration (communication and coordination) among wireless infrastructure and ONs. In particular the results derived from such simulations can be then utilized to design and develop proper algorithms/strategies for the management entities that will be able to decide on the feasibility of creating the ON when required, while in operation or even in a proactive manner. Finally the decision of the management entities will be provided by means of proper policies, which is also one of the targets of this dissertation.

1.2. Dissertation's Contribution

The dissertation deals with the "*Performance evaluation and policy derivation for Operator governed Opportunistic Networks in the Future Internet*". In this respect, its main contribution can be categorized at the following topics:

- Exploitation of ONs by Composite Wireless Infrastructures
- Suitability Determination of ONs with Application and Mobility aspects
- Policy Derivation based on the suitability determination of ONs

1.2.1. Exploitation of ONs by Composite Wireless Infrastructures

As already described, the boom of new applications and users in the mobile/wireless area will create a challenging landscape that will set the networks under stress for resources. This situation motivates the quest for technological solutions that will offer increased efficiency in resource utilization and application QoS provisioning and at the same time exhibit lower transmission powers and energy consumption, in order to achieve green targets.

The proposed solution considers the possibility of extending the wireless network infrastructure, which is owned by a wireless operator and consists of a set of Radio Access Networks (RANs), by network elements and devices that are organized in an ad-hoc mode and are more local/temporary structures, which can be called Opportunistic Networks. Moreover, because of the highly dynamic nature of the environment, including traffic, mobility and applications issues, as well as the potential complexity of the infrastructure, a solution that incorporates self-management and learning mechanisms are deemed essential. In this respect, CMSs seems appropriate for the

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management of the ONs and for coordinating with the infrastructure, leading to robustness and dependability.

1.2.2. Suitability Determination of ONs with Application and Mobility aspects

In the context of the ON-based solution, the operator of the wireless network infrastructure, can exploit ONs for complementing the infrastructure, e.g., for expanding its coverage or for achieving green targets. Given the existence of opportunities in terms of available nodes and spectrum, the suitability of extending the wireless infrastructure with an ON can be determined based on parameters such as the involved applications or mobility levels as well as on the anticipated benefits in terms of adequate QoS level provisioning and energy consumption.

In this respect, the investigation under which circumstances the creation of such an ON will be beneficiary for the overall network is of paramount importance. In order to perform the suitability determination of ONs, the study is mainly based on extensive network simulations, with the intention to cover a large gamut of cases in order to increase the validity of the finally extracted conclusions and recommendations. The emphasis is mainly given to modern type of applications and the mobility level of the terminals in the simulated area. Actually, the importance of the simulation studies is twofold: a) to shed light in those circumstances under which the creation of ONs should be recommended and b) to use the results in order to design and develop proper strategies/algorithms that will be able to decide on the feasibility of creating the ON when required, while in operation or even in a proactive manner.

1.2.3. Policy Derivation based on the suitability determination of ONs

The suitability of extending the infrastructure with the use of ONs can be determined based on the involved parameters, such as location of the terminal, mobility level, type of applications etc., as well as on the anticipated benefits in terms of adequate QoS level provisioning and energy consumption. Therefore, the decision of the wireless network

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infrastructure to create or not such an ON needs to be fast and dynamic and will be provided by means of proper policies by the cognitive management entities.

In this respect the knowledge-based Suitability Determination Algorithm is responsible for making decision upon the feasibility of the creation of ONs when judged as appropriate. The algorithm targets at deriving suitable policies, which the advanced management system will use for the decision of the creation of the ONs when required, while in operation or even in a proactive manner. In this way the algorithm, collects context/profile information and knowledge in order to provide a proper policy, for the actual creation of the ONs.

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 described in Section 1.2. The structure of the dissertation is depicted in Figure 1-7 in order to provide a clear and comprehensive view of the logical sequence of the chapters. Finally a slight description of them is outlined in the sequel.

Chapter 2 In this chapter the proposed solution which comprises operator governed ONs and CMSs is provided. ONs can comprise various terminals/devices, potentially organized in an infrastructure-less (ad-hoc) network mode, and be terminated at a set of Access Points (APs) of the infrastructure-based network. A brief analysis of specific scenarios, with the benefits for the whole network from the creation of the ONs is also presented. The novelty of the approach is highlighted with respect to selected related work in the field. Moreover the concept of CMSs for the management of ONs and their coordination with the infrastructure is presented. CMSs, which comprise self-management and learning capabilities, can be exploited for ensuring the fast and reliable establishment of ONs.

Research on the proposed solution, as it is described in this chapter, resulted in the following publications:

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- V. Stavroulaki, K. Tsagkaris, M. Logothetis, A. Georgakopoulos, P. Demestichas, J. Gebert, M. Filo, "Operator governed opportunistic networks: An approach for exploiting cognitive radio networking technologies in the Future Internet", Vehicular Technology Magazine, IEEE, September 2011, vol.6, no.3, pp.52-59, Sept. 2011.
- M. Logothetis, K. Tsagkaris, P. Demestichas, "Capacity Extension through the Integration of Opportunistic Networks with Wireless Infrastructures", to appear in Proc. OpnetWork 2011, Washington, USA, Aug.29-Sept.1, 2011.

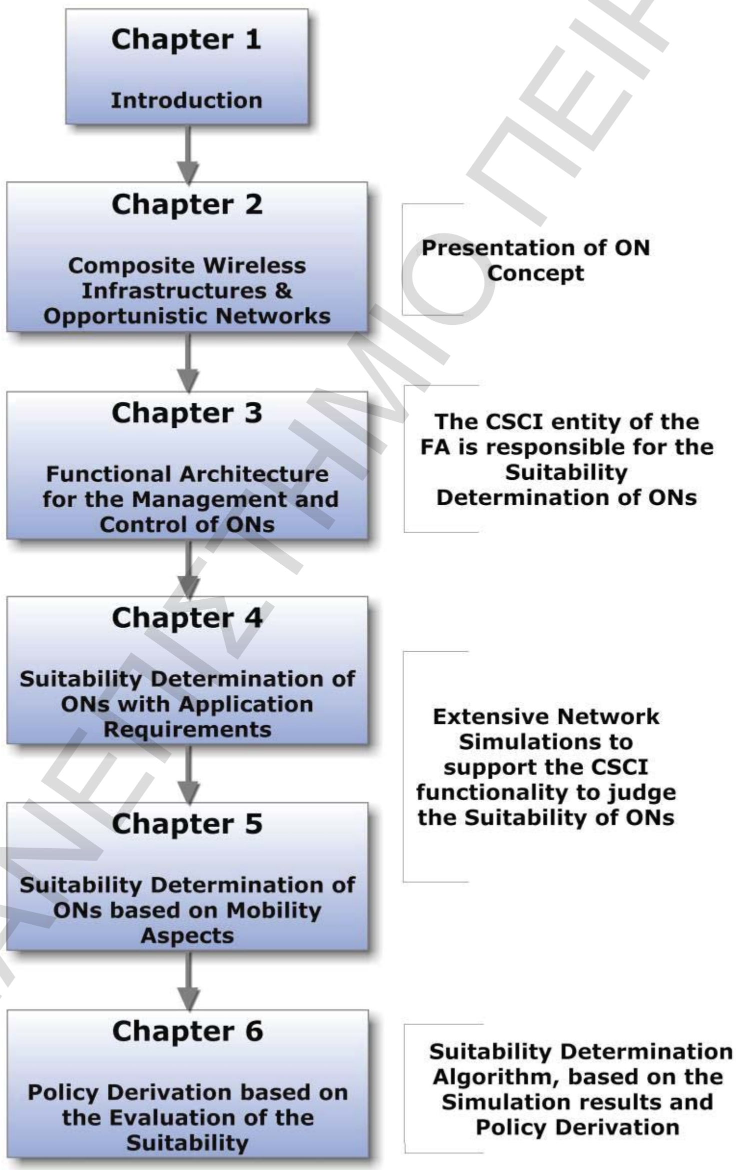

Figure 1-7: Dissertation Structure

Chapter 3 In this chapter an approach for the definition of Functional Architecture (FA) for the management and control of the ONS is provided. The proposed FA includes several functional entities each of which is dealing with specific issues like the suitability determination or the creation of the ONs. Moreover, the interfaces among the functional entities are described in order to provide a clear view on the necessary interactions not only for collecting information but also to perform the actions as provided by the decision entities. The CSCI and CMON functional blocks are responsible for the suitability determination and creation phase, respectively. In particular, the CSCI entity is going to decide on the feasibility of creating the ONs when required, while in operation or even in a proactive manner. Finally the decision of the CSCI will be provided by means of proper policies, to the CMON functional entity for the actual creation of ONs.

Research on the proposed FA, as it is described in this chapter, resulted in the following publications:

- M. Logothetis, V. Stavroulaki, A. Geograkopoulos, D. Karvounas, N. Koutsouris, K. Tsagkaris, P. Demestichas, M. Tosic, D. Boskovic, “Opportunistic Network Creation Schemes for Capacity Extension in Wireless Access and Backhaul Segments”, to appear in 3rd International ICST Conference on Mobile Networks & Management (MONAMI 2011), 21-23 September 2011, Aveiro, Portugal.

Chapter 4 Chapter 4 presents justified recommendations on whether and when the creation of an ON as a temporary extension of the infrastructure, might be beneficiary for the global network efficiency and for the whole of key players. For that reason, extensive network simulation studies are conducted, with the intention to cover a large gamut of cases in order to increase the validity of the finally extracted recommendations. These simulations will mainly support the CSCI functionality to judge the suitability of ONs. The simulation environment is presented with a detailed description of the test cases and simulations that were setup in order to validate the proposed solution. The emphasis is given to specific types of applications, which were selected so as to exhibit varying and scalable resource requirements and sensitivity. In other words, the target of this chapter is the suitability determination of the ONs with application requirements from the user side.

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Research in this field resulted in the following publications:

- K. Tsagkaris, M. Logothetis, P. Demestichas, "Investigation of the QoS provision potentials of the exploitation of instrastructure-less segments by composite wireless Infrastructures", Ad Hoc and Sensor Wireless Networks, Volume 14, Number 1-2, p. 61-105, 2012.
- K. Tsagkaris, M. Logothetis, P. Demestichas, "Studies on the potentials of the exploitation of infrastructure-less segments by composite Wireless networks", In Proc. OpnetWork 2010, Washington, USA, Aug.30-Sept.2, 2010, International Conference Papers.

Chapter 5 Chapter 5 presents the suitability determination of the creation of ONs with the emphasis given to certain mobility levels of the terminals and specific routing protocols. The study is also based on extensive network simulations and covers many test cases in indoor and outdoor environment. The simulation environment is presented, with all the mobility and routing parameters which are used. Moreover specific QoS metrics are used in order to evaluate conditions and assist in coming up with useful recommendations with respect to the creation of the ONs. Finally the results will support the CSCI functionality to judge the suitability of ONs, with the final purpose to extract proper policies.

The work described in this chapter is presented in the following publications:

- M. Logothetis, K. Tsagkaris, P. Demestichas, “Application and Mobility Aware Integration of Opportunistic Networks with Wireless Infrastructures” Computers & Electrical Engineering, Elsevier, to appear.
- M. Logothetis, K. Tsagkaris, P. Demestichas, "Performance evaluation of the suitability of opportunistic networks for the Future Internet", in Proc. IEEE Symposium on Computers and Communications (IEEE-ISCC) 2011, June 28 – July 1 2011, Corfu, Greece.

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Chapter 6 In this chapter an attempt to extract policies from the exploitation of the simulations, which have been conducted in Chapter 4 and 5, is presented. In particular the policy derivation process is achieved by the Knowledge-based Suitability Determination Algorithm, which is located in the CSCI functional block of the FA. The algorithm collects context/profile information and knowledge in order to provide a proper policy, for the actual creation of the ON. In addition, these policies are going to be used by the operator of the infrastructure to control the decision upon creating the ONs, in several situations. Moreover this chapter focuses on the validation platform, the description of the components and the functionalities, including the CSCI and CMON, which have been implemented in order to provide a proof of concept of the ON-based approach.

The outcome of this research, as it is described in this chapter, resulted in the following publications:

- M. Logothetis, K. Tsagkaris, P. Demestichas, "Deriving Policies based on the Evaluation of the Suitability of Integrating Opportunistic Networks with Wireless Infrastructures", to appear in Proc. IEEE 74th Vehicular Technology Conference (IEEE-VTC) Fall 2011, San Francisco, United States, September 5-8, 2011, International Conference Papers.
- K. Tsagkaris, G. Athanasiou, M. Logothetis, Y. Kritikou, D. Karvounas, P. Demestichas, "Introducing Energy Awareness in the Cognitive Management of Future Networks", Journal of Green Engineering, River Publishers, Vol: 1, Issue: 4, Published In: July 2011.

Chapter 7 The last chapter circulates the main aspects introduced by this dissertation in the research area of ONs. Furthermore, on-going challenges are discussed and finally the dissertation is concluded.

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2. COMPOSITE WIRELESS INFRASTRUCTURES AND OPPORTUNISTIC NETWORKS

Chapter Outline

In the scope of the FI, new applications, services and content will require a truly ubiquitous network capacity, capable of handling the amplified data traffic volumes transmitted by internet enabled devices. This calls for more flexible networking paradigms that will offer increased efficiency in resource utilization and application QoS provisioning and at the same time exhibit lower transmission powers and energy consumption. Operator-governed ONs, which are dynamically created, temporary, coordinated extensions of the infrastructure, is a first ingredient for the proposed solution. In addition, CMSs, which comprise self-management and learning capabilities, can be exploited for ensuring the fast and reliable establishment of ONs. CMSs can be located in both the network infrastructure and the terminals/devices. CMSs can determine their behavior in an autonomous manner, reactively or proactively, according to goals, policies and knowledge.

Keywords: Opportunistic Networks, Composite Wireless Networks, Cognitive Management Systems

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2.1. Introduction

As already presented in the previous chapter, it is a common truth that the majority of existing and newly coming applications are more likely to be provided in their mobile/wireless manifestation. This has mainly aroused due to the expansion in using wireless internet access, and accordingly of the increase of data traffic volumes received/sent by internet enabled mobile devices. At the same time all these applications are going to be accessed at any time of a day, will be requested from all types of locations and environments and finally will have to be delivered meeting a set of QoS. Additionally the internet applications will affect the data/control traffic load and this will lead to the increase of the total amount of energy consumption. On the other hand the number of broadband users around the world, who are subscribing to B3G and 4G wireless networks, seems to explode, reaching at the remarkable number of 2.5 billion people by 2014.

Such a challenging landscape in the area of wireless/mobile networks motivates the quest for technological solutions that will offer increased efficiency in resource utilization and application QoS provisioning and at the same time exhibit lower transmission powers and energy consumption.

Framed within this statement, in this chapter it is presented a solution that integrates Wireless Network Infrastructure, on the one side, and extensions of the infrastructure-based wireless network called ONs, on the other side. The rest of the chapter is structured as follows. A detailed presentation of ONs and a brief analysis of specific scenarios follow in Section 2.3. The novelty of the approach is highlighted with respect to selected related work in the field. Section 2.4 presents the concept of CMSs for the management of ONs and their coordination with the infrastructure. Finally the chapter is conducted in Section 2.5.

2.2. Solution for improved efficiency

As already stated, the increasingly demanding landscape of the FI motivates the quest for technological solutions that will offer improved efficiency in resource provisioning and

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provide user with high quality services anywhere, anytime and at the same time exhibit lower transmission powers and energy consumption.

Framed within this statement, in this chapter it is presented the proposed solution that integrates:

- Composite Wireless Networks (CWN), on the one side, which consist of a set of radio networks and lie in the infrastructure side
- Extensions of the infrastructure-based wireless network called ONs, on the other side and
- An advanced management plane, that comprises the set of management functions and/or signalling procedures and channels, which are necessary for the communication and coordination among infrastructure and ONs.

In general the B3G/4G concept dictates that wireless network operators will own heterogeneous infrastructures known as CWN that are able to provide a plethora of Radio Access Technologies (RATs) including among others, cellular UMTS/HSDPA and 3rd Generation Partnership Project (3GPP) Long Term Evolution (LTE), as well as the IEEE 802.1x suite of standards including WLANs (IEEE 802.11 family) and WMANs (IEEE 802.16 family - WiMAX) [1][2]. In its more emerging representation, that is also dictated by the B3G/4G concept, the wireless infrastructure can refer to a heterogeneous network that is composed of several RANs, which include Base Stations BSs (in the general sense), a packet-based core network (CN) for connecting these RANs and a common network management system [3][4][5][6].

On the other hand, ONs can be characterised as operator-governed, temporary, coordinated extensions of the wireless network infrastructure. Particularly, ONs are governed by operators through the provision of policies, e.g. upon resource usage, as well as context/profile information and knowledge, which is exploited for their creation and maintenance. They are dynamically created in places and at the time they are needed to deliver application flows to mobile users. Moreover, they comprise various devices/terminals, potentially organized in an ad hoc mode, as well as elements of the infrastructure itself. More details about the ONs are presented in Section 2.3.

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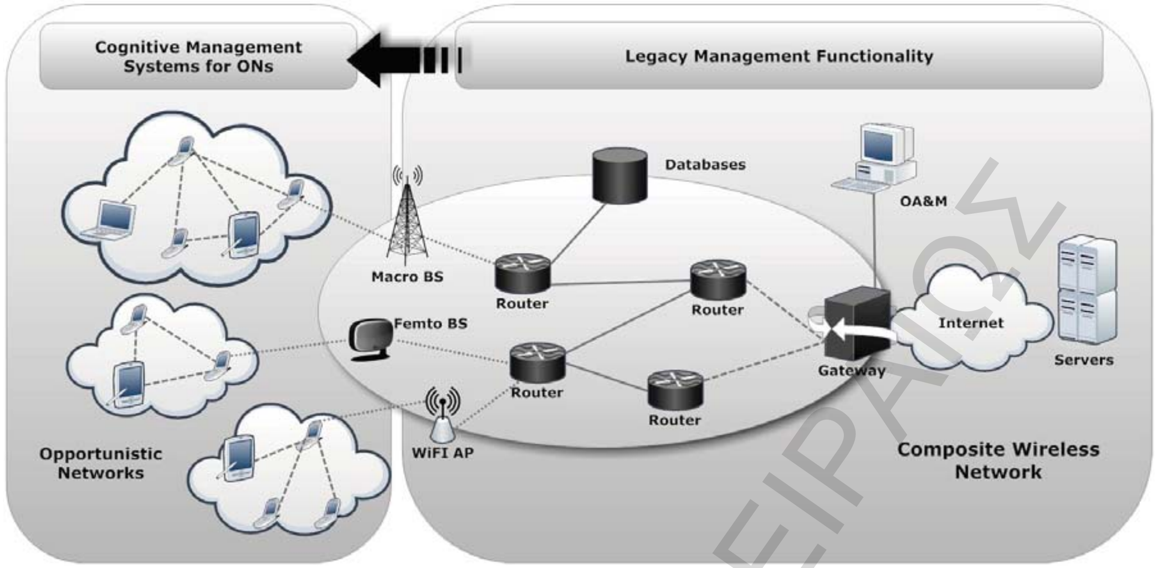

Figure 2-1: High level Architecture of proposed solution

Figure 2-1 is a first illustration of the overall proposed solution. As it is depicted, an ON may include cellular BSs, offering macrocell (macroBS), microcell, picocell, or femtocell (femtoBS) coverage, as well as WiFi APs, mostly connected through wireline networks. The devices included in an ON can be mobile phones, personal computers, cameras, etc.

Furthermore, because of the highly dynamic nature of the environment, including traffic and applications issues, as well as the potential complexity of the infrastructure, the advanced management plane should incorporate self-management and learning mechanisms. Self-management enables a system to identify opportunities for improving its performance and adapting its operation without the need for human intervention. Learning mechanisms are important so as to increase the reliability of decision making. Learning mechanisms also enable proactive handling of problematic situations, i.e. identifying and handling issues that could undermine the performance of the system before these actually occur. In this respect, CMSs, rendering both self-management and learning capabilities [7] seem appropriate for ensuring the fast and reliable establishment of ONs. CMSs can be located in both the network infrastructure and the terminals/devices. Moreover, it is envisaged that the coordination between CMSs and the exchange of information and knowledge can be provide by control channels. Such control channels may be logical channels transporting information on top of a physical

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network architecture. A more detailed approach in the CMS and the control channel will be presented in Section 2.4.

2.3. Opportunistic Networks

As already presented ONs can comprise various terminals/devices, potentially organized in an infrastructure-less (ad-hoc) network mode, and be terminated at a set of APs of the infrastructure-based network. In particular ONs can be characterized by the following features:

- They are governed by operators through the provision of resources (e.g., spectrum available) and policies, as well as context/profile information and knowledge, which is exploited for their creation/maintenance.
- They are extensions of the infrastructure that will comprise various devices and terminals (envisaged in the FI), potentially organized in an infrastructure-less mode, as well as elements of the infrastructure.
- They will exist temporarily, i.e., for the time frame necessary to support particular applications (requested in specific location and time). Applications can be related to the social networking and prosumer (derives from the combination of “producer” and “consumer”) concepts, as well as to the support of an enterprise (in a particular area and time interval) for developing and delivering products or digital services.
- At the lower layers, the operator designates the spectrum that will be used for the communication of the nodes of the ON (i.e., the spectrum derives through coordination with the infrastructure). In this respect, in principle, the bands will be licensed (even though the use of license–exempt bands is not prohibited).
- The network layer capitalizes on context-, policy-, profile-, and knowledge-awareness to optimize routing and service/content delivery.

2.3.1. The lifecycle of ONs

The ON lifecycle is realized by four discrete phases. These phases include the ON suitability determination, the ON creation, the ON maintenance and the ON termination.

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Specifically, the ON suitability determination, concerns node/ infrastructure discovery, identification of candidate nodes, identification of spectrum opportunities from the infrastructure side. The output of the suitability determination phase will be the request for the creation of the ON.

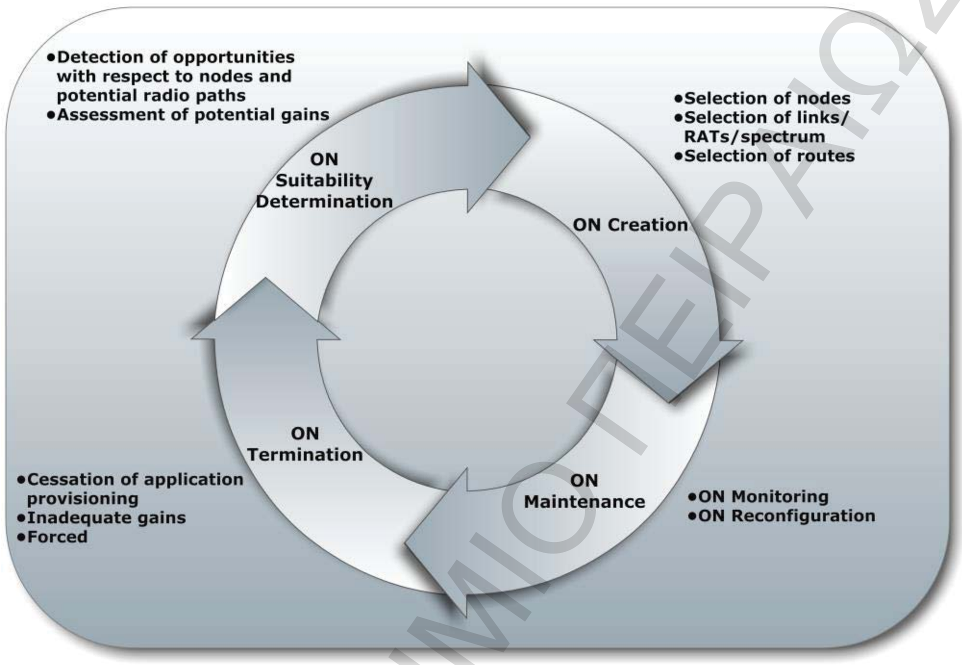

Figure 2-2: The ON lifecycle

The creation phase evaluates the data received from the suitability determination and continues with the selection of the participant nodes, the selection of links / spectrum / RATs and the routes. As a result, the ON is created.

Furthermore, the post-creation stage deals with the monitoring and possible reconfiguration procedures if QoS levels tend to drop significantly. For the monitoring and reconfiguration of the ON, the responsibility lies in the maintenance phase. Finally, the termination phase can be distinguished into termination due to the cessation of application provisioning, termination due to inadequate gains from the ON or forced termination. In the first case, only the release of resources has to be arranged by the ON, while in the latter two the handover to infrastructure in order to maintain flawless application streams is imminent. Figure 2-2 illustrates the proposed approach by expanding the four phases of the ON during its lifetime. We have to mention that one of

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the main objectives of this dissertation is the suitability determination of the creation of ONs.

2.3.2. Scenarios

In order to highlight the ON concept for efficient application provisioning in the FI, specific scenarios are considered. These scenarios can be used with clear benefits for the actors, by creating opportunities for solving persistent issues of mobile networks or for offering new type of services on top of existing infrastructure.

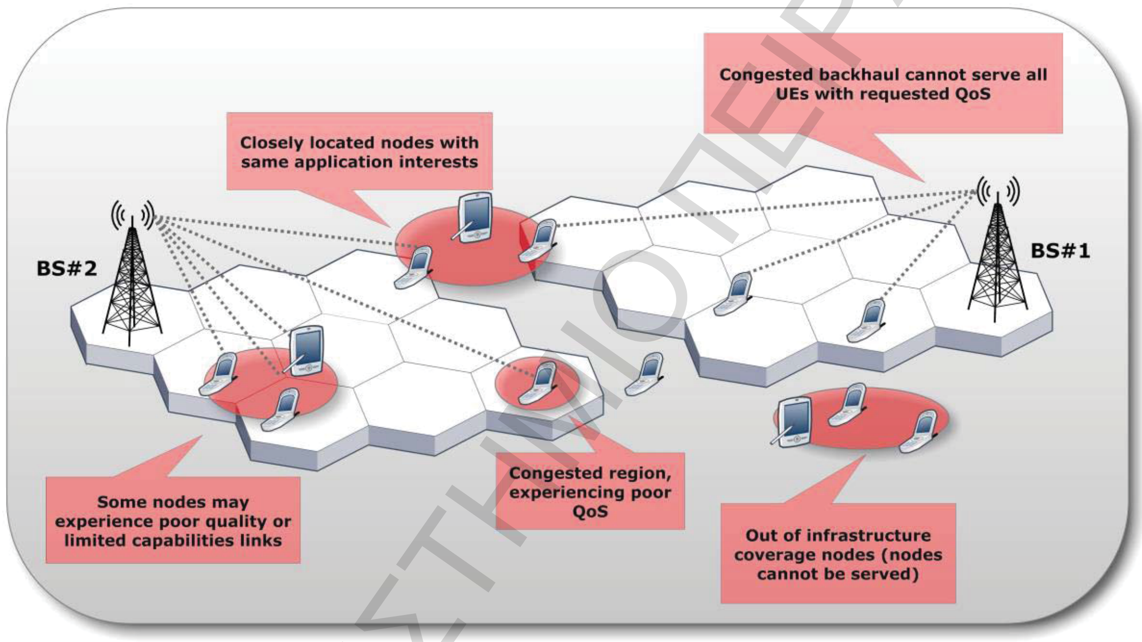

Figure 2-3: Situations which may occur to a network environment, without the use of ONs

In particular, the following scenarios are presented:

(i) *Opportunistic coverage extension*, to serve devices that are out of coverage of the infrastructure or are not capable of operating at the provided RAT

(ii) *Opportunistic capacity extension*, where ONs are exploited to offload service areas with high traffic

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(iii) *Infrastructure supported opportunistic ad hoc networking*, exploiting the closeness of location of application end-points so as to reduce application traffic.

(iv) *Opportunistic traffic aggregation in the radio access network*, where a sub-set of ON terminals exchange data with the infrastructure and

(v) *Opportunistic resource aggregation in the backhaul network*, where backhaul bandwidth is aggregated to match the bandwidth of wireless access technologies towards the user.

Figure 2-3 depicts various situations which may occur in a network environment prior to the use of opportunistic networking, while Figure 2-4 considers the solutions by implementing the ON paradigm.

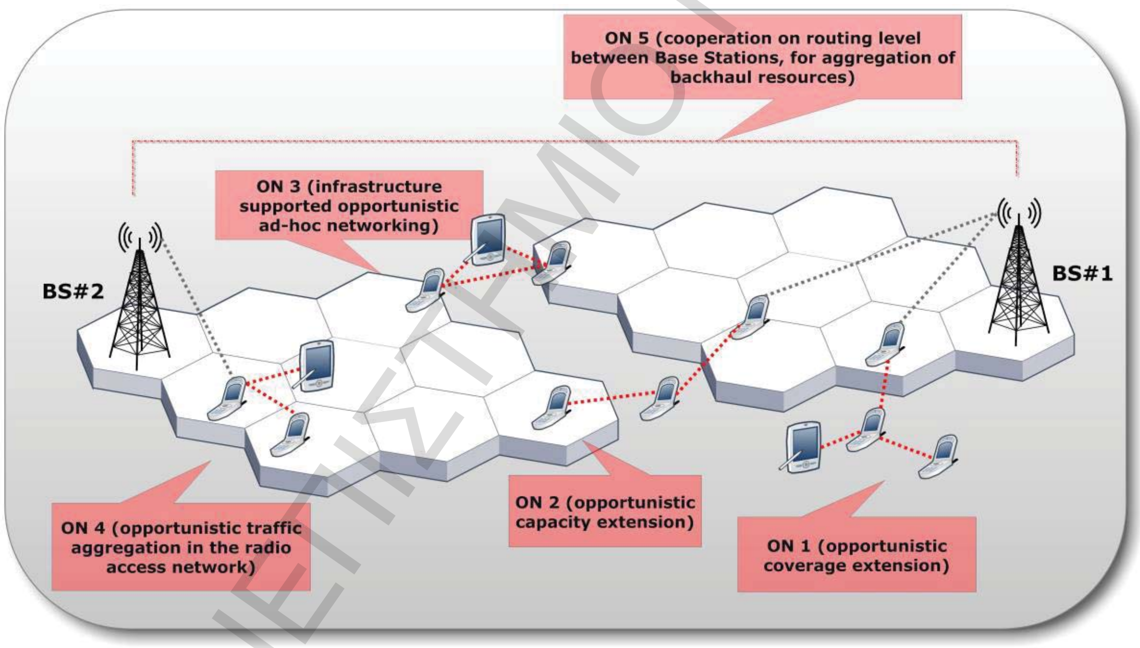

Figure 2-4: Solutions to network issues by implementing the ON paradigm

In this dissertation, we mainly focus in the coverage extension scenario, in order to evaluate the performance of ONs and extract policies, useful for the management extensions of the proposed architecture. A detailed description for each of the five scenarios is presented following.

Opportunistic coverage extension

In this scenario, a device like a laptop or a camera is considered (Figure 2-5), which acts as a traffic source and is out of the coverage of the infrastructure. An ON is created in order to serve the out of coverage source. The notion of opportunism primarily lies in i) the selection for participation in the ON of the appropriate subset of nodes, among candidate nodes that happen to be in the particular area, based on profile and policy information of the operator, and ii) the use of spectrum that will be designated by the operator, for the communication of the nodes of the ON.

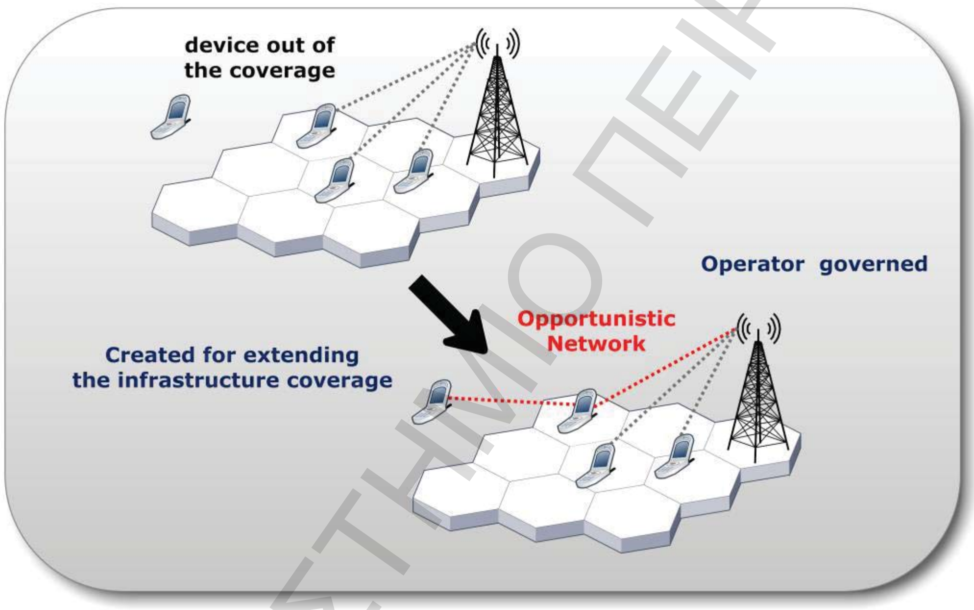

Figure 2-5: Opportunistic coverage extension

Opportunistic capacity extension

In the opportunistic capacity extension scenario (Figure 2-6), it is assumed that a specific area which experiences traffic congestion issues can be offloaded with the creation of an ON in order to re-route the traffic to non-congested APs. This scenario enables devices to maintain the required level of QoS for a wireless communication link even though a congestion situation occurs. In particular, the following two types of congestion situations are considered. In the first situation a system operating in a licensed/ unlicensed band is overloaded and cannot guarantee the provision of the required QoS anymore. In this case, the traffic can be re-distributed to neighboring uncongested cells (which can use different RATs).

In the second situation a system operating in an unlicensed band (such as Wi-Fi, etc.) or licensed band (such as femto BS in a randomly deployed, dense environment) is experiencing high levels of interference, since neighboring APs/BSs are accessing an identical part of the spectrum. Due to this problem, the link throughput is greatly decreased and a congestion situation occurs. As a result, the origin of the interference is identified and the concerned APs/BSs are reconfigured in order to avoid the congestion situation if this is possible.

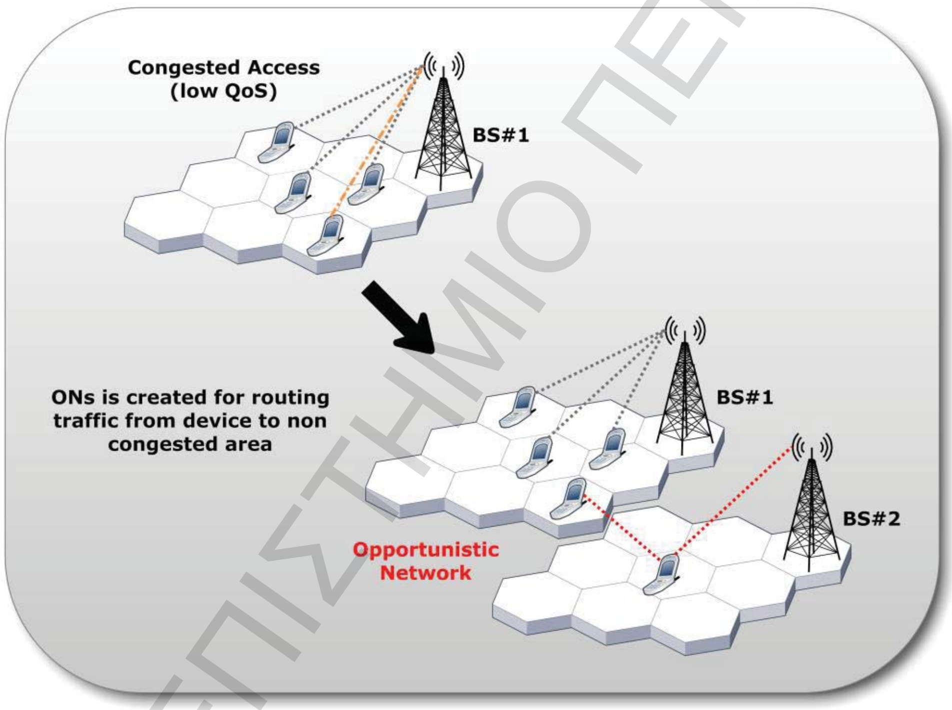

Figure 2-6: Opportunistic capacity extension

Infrastructure supported opportunistic ad hoc networking

This scenario as also depicted in Figure 2-7, considers a completely infrastructure-less, but still operator-governed ON. The fact that often the end-points of an application are “closely” located so that traffic exchange can be limited within its scope is being exploited.

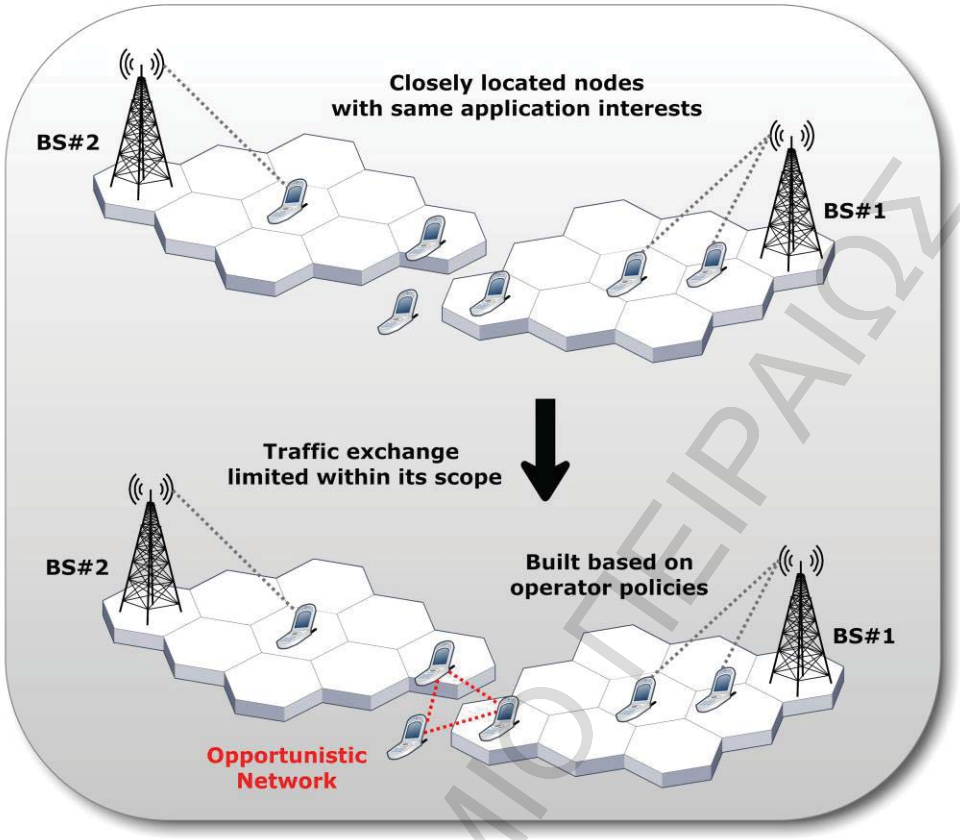

Figure 2-7: Infrastructure supported opportunistic ad-hoc networking

That would result to a potential reduction of the traffic load that has to flow through the infrastructure. The target applications of this scenario are those involving intensive multimedia exchanges between end users located close to each other and applications such as network-enabled gaming etc.

Opportunistic traffic aggregation in the radio access network

The basic concept of this scenario, depicted in Figure 2-8, lies in the fact that there is a certain concentration of users in a certain service area region that request a set of applications. The operator drives the users that are in the particular service area region into forming an ON with, at least, one network element of the infrastructure which can act as a gateway between the infrastructure and the ON.

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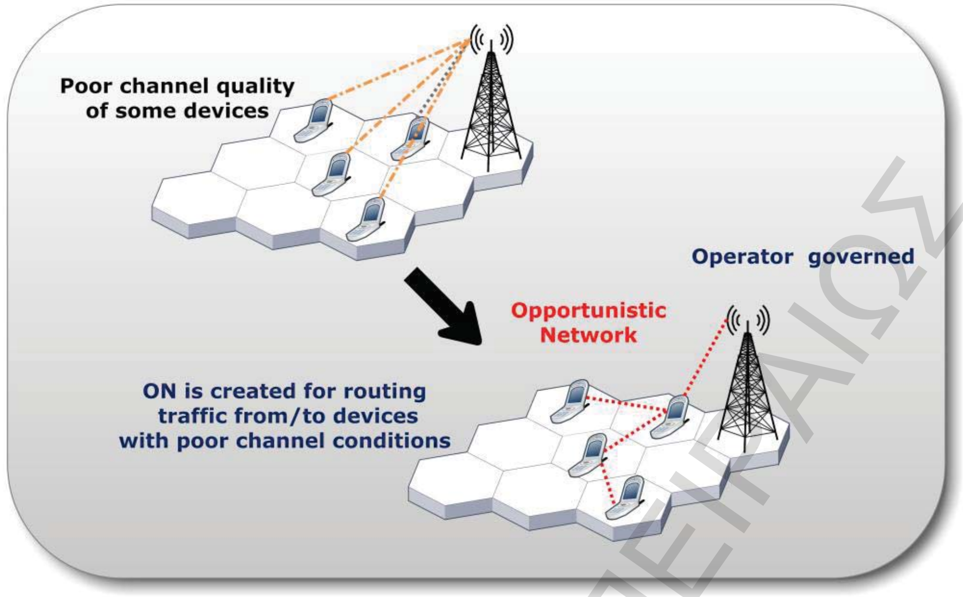

Figure 2-8: Opportunistic traffic aggregation in the radio access network

The formed ON will comprise a BS providing macro-cell (or femtocell) coverage and a set of served devices, a subset of which is organized in an ad hoc network mode. The ON is created in order to enable traffic aggregation from the ON to infrastructure through the gateway instead of having direct links from all nodes to the Macro BS. As a result, traffic exchange with the infrastructure via a limited number of users/ devices may yield improvement of the utilization of resources (assignment of fewer resources, better utilized, compared to the assignment of resources to all users).

Opportunistic resource aggregation in the backhaul network

The idea of this scenario (Figure 2-9) is that an ON is created across multiple APs in order to primarily aggregate backhaul bandwidth and match the bandwidth of modern wireless access technologies towards the user with the adequate bandwidth on the backhaul/ CN side. The same ON can be used to pull together processing or storage resources across multiple APs in order to pre-process user generated content and relieve pressure on the bandwidth resources needed for its transmission or the storage.

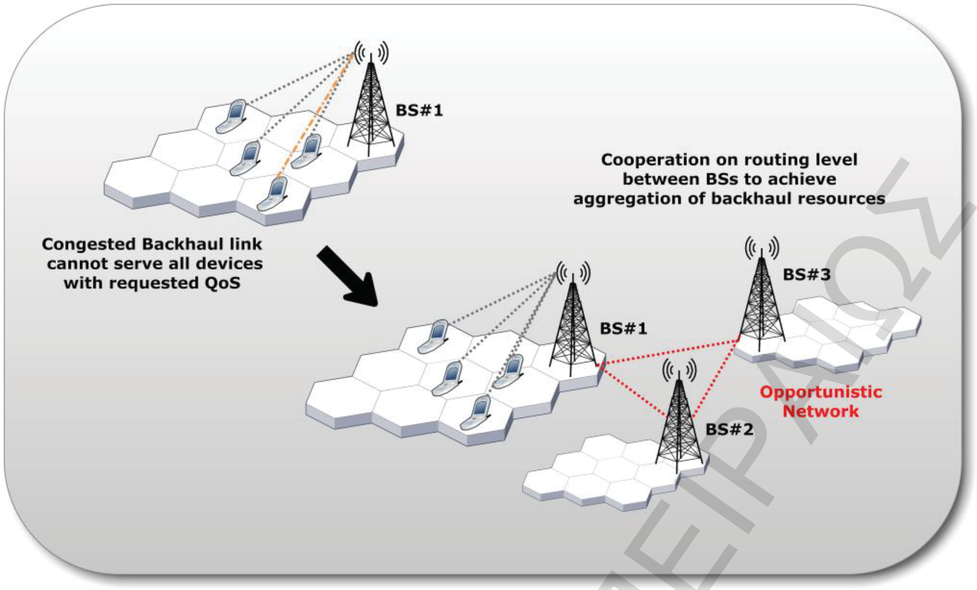

Figure 2-9: Opportunistic resource aggregation in the backhaul network

It is assumed for all scenarios that terminals participating in an ON are those terminals that are made available by their users for such use/creation.

2.3.3. Technical Challenges

This section describes the technical challenges that derive from the previously mentioned scenarios, presented in sub-Section 2.3.2, in relation with the ON suitability determination, the ON creation, the ON maintenance and the ON termination phases, which have been presented in sub-Section 2.3.1.

Suitability Determination Phase

Related to the suitability determination phase the following technical challenges could be taken into consideration: i) identification of opportunities with respect to nodes as the operator needs to be aware (by discovery procedures) of the nodes' related information such as capabilities, energy level, available interfaces etc., ii) identification of opportunities with respect to potential radio paths; as ONs will operate in a dynamically changing environment, where inter-ON interference may be possible. It is important to find how many nodes are within the range of a given node, depending on the spectrum and the power used. In order to select the spectrum for the operation of the ON, there is the need to introduce mechanisms leading to the identification of spectrum opportunities (e.g. the available spectrum from the infrastructure side) that also ensure that the resulting interference conditions are acceptable, and finally iii) the assessment of potential gains. These gains may be achieved through the application provision with a fair QoS, the efficient spectrum utilization and the lower transmission powers, which can lead to lower energy consumption (for the operator's BS).

Creation Phase

The technical challenges of this phase are focused on the development of mechanisms that will lead to the inter-connection of selected nodes, the optimization of routes, and usage of the selected spectrum followed by the signalling procedure establishing the ON. In some cases though, the creation phase could also come up with a decision for not finally establishing the ON. Another additional challenge lies in the necessity, for some optimization, to handover some existing links and traffic from the infrastructure to a relay node.

Maintenance Phase

The ON will have to be dynamic during all its operational life-time. In order to achieve this, once the creation phase has been completed, the maintenance phase has to be initiated. In general, the maintenance phase will have to monitor nodes, spectrum, policies, QoS and decide whether it is suitable to proceed to a reconfiguration of the ON. The maintenance phase is responsible for applying, at the right time, all the appropriate changes at the ON configuration, in order to maintain the efficient operation of the ON and to provide adaptability to changing environmental conditions.

Termination Phase

The termination phase will eventually take the decision to release the ON, thus triggering all the necessary procedures and associated signalling. It is distinguished according to the reason of termination. As a result we may have termination of the ON due to cessation of application provision, termination due to inadequate gains from the usage of the ON and forced termination. The challenge of the first case is to successfully achieve the release of resources, while the latter two cases facilitate the handover to infrastructure as well, in order to maintain as flawless as possible, the application streams.

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2.3.4. Expected high level benefits from the ONs

The main motivation for the proposed solution of combining operator governed ONs comes, as already outlined in the previous sections, from the requirements for the FI, i.e. the demand for new and diversified applications/services, the expanded use of wireless, and the increased efficiency in resource provisioning. Furthermore, the establishment of ONs that are managed and coordinated with the infrastructure through cognitive mechanisms is expected to provide benefits to all the involved stakeholders. More specifically, access providers will efficiently expand their business and service offerings, application/service providers, while end users will be provided with applications/services more efficiently. The main benefits can be summarized in the following points:

- *Value creation for stakeholders*. Access and service providers are enabled to provide applications/services in challenging situations, e.g., when the infrastructure has limited coverage or exhibits congested access. In the first case the ONs can be used for offering the required coverage. Specifically, end users gain access to the infrastructure in situations where it normally would not be possible, while the access provider may experience increased cashflow as more users are being supported. ONs can also be used as means for bridging traffic sources to an alternative AP within the infrastructure. In that case, access providers benefit from the fact that more users can be supported since new incoming users who would otherwise be blocked, can now be served, while already connected users experience improved QoS since congestion situations can be resolved.
- *Increased utilization of resources*. The allocation of specific resources to the newly created ONs is temporary and is designated by the operator side. In this manner, there seems to be enough space for increasing efficiency by putting into effect under-utilized and available in a particular local area resource for use by ONs.
- *Lower transmission power levels, energy consumption, and traffic load*. Sometimes there is need for lower transmission powers, as there is also reduction of data/control traffic load that goes through the infrastructure. Additionally, infrastructure nodes should be able to save resources that could be

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used for new users, enhancing the service level of current ones, or just reducing their energy consumption. In general, these call for management decisions which lead to lower energy consumption in the infrastructure, thus possessing a larger “green” footprint.

- *Cost efficient handling of various situations*. Such situations may include unexpected or not-frequently occurring events and handling in these cases can be done without large investments in infrastructure thus keeping at a low level the total cost of ownership i.e. OPEX, CAPEX and costs associated with the management of customer relations. That is to say, significant cost reductions that also lead to better and more affordable services to the user can be obtained.

2.3.5. Related work

ONs are one of the emerging communication paradigms in wireless mobile communications. ONs enable pervasive communications in an environment where disconnection and reconnection may frequently occur and link performance and availability are highly dynamic.

ONs concepts have been addressed in different research projects, such as the Haggle project [8]. It proposes a new autonomic networking architecture designed to enable communication in the presence of intermittent network connectivity. This architecture includes paradigms on autonomic communications based on advanced local forwarding and on being sensitive to realistic human mobility, it is oriented to opportunistic message relaying, and is based on privacy, authentication, trust and advanced data handling. In turn, the iClouds project [9] addresses the opportunistic peer-to-peer communication and data exchange to make information available to groups based on individual user contributions. An architecture for spontaneous mobile user interaction, collaboration, and transparent data exchange is defined, relying on wireless ad hoc peer-to-peer communications [10].

Similarly, different research topics in the field of Delay Tolerant Networks, which can be seen as a particular case of an ON, are identified inside the NEWCOM++ network of excellence [11],[12]. Activities in NEWCOM++ focus on the localization and tracking of

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nodes, modelling of intermittent behaviour, transport layer based on packet aggregation, and analysis of the impact of nodes mobility.

Focusing in literature, a theoretical approach of ONs is presented in [13], for Delay Tolerant Networks. They present that each level of the infrastructure can be an ON. Every node inside the ON can use routing algorithms to communicate among themselves and may rely on the upper levels of the infrastructure to reach nodes that are too far away.

Authors in [14] present the idea of creating ONs by dynamically expanding them through the inclusion of new nodes in accordance with certain tasks that are needed in the network. They explain that ONs provide a potential for creating from a small network into a very powerful network with capabilities of communication, computing and sensing. Moreover an overview of the state-of-the-art work in providing solutions to various issues in an ON is presented in [15]. Problems at the network, transport and application layers are identified, as well as at the bundle layer, responsible for storing, carrying and forwarding the data in an ON.

Most of the related work in the field of ONs has been conducted by presenting in a more theoretical basis with respect to architectures or in designing routing algorithms for the data forwarding inside the network. One of the main goals in this dissertation, is to focus on QoS issues (e.g. delay, packet loss) and energy related benefits, by giving emphasis in specific newly applications and how these can be supported in a mobility environment. Additionally, we consider ONs that can be controlled and coordinated by the operator of the wireless network infrastructure ("operator governed") by means of proper policies, provided by the advanced management plane.

On the other hand, the concept of extending the infrastructure in a mobile environment, in order to achieve better resource provisioning and utilization is not a very new idea. Well known approaches have been proposed in the past mainly with the aim to increase the cellular coverage and/or capacity and decrease costs, thus abandoning the traditional worst-case (peak-hour) based planning that used to lead to over-provisioning of expensive resources in non-peak times.

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These approaches include the well-known WiFi hotspots [16], and Femto Cells e.g. Home Node-Bs (HnB) [17] that are now aggressively used by operators in order to offload large portions of the traffic from the wide area networks of their infrastructure. This can be seen as the conservative version of the solution, exhibiting minimum or totally absent dynamics. The possibility of exploiting infrastructure-less segments in order to increase the efficiency of the infrastructure-based network in a more dynamic manner has also been considered under the legend of the so-called "hybrid networks". A good overview and comparative study of numerous hybrid networks and different example scenarios can be found is given in [18]. For comparison reasons, some of them are also apposed herewith and described in the following.

The Ad hoc Global System for Mobile Communications (A-GSM) architecture was proposed in [19] for improving capacity and coverage by integrating Mobile Ad-hoc NETworks (MANET) and GSM technologies. The main objective of this work was to address new concepts in the GSM system, in particular elaborating on a generic platform to accommodate relaying capability in GSM cellular networks. As such, it dealt with both standardized features and the necessary, theoretically and technologically feasible improvements (physical and MAC/Link layer protocol adaptation) to accomplish this. Based on the same idea as A-GSM, the Opportunity Driven Multiple Access (ODMA) was a standard proposed under 3GPP in order to improve the efficiency of UMTS TDD technology [20],[21]. Specifically, ODMA was a relaying transmission protocol that provided the capability of delivering high bit rate services in otherwise low bit rate capable border regions of traditional TDD coverage. The standard has been withdrawn, albeit some proprietary, real solutions based on the original, patented ODMA concept can be found e.g. as in [22].

The UCAN, which stands for Unified Cellular and Ad hoc Networks architecture [23], proposes an architecture that unifies Cellular and Ad-Hoc Networks for enhancing cell throughput, while maintaining fairness. It considers dual-mode Mobile Stations (MSs) with both a cellular CDMA interface and an IEEE 802.11b interface that can operate in MANET mode. The proposed system is based on the concept of "proxy clients" that make use of multi-hop routing to improve the throughput by forwarding packets when the quality of the signal in the downlink channel between the BS and the destination MS

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is poor. This is in part similar to what we do; however, the focus of the authors in [15] was mainly placed on proposing and comparing protocols for the discovery of proxy clients that will be used to interface the MANET with the cellular network.

Similarly, [24] presents an analytical framework which aims at determining under what conditions and by how much is the downlink capacity of a hybrid cellular-ad hoc network higher or lower than that of the original pure cellular network. This work is mostly theoretical and focuses mainly on estimating the possible capacity enhancements, whereas no attention to more specific applications and their requirements is paid. In our dissertation, we take a more realistic view of the problem, in terms of applications requested and corresponding traffic demand patterns.

In addition, similar schemes have been proposed for balancing the traffic load between cells in a cellular network, in order to avoid QoS degradation in overcrowded/congested cells. The iCAR architecture [25] can efficiently balance traffic loads between cells by using Ad-hoc relay stations (ARS) to relay traffic from one cell to another in a dynamic manner. Another approach similar to iCAR, called Mobile-Assisted Data Forwarding (MADF) has been proposed in [26] to achieve load balancing between cells by forwarding part of the traffic in an overcrowded cell to some free cells. It must be noted that the above papers are mainly dealing with system design issues, such as the number and placement of ARS's leaving out crucial considerations on how to address the peculiarities of infrastructure-free networks for QoS provision.

In the general sense, all the above refer to the typical scenario, where mobile ad hoc networks can be visualized as an extension to the existing infrastructure networks such as cellular and wireless local area networks for further improvement in performance (e.g. higher system throughput/user capacity, reduced power consumption, etc.).

A more empirical analysis (and accordingly closer to our work) of the coexistence of infrastructure-free networks with network infrastructure has been given in [27],[28]. In particular, it is observed that after a certain point, the benefits of additional infrastructure deployments are minor and the utility of the ad-hoc communication system remains stable (phase transitions). However, the main focus has been given on Delay Tolerant Networking (DTN) [29] and intermittent communication related metrics for applications such as asynchronous peer-to-peer unicast messaging system and a

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data push service, such as an email or news delivery service. In this dissertation, we are focusing on services and applications that are bandwidth-intensive and we study how these can be supported in high level QoS. In addition, as also indicated in [27],[28], there is much space for study, especially with respect to metrics (other than throughput and delay) e.g. including power consumption and additional packets in the system due to the creation of infrastructure-less network(s).

As revealed, there is rather rich literature related to the subject the whole of which could not be referenced here, obviously. However, most of the related work has been conducted towards presenting new communication architectures and protocols (control messages) and much less focus has been given to more fundamental analysis e.g. with respect to QoS control issues. When this happened, the analysis was put in a more theoretical basis.

2.3.6. Business, application provision in the FI area

The deployment of mobile broadband data services which is already underway is being accompanied by a business model that the market is de facto imposing on the mobile operators, and which can be defined by two characteristics: an unending request for higher bit rates and flat rates. The combination of these two features poses a serious threat for the services business plan, and is forcing the operators to use previously rejected policies, like network sharing and common network planning procedures, to name a few. Another area for decreasing network and operational costs without degrading the service quality is the collaboration with third parties that pool disjoint resources for the provision of a single service, or group of services, and later divide the service revenue.

This last area opens a new field of network operation, that of opportunistic (cooperative) networks, the subject of research in this dissertation. Two or more parties like a network operator with its outdoor infrastructure, information systems and customer knowledge, teams up with a company that delivers or manages corporate or residential customer networks, or even network devices. The company can also be a single customer with varied communication appliances in his home. Whichever the case, the second party connects its small network to that of the operator through a well-defined physical and

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service interface. In this context, the small network becomes attached to the larger operator network under an agreed cooperation frame. Technology advances open the door for a large range of cooperations which in the wireless domain can range from simple connectivity to spectrum use, among others. Numerous examples of these possible cooperations are being proposed, like nomadic support to physically impaired people, wireless multi-room video content distribution, security services, etc.

This is the innovative basis for a new “win-win” model, appropriate for mobile operators in the FI era. The network must be flexible enough to react at any time and in any place, on any future demand of applications, as well as on the capabilities of the networks, and frequently the time to market for operators is too slow. In [30] the flexibility of the communication systems in the communication clouds is highlighted, in order to be prepared for future applications. In the near future there will be a need to find the right relations between application demands and network capabilities, where functionalities and components within the clouds will be able to float, not in a hierarchical traditional fashion, depending on the temporal and spatial capabilities of the cloud.

ONs working in a cooperative way with infrastructure networks appear as a very good tool for mobile operators in order to reach to more users, who will act in many cases as prosumers, with more innovative services.

2.4. Cognitive Management Systems

As already presented, due to the dynamic nature of the environment, CMSs seems appropriate for the management of the ONs and for coordinating with the infrastructure, leading to robustness and dependability.

CMSs comprise self-management and learning capabilities and can determine their behavior in an autonomous manner, reactively or proactively, according to goals, policies and knowledge. Particularly, a CMS makes and enforces decisions on the creation of an ON by taking into account the context of operation (environment requirements and characteristics), goals and policies, profiles (of applications, devices and users), and machine learning (for managing and exploiting knowledge and

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experience). The components of a CMS are depicted in Figure 2-10 and can be described as follows:

Context. Context awareness functionality comprised in a CMS involves the monitoring of the status of the network, in order to be aware of the necessity to create an ON. In this sense, context includes traffic, radio and mobility conditions. In general, this part provides the current status of the environment.

Policies. Policies designate rules that should be followed in context handling and refer to reconfiguration strategies that may applied by the opportunistic nodes, such as operator's preferences and priorities on goals to be achieved. These are related to the maximization of the QoS levels, and the minimization of cost factors (e.g. resource consumption).

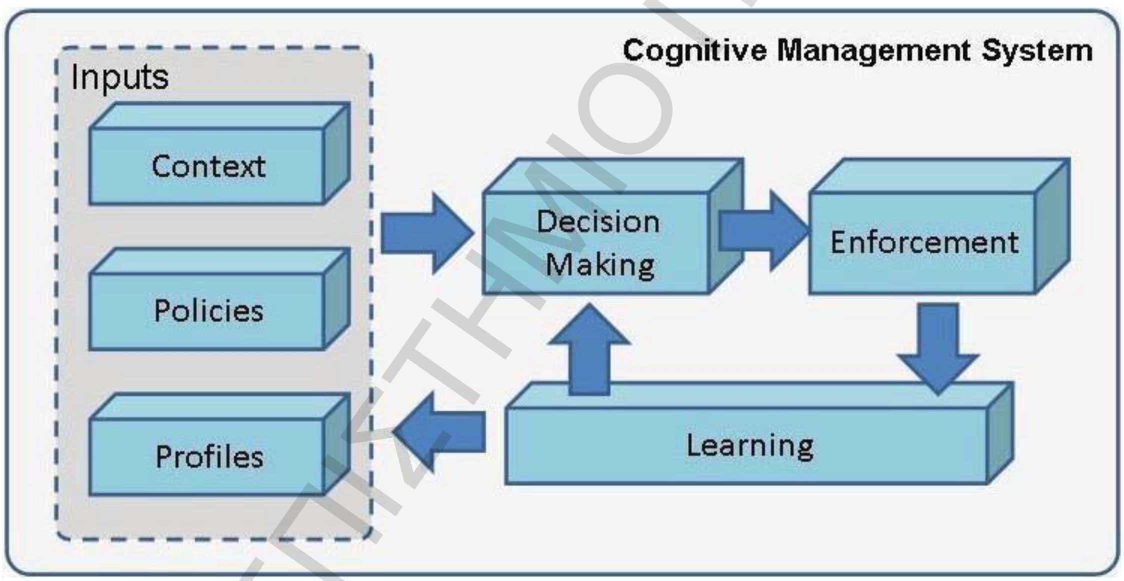

Figure 2-10: Components of a CMS

Profiles. Profiles include preferences, requirements and constraints of user classes and applications which are required for the decision making. Particularly, regarding users the goal is to express their requirements, preferences, constraints. Regarding applications the goal is to express various options for their proper provision. Finally, regarding the served devices the goal is to describe their capabilities.

Learning. Learning taking place during the life-cycle of an ON is used to produce knowledge on the acquired contextual and performance parameters, thus improving reliability and speed of management decisions.

Control Channels

The accuracy of obtained knowledge on the context of the environment can be increased through the deployment of a cooperation mechanism between CMSs. Moreover, efficient coordination between the infrastructure and the devices in the scope of an ON is required, as well. Cognitive control channels (CCC) enable such exchange of information and the coordination between CMSs.

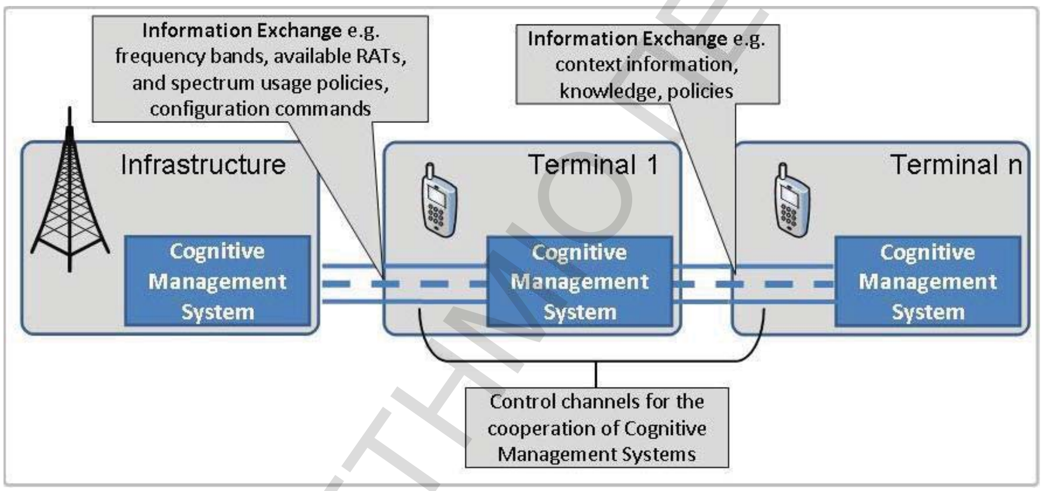

Figure 2-11: Control Channel for the Cooperation of CMS

These control channels (Figure 2-11) can be based on the exploitation and evolution of two concepts: the Cognitive Pilot Channel (CPC) [31] and the Cognitive Control Radio (CCR) [5]. The CPC is defined as a channel (logical or physical) which conveys the elements of necessary information facilitating the operations of Cognitive Radio Systems and can be seen as an enabler for providing information from the network to the terminals, e.g., frequency bands, available RATs, and spectrum usage policies. The CCR can be seen as a channel for the peer-to-peer exchange of cognition related information between nodes (e.g., between terminals) belonging to the same network.

The components/ sub-systems that constitute the entities of an ON management system are presented with details in Chapter 3, along with the FA of the proposed solution.

2.5. Conclusions

This chapter has presented a solution that considers the possibility of extending the wireless network infrastructure, which is owned by a wireless operator by the so called ONs, which comprise network elements and devices that are organized in an infrastructure-less manner to serve specific local and temporary application provision needs. Additionally, due to the dynamic nature of the environment, CMSs seems appropriate for the management of the ONs and for coordinating with the infrastructure, leading to robustness and dependability. CMSs can be used for managing the ONs by making decisions based on context, policies and profiles and empowered by knowledge and experience deriving from learning functionality. In order to highlight the ON concept, detailed features are presented and specific scenarios are considered along with the technical challenges that derive from them. Finally the establishment of ONs that are managed and coordinated with the infrastructure through CMSs provides various benefits to all the involved stakeholders.

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ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

3. FUNCTIONAL ARCHITECTURE FOR THE MANAGEMENT AND CONTROL OF OPPORTUNISTIC NETWORKS

Chapter Outline

The FI is rapidly moving towards the next generation of systems, featuring several RANs and various terminals/devices, potentially organized in ad-hoc network mode that can be called ONs. In this respect, conventional management techniques ought to be replaced by advanced schemes capable to handle an increased complexity and high speeds of this versatile landscape. The management should be performed in a distributed manner, so as to be fast, scalable and reliable and finally should be attributed with cognitive networking capabilities, so as to incorporate self-management and learning mechanisms. Framed the above, this chapter presents a complete management framework, namely the Functional Architecture (FA). The proposed FA can be deployed in the anticipated future compound communication systems as a means to ensure satisfactory QoS provision and exhibit lower energy consumption. The fundamentals and the approach followed in the architecture are discussed, and its functionality is investigated.

Keywords: Functional Architecture, Management and Control of ONs, Suitability Determination

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3.1. Introduction

As already presented the CWN is composed of several RANs which include BSs in the general sense, a packet-based core network for connecting these RANs and a common network management system.

The management should exploit this versatile landscape (i.e. the availability of alternative RATs), should also be performed in a distributed manner, so as to be fast, scalable and reliable and finally should be attributed with cognitive networking capabilities [1], so as to incorporate self-management and learning mechanisms.

Framed within the above and in order to meet the requirements, for improved efficiency in resource provisioning and providing users with high quality services anytime, anywhere through the combination of ONs and CMSs new management and control functionalities for ONs need to be added to network management architectures. In this direction, this chapter gives an overview of a corresponding FA, which is an extension of an existing architecture, namely the "Functional Architecture for the Management and Control of Reconfigurable Radio Systems" as defined by the European Telecommunications Standards Institute (ETSI), Reconfigurable Radio Systems (RRS) Technical Committee (TC) in the Technical Report (TR) 102 682 [2], [3].

In brief, the ETSI FA is designed for a network with heterogeneous radio access technologies where the mobile devices as well as the BSs are reconfigurable. The following features are provided by the ETSI FA:

- Access Selection & Handover Decisions: Select the best radio access for a given user/session based on service requirements, radio conditions, network load, policies
- BS Configuration and Reconfiguration to maximise the networks efficiency
- Spectrum management for optimal, dynamic spectrum usage
- Self-Management of the Radio Network Infrastructure
- Cognition Support Mechanisms (e.g. CPC, Spectrum Sensing).

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The ETSI FA is built on top of existing RATs and Protocol Stacks, and therefore relies on all legacy features of operator-governed infrastructure-based networks, including credentials management, authentication, ciphering and other security-related feature.

The rest of the chapter is structured as follows. The detailed description of the basic functional blocks of the proposed architecture, as well as of the interfaces among them, is given in the sequel. Then, an indicative scenario is presented showcasing the FA operation and a potential mapping of the introduced FA to existing networks. Furthermore, the factors that can determine the suitability of the ON approach, in order to achieve adequate QoS level provisioning and energy consumption, are also discussed in this chapter. In particular an approach of the suitability determination process for the investigation under which circumstances the creation of such an ON will be beneficiary for the overall network follows in Section 3.6. Finally the chapter is conducted in Section 3.7.

3.2. High Level view of the FA

The proposed FA constitutes an amalgamation of different management mechanisms, represented as functional blocks. The feature which is added to the ETSI FA is the ONs Management to provide mechanisms for operator-governed ad-hoc extensions of infrastructure networks. This infrastructure governed ONs Management is divided into two building blocks, namely the “Cognitive management System for the Coordination of the infrastructure” (CSCI) and the “Cognitive Management system for the Opportunistic Network” (CMON). The resulting FA comprising mechanism for the management of ONs through CMSs is depicted in Figure 3-1.

The CSCI is mainly responsible for the activities before an ON created. This includes ON opportunity detection and ON suitability determination. The CSCI is in charge of the context acquisition, processing of the same and the determination whether or not right conditions are in place for creating the ON. When the CSCI has made a decision that an ON is suitable, the decision is then sent to the CMON.

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The CMON is controlling the life cycle of the ON from creation to termination. This includes the execution of the creation procedures as well as maintenance and termination of a given ON.

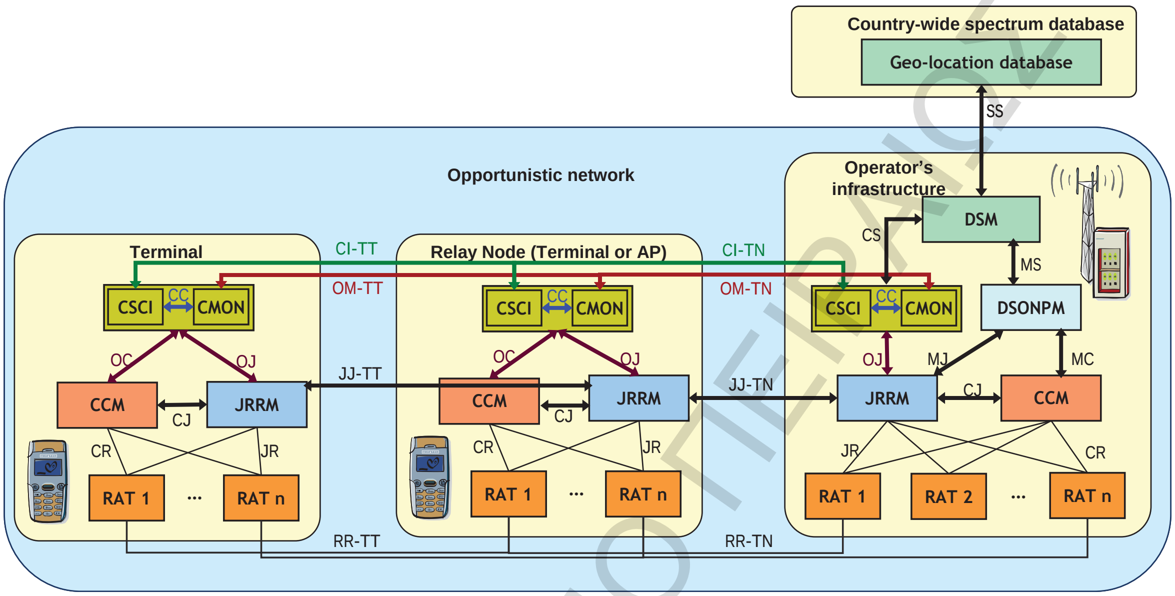

Figure 3-1: Functional Architecture for the Management and Control of infrastructure governed Opportunistic Networks as an evolution of the ETSI RRS FA [4]

In general, CMONs and CSCIs will have functionality and will collaborate for performing the following tasks:

- Determination of the suitability of the ON approach. This includes node/infrastructure discovery, identification of candidate nodes, identification and generation of spectrum opportunities from the infrastructure side, interference coordination through the exploitation of results from off-line studies.
- ON creation. This includes the selection of the optimal, feasible configuration of the ONs. A configuration includes the selection of participant nodes, spectrum and routing pattern.
- ON maintenance. This involves QoS control (monitoring and corrective actions) of the data and control flows served by the ON, and the realization of reconfiguration actions in the case of alterations in the node status, and the spectrum and routing conditions.

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- Handling of forced terminations of the ON. This means to try to preserve the provision of applications as much as possible, even when the ON has to be terminated before the data session ends.

A summary of this split of the functionalities for the ON coordination and management between the CSCI and CMON is shown in Table 3-I. Moreover a more detailed description of the functions of CSCI and CMON is presented in sub-Sections 3.2.1 and 3.2.2, respectively.

Table 3-I: Functional split between CSCI and CMON

	CSCI	**CMON**
Coordination with the Infrastructure (Infrastructure not necessarily part of the ON)	YES	-
Coordination with other nodes in the ON	-	YES
Detection of situations where an ON may be useful	YES, typically based on external triggers, e.g. information from JRRM	-
ON Suitability determination	YES	-
Execution of ON establishment/creation	-	YES
Maintenance of ON, e.g. reconfiguration	-	YES
Decision on termination of ON when ON is no longer suitable	-	YES, typically based on external triggers
Execution of ON termination	-	YES

Apart from the CSCI and CMON other main building blocks of the FA which act on top of existing Radio Access Technologies (RATs) include:

- The Dynamic Spectrum Management (DSM) which provides mid- and long-term management (e.g. in the order of hours and days) of the spectrum for the different radio systems.

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- The Dynamic, Self-Organizing Network Planning and Management (DSONPM) which provides mid- and long-term decisions upon the configuration and reconfiguration of the network or parts of it. The DSONPM decides for example on the configuration of a BS and then instructs the Configuration Control Module (CCM) to execute the reconfiguration.
- The Joint Radio Resources Management (JRRM) which performs the joint management of the radio resources across different radio access technologies. It selects the best radio access (Access-Selection & Handover Decisions) for a given user based on the session's requested QoS, radio conditions, network conditions like cell load, user preferences and network policies. The JRRM also provides Neighborhood Information which can then be distributed via CCC or a CPC.
- The CCM which is responsible for executing the reconfiguration of a terminal or a BS, following the directives provided by the JRRM or the DSONPM.

3.2.1. Cognitive management System for the Coordination of the Infrastructure (CSCI)

The CSCI is the functional entity in charge of the context acquisition, processing of the same and the determination whether or not right conditions are in place for creating an ON.

The CSCI is responsible for the detection of situations where an ON may be useful as part of the ON suitability determination phase. The CSCI delegates the actual creation, maintenance and termination of a given ON to the associated CMON functional entity and it is located in both the operators' infrastructure side (then called "CSCI-N") and the terminal side (then called "CSCI-T").

The suitability determination is a centralized process, with the decision making located typically in the infrastructure but in some cases (e.g. out-of-coverage scenario) located inside a device. The decision making is based on infrastructure-level information provided by functional entities in the network and user/device-level information provided by the CSCI-T entities from a selected set of devices.

The suitability determination runs before the creation of an ON but also during the lifetime of the ON in order to check that context changes and ON reconfigurations (information from CMON) have not cancelled the benefit/suitability of the ON.

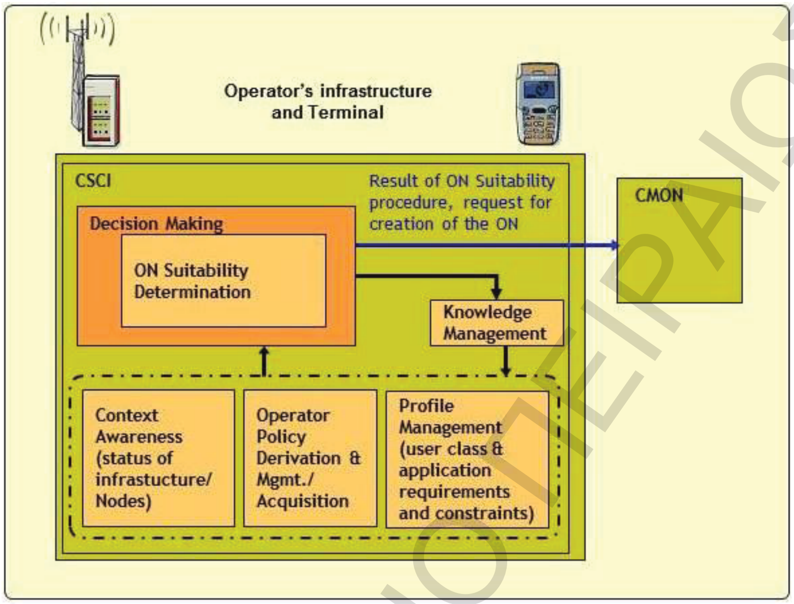

Figure 3-2: Detailed functional view of the CSCI in the operator's infrastructure and Terminal's side

The CSCI-N, as also depicted in Figure 3-2, involves context awareness, operator policy derivation and management and profile management which provide the input to the decision making mechanism. The CSCI-T involves context awareness, operator policy acquisition and profile management which provide the input to the decision making mechanism as well. The cognition relies on the fact that knowledge management functional entities interact with the previously mentioned entities in order to make better decisions in the future, according to the learned results.

Specifically, the context awareness functional entity of the CSCI-N involves the monitoring of the status of the infrastructure network, in order to be aware of the necessity to create an ON. Also, node information is nested in the context entity which includes node's capabilities, node's status, node's location (including information from a geo-location database), node's mobility level and node's supported applications. Node information is very useful in the decision making process as it provides the necessary data of the available, candidate nodes, in order to select afterwards the best of these nodes. On the other hand, the context awareness functional entity in the CSCI-T is needed in order to acquire information for the status of nodes, which then will be used as input to the decision making mechanism.

Further on, the operator's policy derivation and management in the infrastructure side designates high level rules that should be followed in context handling. Usually, they are imposed by operators/ regulators and refer to reconfiguration strategies, such as operator's preferences and priorities on goals to be achieved. These are related to the maximization of the QoS levels, and the minimization of cost factors (e.g. resource consumption). In the terminal side, the operator's policy derivation and management is replaced by the policy acquisition from the operator which is responsible for acquiring the necessary policies from the CSCI in the infrastructure side.

In turn, the profile management functional entity in the CSCI includes preferences, requirements and constraints of user classes and applications which are required for the decision making. In the terminal side, the profile management functionalities are also included in order to provide details on the user class and application requirements and constraints.

In case that the conditions (dictated by the policy engine) or the potential gains by the operation of the ON are satisfied, the CSCI will come up with an ON blue print design and pass it to the CMON for the execution. To that respect, the result of the ON suitability determination phase (i.e. the request for creation of an ON) will be passed to the CMON which will handle the actual creation of the ON.

3.2.2. Cognitive Management System for the Opportunistic Network (CMON)

The CMON is responsible for executing on the design obtained from the CSCI and then operationally supervising the created ON. This entity is in charge of the creation, maintenance and termination (according to the policies maintained in the CSCI) of the ON. Moreover, the CMON is responsible for the coordination of nodes in the ON. The CMON is also located in both the operators' infrastructure and the terminal side.

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Generally, as also depicted in Figure 3-3, the CMON in the operators' infrastructure involves context awareness, policy acquisition and profile management which provide the input for the decision making mechanism. In the terminal side, the CMON provides functionality for the context awareness, the policy acquisition as defined by the operator and the profile management. The cognition relies on the fact that the knowledge management functional entity interacts with the previously mentioned entities in order to make better decisions in the future, according to the learned results.

Specifically, the context awareness functional entity of the CMON in the operators' infrastructure involves QoS assessment, in order to provide constant feedback of the ON's experienced QoS and to initiate reconfiguration or termination procedures in case of a sudden drop of QoS. Also, application status monitoring is essential in order to know whether the application provision has ended, in order to terminate the ON. Resource monitoring is also included to the context entity in order to initiate reconfiguration or termination procedures in case of a sudden loss of resources. In other words, context awareness obtains the following: measurements from radio link layers, geo-location coordinates from device built-in positioning functions, application flows characteristics (e.g., QoS parameters), ON-related device capabilities and context information from specific monitoring mechanisms (e.g., wide-band spectrum sensing functionality). In the terminal side, the CMON provides functionality for the context awareness on the status of QoS and application flows which in turn, provide the input to the decision making mechanism.

The policy acquisition functional entity in both infrastructure and terminal sides, obtains and manages the policies which are being defined by the operator. Policies are used as input during the decision making mechanism for selecting the most appropriate configuration, based on the user profile (preferences) and the context. More particularly, a certain policy specifies a set of rules that the CMON must follow.

The profile management functional entity involves the device capabilities and user preferences. Indicative information includes (i) the set of potential configurations (such as the RATs that the device is capable of operating with, the associated spectrum and transmission power levels), (ii) the set of applications/services that can be used and the sets of QoS levels associated with the use of an application/service, and (iii) the ON-

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related user preferences (e.g. the utility volume/ user satisfaction) associated with the use of an application/service at a particular quality level.

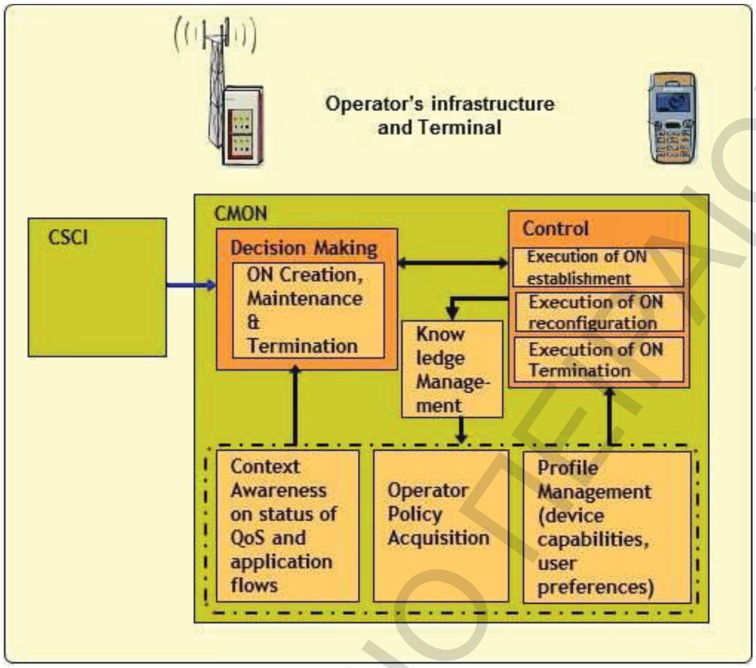

Figure 3-3: Detailed functional view of the CMON in the operator's infrastructure and Terminal's side

Further on, the decision making functionality is present in order to handle effectively the ON creation, maintenance and ON termination according to the input from the context awareness, policy acquisition and profile management functional entities. According to the derived decision, the control entity deals with issues such as the execution of ON establishment/ creation, execution of ON reconfiguration/ maintenance or execution of ON termination. To that respect, it controls whether to proceed with an ON reconfiguration as defined in the maintenance phase or initiate the handover to infrastructure and release of resources in the case of the termination. In case a reconfiguration is deemed necessary, the CCM component will be triggered to control over terminal reconfiguration capabilities. Via the JRRM entity, CMON will control over communication protocol stacks in the terminals and infrastructure nodes by managing radio layers operation (e.g., radio link setup, radio link configuration) and network layer operation (e.g., route management internal to ON and to/from infrastructure).

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The contextual and performance parameters collected by the CMON during the life cycle of an ON are used for learning and improvement of its management functions/logic. Equally these data are passed onto the CSCI for improving the governance functions/logic hosted by the CSCI.

Epigrammatically and considering the functions of the CMON, it is expected to have the ability of managing information exchange with CSCI and other CMONs to allow the discovery of supported ON capabilities in neighbouring infrastructure nodes and devices through capability announcement and pairing mechanisms among peer CMONs. Also, with respect to the context and policy information exchange, the CMON obtains context and policy information from the CSCI, provides context information to the CSCI, both by utilizing the CC interface, and obtains or provides context and policy information from/ to other CMONs by using the OM interface. Also, it issues commands for managing the ON operational phases (e.g., ON establishment, maintenance/ reconfiguration and termination procedures).

Additionally, the CMON manages access to local context information by obtaining measurements from device radio link layers, obtaining geo-location coordinates from device built-in positioning functions, obtaining application flows characteristics (e.g., QoS parameters), obtaining ON-related user preferences, obtaining ON-related device capabilities and obtaining context information from specific local monitoring mechanisms (e.g., wide-band spectrum sensing functionality).

The CMON-T has control over terminal reconfiguration capabilities and over the communication protocol stacks in the terminal by for example controlling of radio layers operation between terminals (e.g., radio link setup, radio link configuration) or controlling of network layer operation (e.g., route management internal to ON and to/ from infrastructure).

Finally, the CMON-N has control over the establishment/modification/release of bearer services in the infrastructure network to support ON traffic.

3.2.3. Cooperation of Cognitive Management Systems

The exchange of information, knowledge and commands between the different CMON instances as well as between different CSCI instances relies on control channels

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(information, signaling flows and protocols). These “Control Channels for the Cooperation of the Cognitive Management System” - C4MS can be seen as a combination and extension of two concepts: the CPC [5] and the CCR [6], which have been originally proposed and elaborated in the IST-E2R [7], IST-E2R II [8] and ICT-E3 projects [9].

In particular, the CPC is a (logical and optionally in part a physical) channel, which provides information from the network to the terminals, e.g., on frequency bands, available Radio Access Technologies, and spectrum usage policies. Therefore, the CPC will be the basis for the coordination between infrastructure and ONs, i.e., the communication between CSCIs and CMONs.

The CPC concept has been mainly derived from the necessity of the terminals to obtain knowledge of its radio environment in order to switch to the most appropriate available technology and frequency, without the use of spectrum sensing, which is a very time- and power-consuming operation. CPC is a common pilot channel aiming at providing the necessary information for the terminal to get the knowledge of radio spectrum.

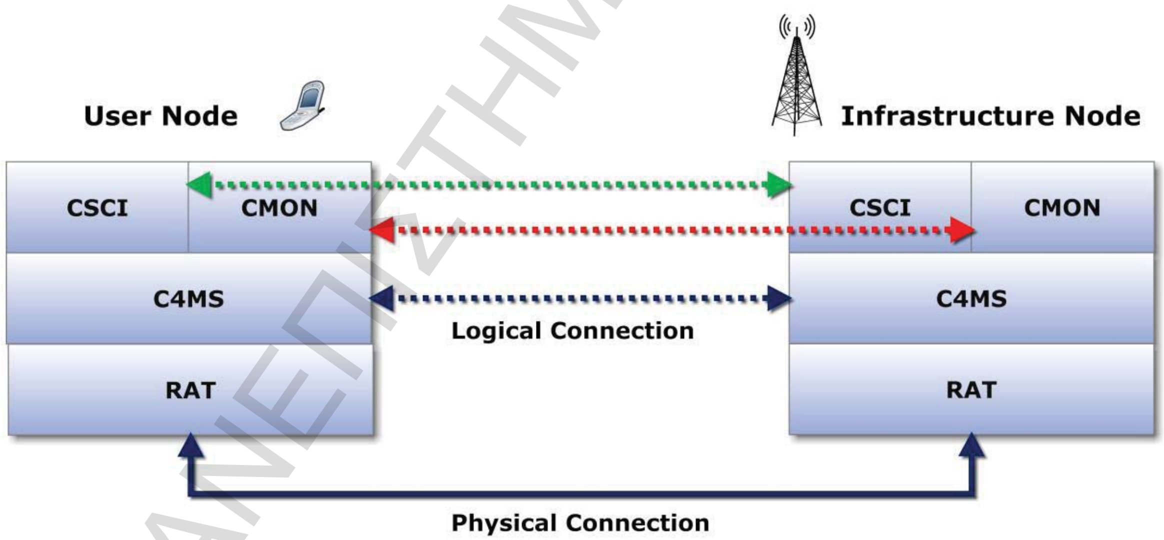

Figure 3-4: C4MS, CSCI, CMON in protocol stack

In addition, the CCR is a channel for the peer-to-peer exchange of cognition related information between heterogeneous network nodes (e.g., between terminals) [10]. Therefore, it will be the basis for the exchange of information/knowledge between the nodes of the ON, i.e., the communication between CMONs. The integration of the two concepts is the product of the C4MS.

Figure 3-4 depicts the C4MS and the two functional blocks CSCI, CMON in the protocol stack for the interworking of network nodes participating in a given ON.

The C4MS provides a common framework integrating both concepts and thus enable communication between terminals as well as between terminals and infrastructure networks. Additionally, C4MS provides functionalities originally defined for CPC and CCR. These functionalities include:

- providing means for exchange of context information, policies, etc., to enable better radio resource utilization,
- provision of context information for supporting terminals in their start-up phase,
- provision of context information for supporting spectrum scanning and spectrum sensing procedures
- providing means for enabling the coexistence and coordination among different networks and devices

3.3. Interfaces Description

FA's operation is realized by means of information exchange among its functional blocks. For this purpose, several interfaces are envisaged.

CI-Interface for the "Coordination with the Infrastructure" located between different CSCI-instances. This interface is used by the infrastructure network to inform terminals (or other infrastructure network elements) about the suitability of an ON and to provide context and policy information which are needed for the later creation and maintenance of the ON. Via this interface, the network can also collect context information from the terminals to enable the ON suitability determination. A distinction can be made between the CI-TT interface connecting the CSCI-instances of two terminals, the CI-TN interface connecting the CSCI in a terminal with the CSCI on Network side and the CI-NN interface connecting the CSCI-instances of two network entities.

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OM-Interface for the "Opportunistic Management" located between different CMON-instances. Via this interface, nodes can first negotiate about the creation of an ON. During the negotiation, node capabilities and user preferences can be exchanged and the QoS capabilities of an ON can be negotiated. After the negotiation, this interface is also used for the exchange of creation, maintenance and release messages. A distinction can be made between the OM-TT interface connecting the CMON-instances of two terminals, the OM-TN interface connecting the CMON in a terminal with the CMON on Network side and the OM-NN interface connecting the CMON-instances of two network entities (e.g. Opportunistic resource aggregation in the backhaul network).

CC-Interface connecting the CSCI in a node with the CMON in the same node. This interface is used e.g. to send a trigger for the creation of an ON from the CSCI to the CMON as well to provide information about the resources which can be used by the ON. Please note that this node interface will only exist if CSCI and CMON are implemented separately. In the case that CSCI and CMON are tightly integrated in one module, then there will be no explicit CC-interface in that node. A distinction can be made between the CC-T interface connecting the CMON and CSCI instances in a terminal, and the CC-N interface connecting the CMON and CSCI instances on network side.

CS-Interface between CSCI/CMON and the DSM. This interface is used by the CSCI/CMON to get information on spectrum usage and spectrum policies from the DSM. This spectrum related information can be used for the suitability determination of ONs as well as for the decision making on which spectrum shall be used in an ON. It is assumed that this interface uses identical procedures and protocols as the MS-interface.

MS-Interface between DSONPM and DSM. This interface is used by the DSONPM to get information on spectrum usage and spectrum policies from the DSM. It allows DSONPM to obtain information about the available spectrum for different RATs, unoccupied spectrum bands and spectrum opportunities.

OJ-Interface between JRRM and CSCI/CMON. Although CSCI and CMON can be separated in different blocks, it is assumed that they use both the same protocol or Application Programmable Interface (API) to exchange information with the JRRM. This interface is used to trigger the JRRM for the establishment and release of radio links during the creation, maintenance and deletion of an ON. Further on, context information e.g. on available access networks or on link performance can also be exchanged via this interface. A distinction can be made between the OJ-T interface connecting the CMON/CSCI instances with the JRRM in a terminal, and the OJ-N interface connecting the CMON/CSCI instances with the JRRM on network side.

OC-Interface between CCM and CSCI/CMON. This interface is similar to the OJ interface and may be used to obtain additional information about the current device configuration which cannot be provided by the JRRM. However, it is assumed that for the normal ON management procedures, the CCM is not involved because the CMON uses the OJ-interface to trigger link setup or release procedures.

The interfaces used by CSCI and CMON (CI, OM, CC, OC, OJ) are new interfaces in the existing architecture of ETSI RRS useful for the management and control of ONs [2]. Furthermore other interfaces (JJ, CJ, CR, JR, MJ, MC, MS, SS) are used for the FA's operation.

CR: Interface between the CCM and the underlying RAT to control the reconfiguration of the radio access in a terminal or BS by the CCM.

JR: Interface between JRRM and RAT used to report information on resource status such as cell load or link measurements towards the JRRM; Further on, this interface is used for the creation, modification and release of radio links in the underlying RATs.

CJ: Interface between CCM and JRRM used by the JRRM to instruct the CCM on reconfigurations;

MJ: Interface between DSONPM and JRRM used to provide status information like cell load and other Key Performance Indicators (KPIs) from the JRRM towards the DSONPM;

MC: Interface between DSONPM and CCM used by the DSONPM to instruct the CCM on reconfigurations;

JJ: Interface between different JRRM-instances for the exchange of JRRM related information between different nodes. A distinction can be made between the JJ-TT interface connecting the JRRM-instances of two terminals and the JJ-TN interface connecting JRRM in a terminal with the JRRM on Network side;

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SS: Interface between different DSM instances or between the DSM and an external geo-location database;

RR: Interface between the different RATs. This can e.g. be the interface used by a GSM, UMTS, LTE, WLAN or other protocol stack in the terminal towards a protocol stack of the same RAT in another terminal or in the network infrastructure.

3.4. Indicative FA Operation

This section presents an indicative use case, for exemplifying the FA's operation. Figure 3-6 depicts an overview of the overall process and the corresponding interactions between the various FA entities for the capacity extension scenario, which it is divided in three main phases. The first is the Problem Identification Phase (P1 in Figure 3-6), Suitability Determination Phase (P2 in Figure 3-6), and finally the Creation Phase (P3 in Figure 3-6). As already presented and depicted in Figure 3-5, it is assumed that a specific area which experiences traffic congestion issues can be offloaded with the creation of an ON in order to re-route the traffic to non-congested BSs.

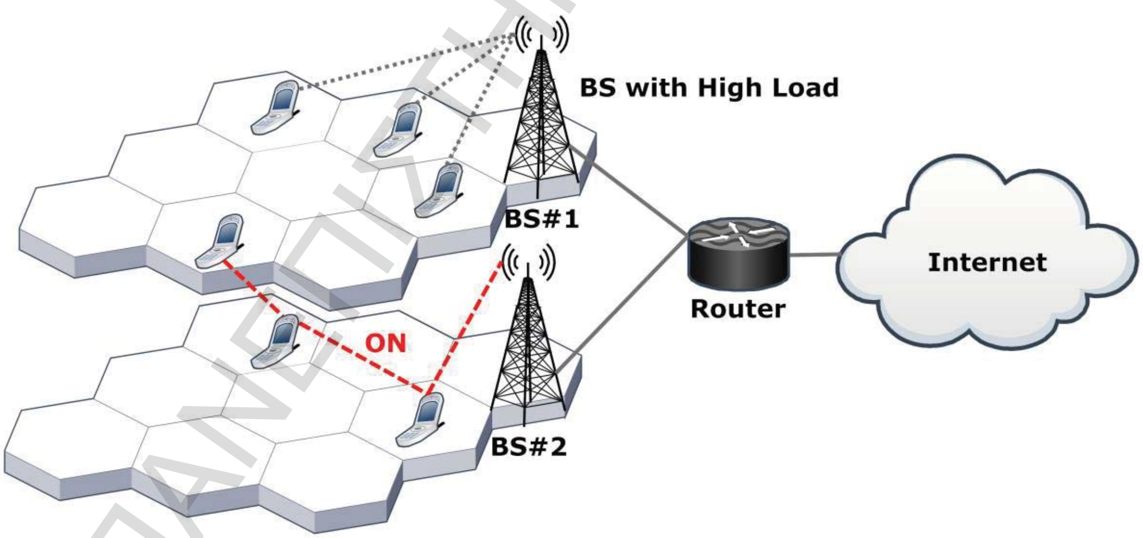

Figure 3-5: Capacity extension Scenario

In particular, the procedure starts when a BS identifies a congestion situation, through its CSCI entity. This is depicted in the "Problem identification" phase of Figure 3-6. As

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soon as an infrastructure element starts experiencing congestion issues it reaches a warning level where reconfiguration is imminent. The congested BSs, and especially the CSCI functional block sends the notification to the DSONPM entity in order to inform it about the problematic situation. The DSONPM indicates the BS that will solve the problem, which will also populate the set of terminals that will be moved from the congested area to alternate BSs ("Suitability determination" phase of Figure 3-6). All non-congested BSs in the vicinity are identified.

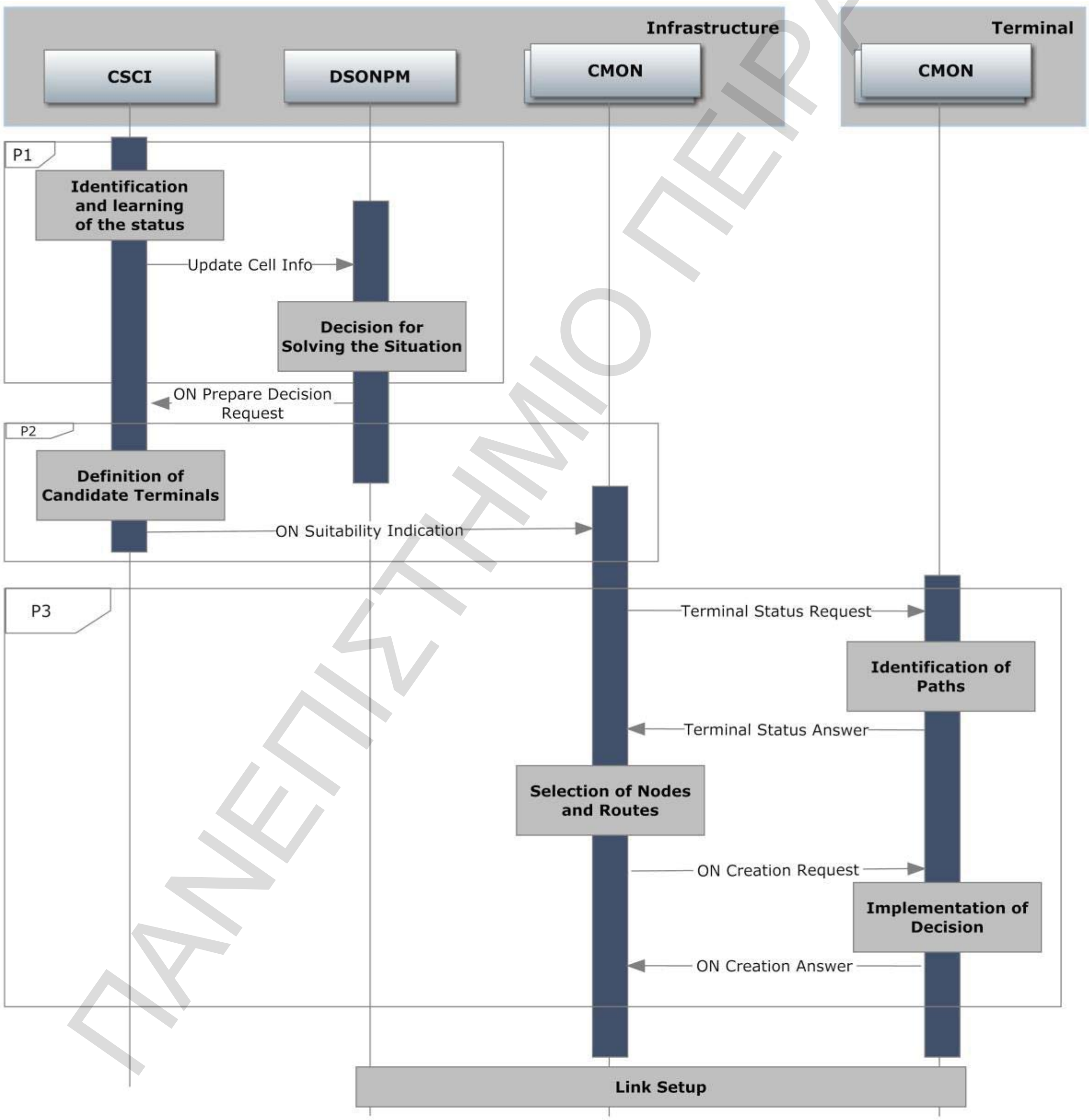

Figure 3-6: Indicative Message Sequence Chart for Capacity extension

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For both the congested as well as the uncongested BSs information on the respective terminals is acquired through the CMON entities ("Creation" of Figure 3-6). This information includes the BS to which each terminal is currently connected, the capacity of each terminal, and its neighboring terminals. The information from all terminals is collected by the selected BS CMON entity in order to obtain information on all potential paths from terminals in the congested area to alternate BSs, through other terminals in the non-congested or congested area.

The aim is to find the most appropriate paths to re-route the terminals in the congested area to alternate BSs (*Selection of Nodes and Routes* process). As an outcome, each terminal should be provided with a path to a BS, allowing it to obtain the required QoS.

3.5. FA Mapping to network entities

As already presented, for the management and the cooperation of the ONs the FA consists of two main building blocks: the CSCI and the CMON, and for the coordination and collaboration of these two, the C4MS.

The FA can reside in various elements of an underlying network. ONs may consist of different systems (e.g. 3GPP based systems such as GSM, UMTS or LTE and non-3GPP systems such as WiMax, WiFi, Bluetooth, WiMedia). In order to enable the realization of the ON management and the exchange of context information for such scenarios, the C4MS needs to allow for the establishment of connections (logical or physical) between different entities which reside on the terminal as well as on the infrastructure side, over different underlying technologies. In order to minimize the impact on the existing networks the management extensions are proposed to be placed in the RAN, leaving the CN intact.

Figure 3-7 shows an attempt to map the proposed FA to existing network entities. As can be seen from the figure, the C4MS is supported by all the entities which employ CSCI and/or CMON and it can be seen as an intermediate layer residing between CMON/CSCI and the underlying layers. The blue dashed lines represent interfaces between CSCIs of different network nodes (CI) or interfaces between CMONs of

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different network nodes (OM). The interface between CSCI and CMON inside the network nodes is not shown here.

Figure 3-7 shows also the JRRM, CCM and DSM blocks. The nodes are based on existing network nodes, especially on nodes used in 3GPP based networks. Devices depicted in the CN correspond to the 3GPP EPC (Evolved Packet Core) network structure [11].

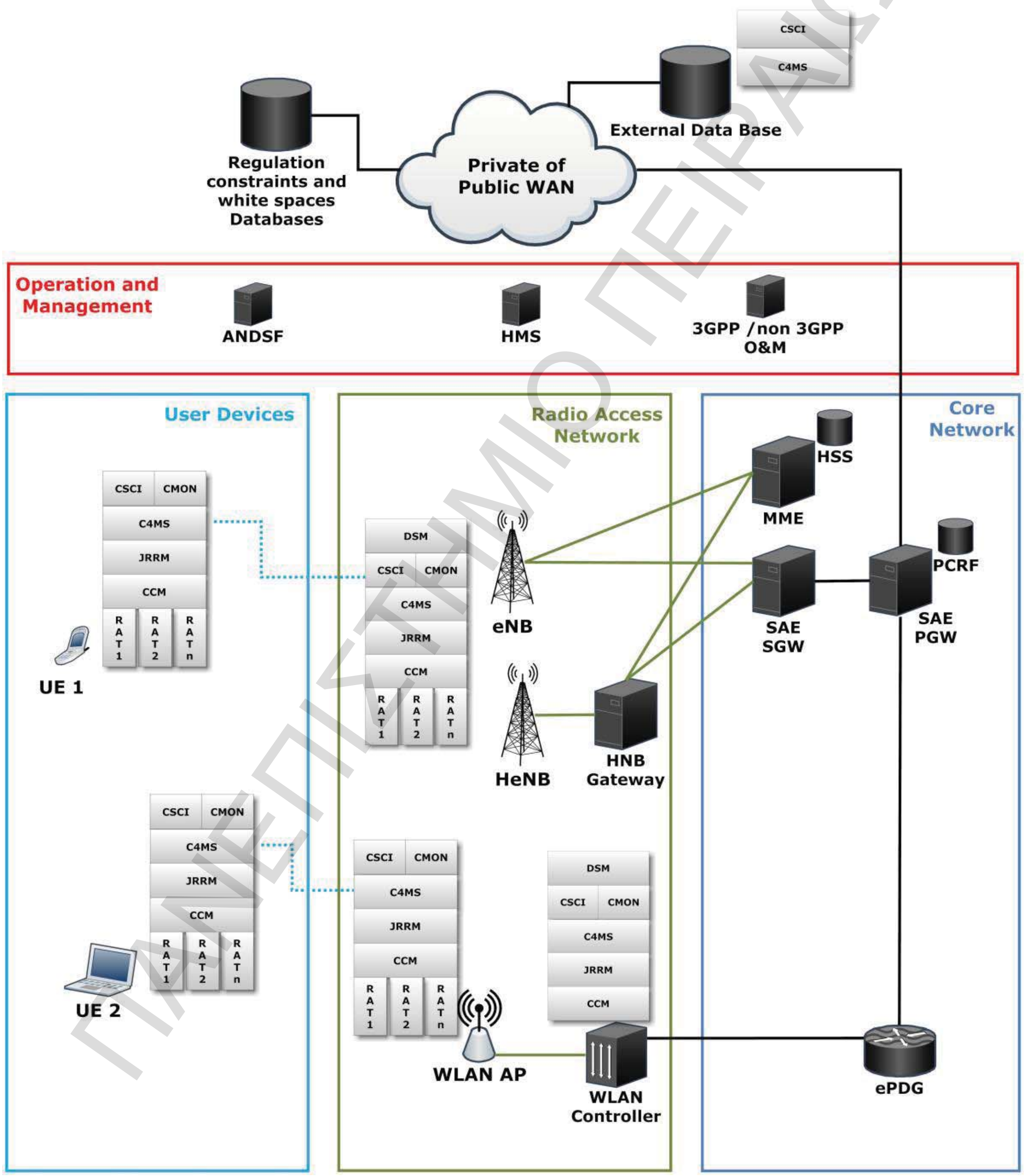

Figure 3-7: Mapping of the building blocks to the underlying network

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In the radio access part of the infrastructure network, the FA will be mapped onto all types of radio access devices: BSs (enhanced Node B), APs (WLAN 802.11a/b/g/n, WiMAX), femto-cells (Home enhanced Node B), etc. These devices will be able to trigger the ON suitability determination, to participate in the ON creation, to forward ON parameters to other network devices, to gather spectrum sensing and traffic monitoring data for cognitive systems and to participate in the ON termination process. A WLAN controller is introduced in the access network in order to present the fact that the FA can also be established over 802.11 networks.

Parts of the CSCI may also be located in a database in a public or an operator owned WAN cloud. Cognition related information may be stored in this data base and processed in coordination with the operator and regional/country wide policies and rules on spectrum usage, application provision, QoS requirements, etc. Results of this data processing step will be a set of predefined actions and instructions how the system should react to detected changes in the network environment. Also, responses to earlier encountered triggers for ON creation will be faster. CSCI is depicted as part of this database in order to represent the fact that this data base will be able to receive cognition related information from CSCI blocks of other network nodes but will not be part of ONs.

3.6. Suitability Determination

As already stated, one of the main goals of this dissertation is the investigation of the potentials of the proposed solution (depicted in Figure 2-1) that is based on dynamically created ONs, which are operator-governed and coordinated, temporary, extensions of the wireless network infrastructure. That is to say, the main objective is the investigation under which circumstances the creation of an ON will be beneficiary for the overall network. This is actually done by recognizing that the first step prior to proceeding with the establishment of such an ON, is to be able to judge the suitability of doing so. Normally, the responsibility for such functionality burdens the CMSs, in particular the CSCI entity and the suitability determination process, which should be able to reply positively or negatively upon taking such an action.

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Suitability determination should take into account multiple input parameters consisting in (i) the availability of spectrum from the infrastructure side (ii) the number, location and capabilities of candidate nodes (available interfaces, supported RATs/frequencies, support of multiple connections, relaying/bridging capabilities, existing paths to the infrastructure), (iii) the availability of resources (storage, processing and energy), (iv) the type of applications and services to be used, (v) traffic, demand and mobility patterns. At the same time is should provide the mechanisms for carefully evaluating the anticipated benefits such as i) the provision of adequate QoS levels to applications/users or the provision of more and enhanced applications, ii) the efficient spectrum utilization and the lower transmission powers, which can lead to lower energy consumption or iii) other impacts and costs e.g. related to signalling and data traffic reduction through the infrastructure, to potential increase in operator's cash-flow or to caused interference.

The suitability determination process is going to decide whether or not it is appropriate to set up an ON, at specific time and place and this is going to trigger the creation of these networks. Additionally, it will give as an output a request for the creation process of the ON, associated with a pre-selected set of candidate nodes that offer at least on radio path to an infrastructure AP and at least one radio path between each pair of nodes.

Moreover, under certain circumstances/criteria, the suitability determination process will be triggered. Such criteria could be (i) the bad coverage of nodes inside the cell or (ii) the existence of nodes out of the coverage. Furthermore high level rules from the infrastructure can trigger the process. These are related to the maximization of the QoS levels, and the minimization of cost factors (e.g. resource consumption). Interference problems among APs or/and nodes could also trigger suitability determination process but this is not covered by the results of this dissertation and will be subject of our future study.

Obviously, the above is not a trivial task to accomplish. A rough initial feasibility analysis is required in order to keep complexity moderate. This can rely on off-line simulations, which are conducted a priori so as to evaluate candidate solutions against multiple, disparate input parameters and assessment criteria. The results derived from such simulations can be then utilized to design and develop proper algorithms/strategies for

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the CSCI entity (Suitability Determination process) that will be able to decide on the feasibility of creating the ON when required, while in operation or even in a proactive manner.

Finally the decision of the CSCI will be provided by means of proper policies, to the CMON functional entity for the actual creation of ONs. These off-line simulations are conducted in Chapter 4 and 5, which are differentiated with respect to the type of applications and services to be used and the mobility level of the terminals, respectively.

3.7. Conclusions

This chapter has presented a FA, by means of functional blocks and interfaces, for the management and the control of the ONs as an extension to the wireless infrastructure. The proposed FA will help to improve efficiency in resource provisioning and provide to users high quality services anytime and anywhere. Moreover the FA incorporates CMSs that can be used for managing the ONs by making decisions based on context, policies and profiles and empowered by knowledge and experience deriving from learning functionality. Particularly CSCI and CMON are the main functional blocks for the control of the ONs during their lifecycle. The CSCI is responsible for the activities before an ON is created and includes mainly the suitability determination process. When the CSCI has made a decision that an ON is suitable, the decision is then sent to the CMON for the actual creation of the ON. In this respect the suitability determination process has also been presented in this chapter, which is going to decide whether or not it is appropriate to set up an ON, at specific time and place, in order to be beneficiary for the overall network.

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4. SUITABILITY DETERMINATION OF OPPORTUNISTIC NETWORKS WITH APPLICATION REQUIREMENTS

Chapter Outline

The smooth advent and adoption of FI requires solving problems associated with the provisioning of QoS in applications, taking into account factors like resource utilization efficiency, low energy/power consumption and reduced total cost. In this respect, the proposed ON-based solution seems very promising and can prove beneficiary in various scenarios of the FI. The aim of this chapter is to study the feasibility of extending the infrastructure with an ON (why, where and when) so as to find the conditions under which it will be beneficiary for the overall network. The emphasis is primarily given to the type of the applications offered to the users. The study is mainly based on extensive network simulations, which revealed that the ON-based scheme seems to work and has great potentials to bring about benefits under certain circumstances. This chapter presents also the simulation environment and a detailed description of the test cases and simulations that were setup in order to validate our proposed solution. Moreover a great set of the results obtained by the simulations is presented in order to extract useful recommendations.

Keywords: Suitability Determination, Network Simulations, Application Requirements, Uniform – Random Distribution, Business - Case

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4.1. Introduction

In the context of the ON-based proposed solution, it is advocated that an operator will exploit infrastructure-less networks for complementing the infrastructure, in order to achieve green targets or to expand its initial coverage. The suitability of extending the infrastructure with the use of ONs can be determined based on the involved applications as well as on the anticipated benefits in terms of adequate QoS level provisioning and power consumption. In particular, this chapter aims to provide justified recommendations on whether and when the creation of an ON as a temporary extension of the CWN, might be beneficiary for the global network efficiency and for the whole of key players. For that reason, extensive network simulation studies are conducted with the intention to cover a large gamut of cases in order to increase the validity of the finally extracted recommendations. The emphasis is mainly given to modern type of applications and the distribution of the terminals in the simulated area. Actually, the importance of such simulation studies is twofold: a) to shed light in those circumstances under which the creation of ONs should be recommended and b) to use the results in order to design and develop proper strategies for the CSCI entity (Suitability Determination process) that will be able to decide on the feasibility of creating the ON when required, while in operation or even in a proactive manner. In general, it is claimed that under certain conditions, the coordinated extension of CWNs by ONs will probably result in QoS and power efficient overall network states. Eventually, this is supported by the results obtained from the respective simulations of this chapter.

Accordingly, the rest of this chapter is structured as follows. A detailed description of the test cases and simulations that were setup in order to validate our concept are presented first. Then the set of the results obtained from the simulations with a general discussion on the derived recommendations for the creation of ONs is presented in Section 4.3. Finally, the chapter is concluded in Section 4.4.

4.2. Simulation Setup

This section discusses on the simulations that have been setup, in order to validate the ON-based proposed concept and give some evidence on the potentials arising from the

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exploitation of infrastructure-less segments by composite wireless infrastructures. A large set of scenarios and test cases were executed in the simulation environment, which was based on the widely used OPNET/OMNeT++ network simulation environments [1], [2] and ran on an Intel Pentium - 4 3,0 GHz with 1,5 GB of RAM.

4.2.1. General Setup

The topology comprises a single AP operating at IEEE 802.11b technology and a total set of 20 terminals which are served by this AP. The propagation model is set to Free Space, with no effects from the environment and the terrain profile is flat with the elevation of the AP set to 20m. The initial transmission power of the AP is set equal to 0.03W, thus resulting in a cell with a radius equal to about 500m.

Table 4-I: General parameters of the simulation environment

Area	*250 x 250 m*
Simulation Time	*60min*
Physical Characteristics	*802.11b, Direct Sequence Spread Spectrum (DSSS)*
Physical Layer Data Rate	*11Mbps*
Total Number of Terminals	*20*
Access Type	*DCF*
Reception Power Threshold	*-95 dbm*
Initial AP Trx Power	*0,03 W*
Terminals Trx Power	*0,02 W*

The choice of one single AP was made deliberately so as to relax our study from bothering about any frequency planning/ interference aspects inherent to a multi AP environment. Moreover, terminals are assumed to be static. Table 4-I summarizes the general input parameters of the considered simulation environment. Last but not least, a

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set of applications are considered to be offered to the terminals through the AP and further analyzed in the following.

4.2.2. Application aspects

Three types of applications are considered in the simulation scenarios, which were selected so as to exhibit varying and scalable resource requirements and sensitivity e.g. with respect to bandwidth, delays, jitter, packet loss etc. These are a) Internet browsing b) Voice over IP (VoIP) and c) Video conference.

Internet browsing is modelled as a so called "Internet light Browsing". In particular, it uses HTTP protocol [4] to download a web page of size equal to 500 bytes, plus an embedded, small image of 250 bytes. Other important properties for the browsing application are listed in Table 4-II.

Table 4-II: Traffic Input Parameters

Browsing	*Light, Protocol Version : Http 1.1 [4]*	
	Page Interval Time : Exponential 720 sec	
	Pages Per Server : Exponential 10	
	Page propeties:	*1 constant part : 500 bytes*
		5 Small Images : 250 bytes each
VoIP	*Encoder Scheme G.711 (silence) [3]*	
	Compression / Decompression delay 0.02 sec	
	1 voice frame per packet	
	Incoming and outcoming Conversation environment : Land Phone – Quiet room	
	No control signalling(e.g. for setup/release) included	
Video Conferencing	*Low Resolution Video : 128X120 pixels, 9 bits/pixel*	
	10 frames/sec	

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The VoIP application is based on the G.711 [3] voice encoding scheme for both the caller and the callee, with 1 voice frame per packet and without containing any control messages for the setup/release. Further values for the attributes of the modeled VoIP application are given in Table 4-II.

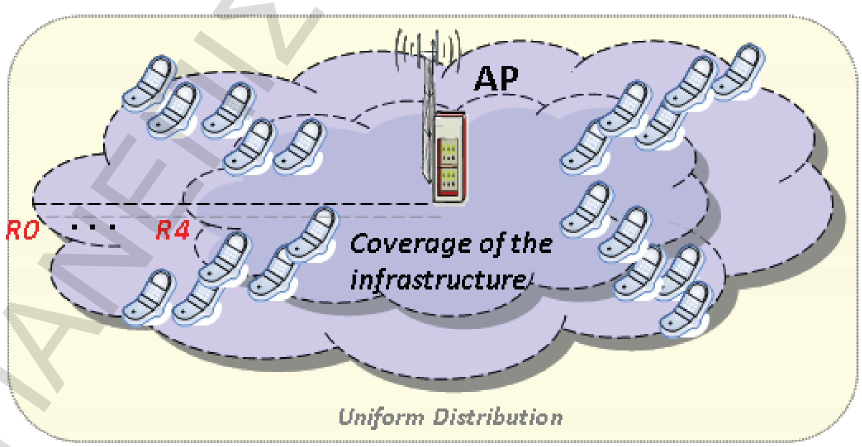
Finally, a Video conferencing application is considered for the transfer of video streaming frames between the terminals of the network. The application is a low resolution video with 128x120 pixels, 9 bits/pixel and 10 frames/sec. Once again, the details for the assumed values for some important video conference attributes are also summarized in Table 4-II.

It should be noted that the type of service for all the three assumed applications is set to Best Effort (BE). This is quite fair, since we are not interested in giving priority to the traffic of a specific application against another. Actually, as revealed in the sequel, the simulations were run assuming one application each time.

4.2.3. Simulation scenarios

Two main cases are considered, which are differentiated with respect to the way that terminals are distributed around the WLAN AP. In the first case, terminals are uniformly distributed in the cell around the AP, whereas the second case assumes a random distribution of the terminals in the cell. Figure 4-1 depicts the uniform and random distribution of the terminals in the area.

(a)



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(b)

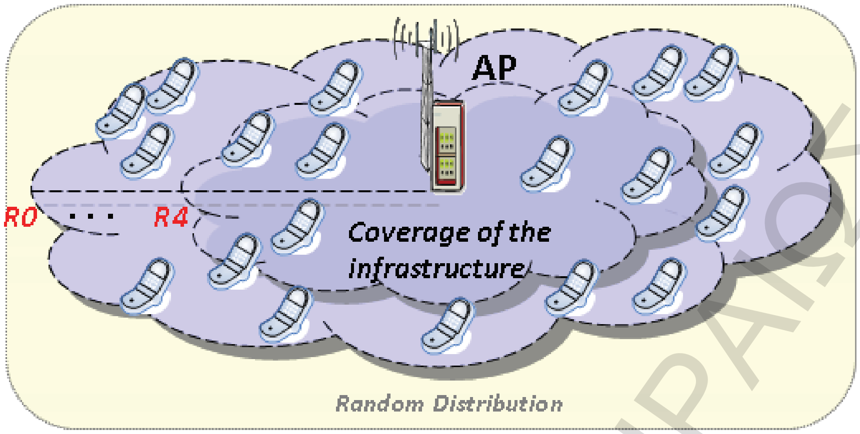

Figure 4-1: Coverage area *(a)* Uniform and *(b)* Random Distribution

In both cases above, the examined simulation scenarios evolve as follows. The initial transmission (TRx) power of the AP is gradually decreased. Five steps (phases) are considered, each one corresponding to a specific percentage of the initial TRx power, namely: 100% (initial), 90%, 80%, 70% and 60% , thus resulting in ranges R0, R1, R2, R3 and R4, respectively. This is depicted in Figure 4-2 in which it is also shown how the initial coverage of the AP is being reduced to a smaller one as a result of the gradual decrease of its transmission power. Apparently, it holds that R0> R1> R2> R3> R4.

During the gradual reduction of the AP's TRx power, a number (percentage) of terminals are left out of the APs' range. These terminals are then supposed to create ONs among them in an ad-hoc manner and operating in WLAN 802.11b as well. It should be noted that the issue of interference between the transmitting terminals is not taken into account and is left out for future study.

The exact number of nodes connected in ad-hoc mode in each of the phases and for both scenario cases is shown in Table 4-III. In the uniform distribution case, as the initial range of the AP decreases, the number of the terminals that are out of this range increases in a constant way. On the contrary, in the random distribution case the number of the ad-hoc connections increases in a rather irregular way, leading for example in situations like the ones observed in Table 4-III, where the same number of ad-hoc nodes appear in both phases 4 and 5.

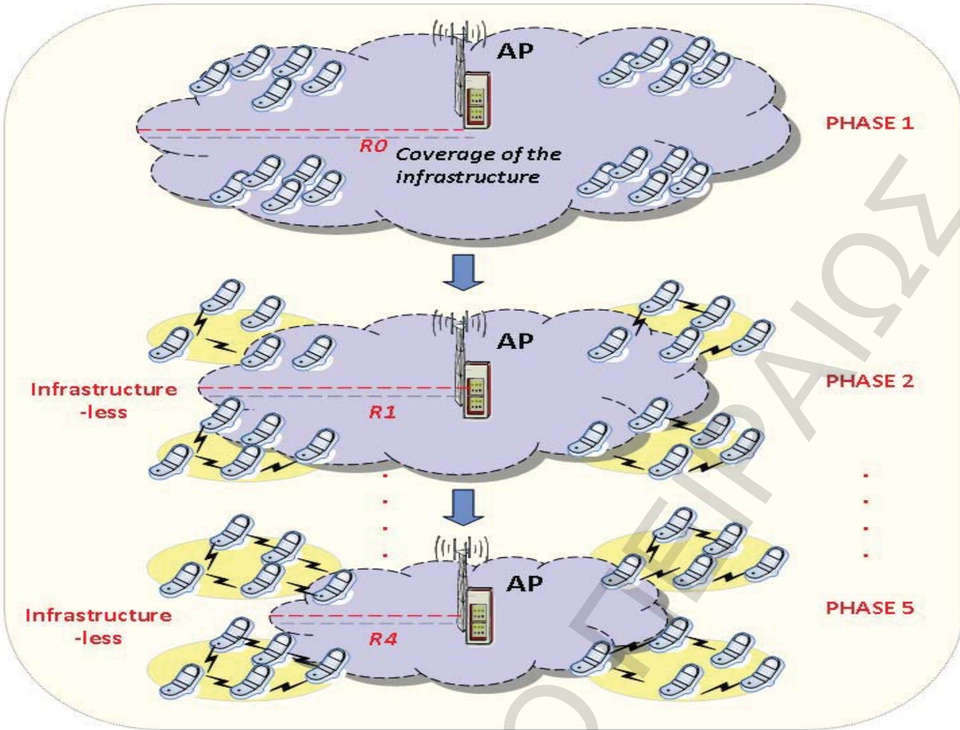

Figure 4-2: Considered scenarios

Table 4-III: Number of out of range terminal nodes per phase

Phases	Ranges	Number of out of range terminal nodes	
		Uniform Distribution Case	Random Distribution Case
1	**R0**	*0*	*0*
2	**R1**	*4*	*3*
3	**R2**	*8*	*7*
4	**R3**	*12*	*11*
5	**R4**	*16*	*11*

Finally, we also experiment on the routing protocol which will be used to route traffic to terminals that are found out of range during the AP's transmission power reduction. Although, this might be more interesting to study when considering a mobile environment (Chapter 5), for completion reasons, we conduct all the simulation scenarios assuming 3 different kinds of ad-hoc routing protocols, namely Ad hoc On-Demand Distance Vector routing protocol (AODV) [5], Optimized Link State Routing protocol (OLSR) [6] and Geographic Routing Protocol (GRP) [7].

4.3. Simulation results and recommendations

In this section, a description of the QoS metrics used for the evaluation of the creation of ONs is presented, along with the comprehensive results from the execution of the simulations.

4.3.1. QoS Metrics

As also stated in the introductory sections, in a real environment the decision on whether or not to create the ad-hoc network(s) should be done in a dynamic manner and by taking into account certain suitability criteria. Accordingly, the major concern of these simulation studies is to investigate the QoS provision potentials of such a scheme and thus, assist in the definition of these criteria.

Accordingly, in each of the phases our study focuses on specific QoS metrics, which are used to evaluate conditions and assist in coming up with useful recommendations with respect to the creation of the ONs. Particularly, in this simulation study, QoS evaluation is carried out by the following performance metrics:

a) Delay (sec): which is the one way, end to end delay of data packets from the sending to the receiving node. It includes a) processing delays e.g. voice packet compression/decompression, packetization etc. b) queuing and medium access delays in the AP as well as in the intermediate nodes, c) TRx delay of the AP and the intermediate nodes and d) the propagation delay for each connection between the AP and the destination node.

b) Data received (Kbps): which corresponds to the total number of the successfully received packets (including PHY/MAC headers) by a wireless node, regardless of the destination of the received frames.

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c) Data Dropped (Kbps): which is defined as the rate at which data is dropped due to full higher layer data buffers or because of too many retransmission attempts

Table 4-IV: QoS requirements per application type [8]

Applications	Technology	QoS Metrics			
		Delay (ms)	*Jitter (ms)*	*Bit Rate (Kbps)*	*Packet Loss*
Browsing	Non real time and Asymmetric	<400	N/A	<30	0%
VoIP	Real Time and Symmetric	<100	<400	64	<1% (lasting 2-3 sec)
Video Conferencing	Real Time and Symmetric	<150	<150	1382,4	<1%

d) Throughput (Kbps): which corresponds to the total data traffic in bits per sec, successfully received by the destination excluding packets for other destination MACs, duplicate and incomplete frames.

e) Jitter (sec), which is used to denote the average time difference between the arrivals of two consecutive packets at any destination node.

All the above metrics are averaged to the set of terminals in the simulated network. Moreover, Table 4-IV summarizes the requirements for specific QoS metrics [8] and for each of the considered applications. This table will be used as a reference throughout the rest of this chapter and will assist in extracting conclusions and recommendations from the derived statistics.

4.3.2. Results

In the sequel, the possible QoS provision potentials from the exploitation of the ONs by the infrastructure-based part during the five defined phases will be investigated. Specifically, comprehensive results from the execution of various scenarios differentiated with regard to the type of application offered and the deployed ad-hoc routing protocol follow. Furthermore, a business case scenario is presented in order to showcase and validate the ON-based solution in a situation more likely to a real-life.

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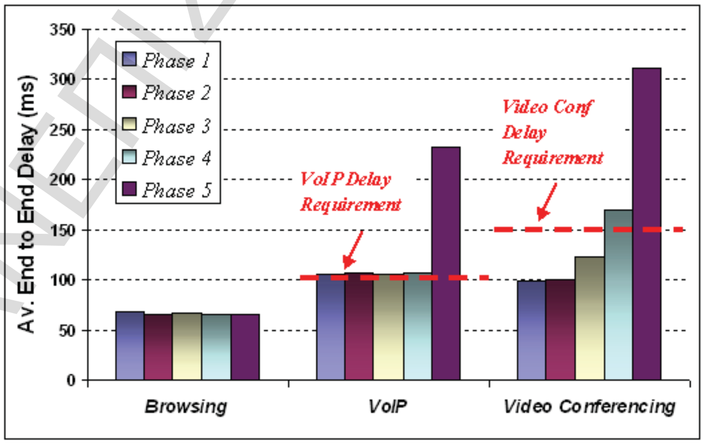
Case 1 – Uniform distribution

Figure 4-3 depicts the average end-to-end delay that the packets of each terminal nodes see and which, as already said, is estimated by summing up processing, queuing, MAC, transmission and propagation delays as well. It should be noted here that the end-to-end delay that is measured by the network simulator, actually assumes a terminal node in the one end and the AP in the other end.

That is to say, in order to obtain the actual end to end values, we should first double the obtained simulation measurement (reach the other terminal node) and add a worst case delay of about 65ms [9] corresponding to the extra delay due to the packets traversing the public internet. Therefore, Figure 4-3 depicts exactly these elaborated results.

For the Internet browsing application the average delay (averaged in all phases and routing protocols) is about 67,09ms. In the case of VoIP application, the average value for the delay is about 126,82ms. Finally, the Video conferencing application exhibits an average delay of about 188,12ms and as the number of the terminals that are out of the range is increasing, there is a big rise in the delay.

(a)



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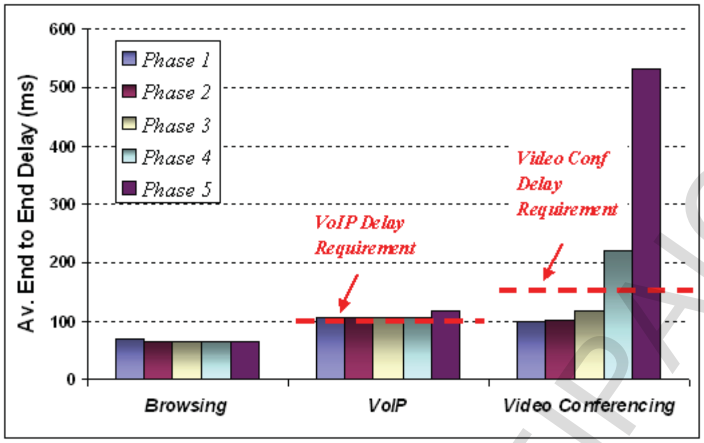
(b)



(c)

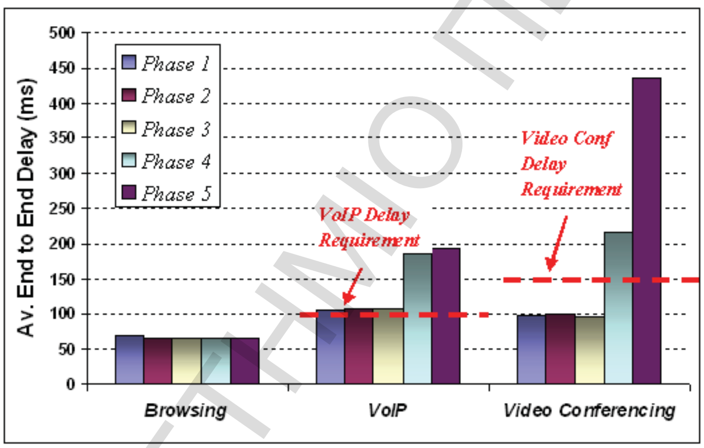


Figure 4-3: Av. End to End Delay per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

As a general observation, since the number of the intermediate, out of range nodes is increasing, while the AP's range is shrinking from R0 to R4 (phase 1 to 5), the overall delay is also increased as more terminals are responsible for routing and forwarding the received packets. Nevertheless, the end-to-end delay increases in a nonlinear manner in contrast with the number of out of coverage terminals, which increases linearly, due to the uniform kind of terminals' distribution (see Table 4-III). In particular, this increase is almost inexistent in the case of Internet browsing application, keeping the delay values negligible in all phases. The increase is made clearer in the case of VoIP, but still remains at low levels in the first 4 out of the total 5 phases and in almost all cases of

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routing protocols. Finally, it is rather considerable in the case of Video conferencing in almost all the phases, especially in phases 4 and 5.

Similar results can be derived when examining Figure 4-3 with respect to the used routing protocol. For instance, there are negligible differences in the produced delays for the three protocols, when using the internet browsing application. On the other hand, OLSR seems to clearly outperform its competitors in the case of VoIP application giving an average delay (for the 5 phases) almost 30ms less than the ones collected in the case of AODV and GRP, respectively.

However, it should be noted that this variation is mainly ascribed to the last two phases, 4 and 5. While in phases 1 to 3, no significant differences exist. A quite similar situation appears in the Video conference application, but with the AODV being the winner this time, resulting in 75ms and 30ms less delay values compared with the OLSR and GRP, respectively.

In the sequel, we examine the obtained results against the set of predefined application requirements given in Table 4-IV. By advising the table, it is assumed that the one way acceptable end-to-end delay for VoIP and Video conferencing applications are 100ms and 150ms, respectively [8]. The results are also depicted in Figure 4-3, where single dotted lines corresponding to the delay requirements for the two time-sensitive applications are also drawn for readiness purposes. The delay requirement for web browsing (< 400ms) is not depicted, since it is far away from being violated in all the examined cases. Phase 5 seems to be a prohibitive state for the network, when considering VoIP and Video conference applications. Moreover, phase 4 can also result in intolerable delays e.g. when OLSR and GRP routing are deployed.

Accordingly, the above designate cut-off values for the transmission range (or transmission power), which in the majority of the combinations of the tested application and routing protocol can be found somewhere between the 70% and 60% (fine-tuning might be needed) of the initial one. A 30% or 40% reduction of the AP's transmission power while offering applications with tolerable values of delays is very promising with respect to power/energy savings and gives a positive feedback to the suitability question upon creating the ON.

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The next set of results focuses on the total received data metric. In particular, Figure 4-4 depicts the average data traffic per node, which is successfully received by the MAC from the physical layer in Kbps and comprises all the data traffic received regardless of the destination of the received frames and including also the PHY/MAC headers of the packet.

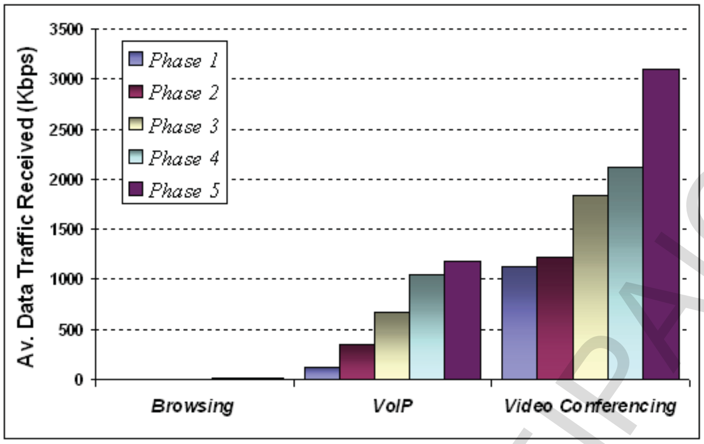
In general since the number of the ad-hoc connections increases from phase to phase, the average number of control and data packets circulating in the network, also increases. This can be justified by the fact that, as the AP's coverage is reduced, the number of terminals that are forced to route traffic to other terminal nodes increases and thus, more traffic is traverses each node in average.

What is shown in Figure 4-4 is that independently of the application and/or routing protocol considered, there is a common trend towards increasing the number of received data while moving from phase 1 to phase 5. In the case of Internet browsing, the average data received (averaged in all phases and routing protocols) remain low i.e. about 8.25Kbps. On the contrary, the data received in the rest two, more bandwidth consuming applications, are by far higher compared to the case of Internet browsing, namely equal to 699.20Kbps and 1944.16Kbps, respectively.

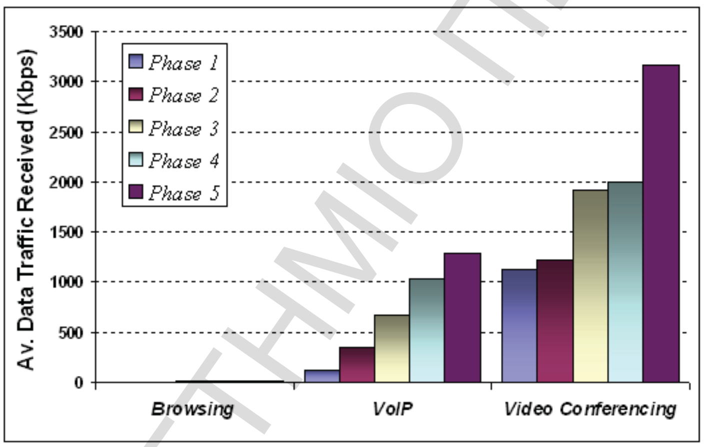
In addition, when examining Figure 4-4 with respect to the used routing protocol, we observe that there are little differences in the total data received metric for the internet browsing case. However, the differences become more considerable in VoIP and video conference applications with AODV leading to clear less average data received per terminal node. In VoIP case, AODV gives average data traffic received (for the 5 phases) about 16Kbps and 37Kbps less than the ones collected in the case of OLSR and GRP. In the video conference case, these differences are found to be about 4Kbps and 172Kbps, respectively.

ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

(a)



(b)



(c)

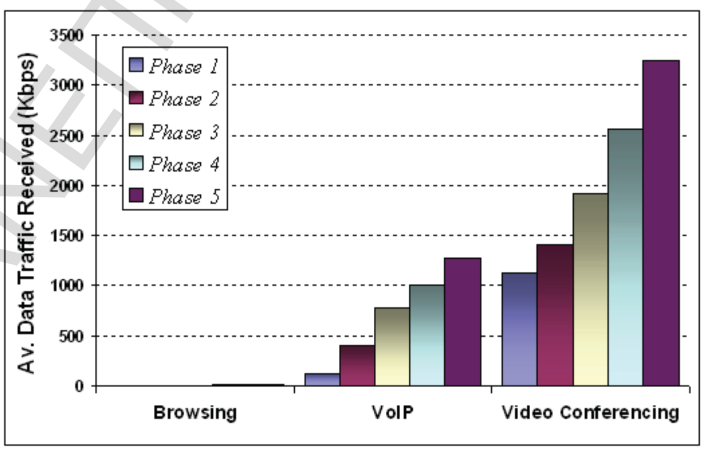


Figure 4-4: Av. Data Received per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing Protocol

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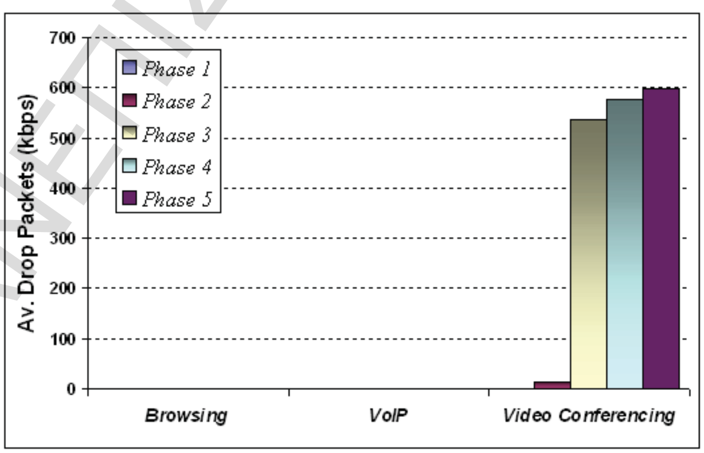
Although not directly seen, this metric can prove rather critical since it highly impacts the energy consumed per node, mainly due to requirement for processing and forwarding extra packets from phase to phase. Going one step further, this might be prohibitive in case the terminal is mobile and its life is purely based on its battery level. Actually, there exists an interesting trade off among the AP power and the power consumed by each terminal as a result of this gradual decrease of the AP. The proper handling of this trade off can be used to set suitability criteria that will boost infrastructure-less network creation decisions with a "green" footprint.

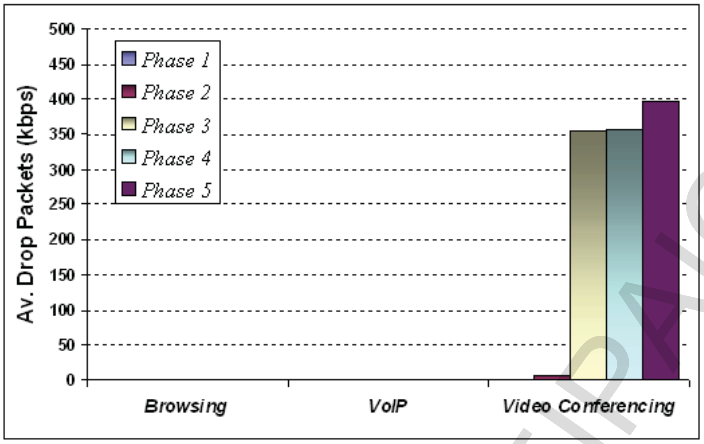
Next we concentrate on the packet loss experienced by each terminal node. The metric that is collected is the average data dropped in bits/sec as a result of either buffer overflows or exceeds in retry thresholds. Results are depicted in Figure 4-5 *(a), (b)* and *(c)*.

However, in order to make the results comparable to the respective requirement expressed as Packet Loss rate in Table 4-IV, we slightly elaborate on the collected metric. In particular, what is actually calculated and finally depicted in Figure 4-6 is the % percentage of packet loss which arises after dividing the number of dropped data with the data sent by all clients.

(a)



(b)



(c)

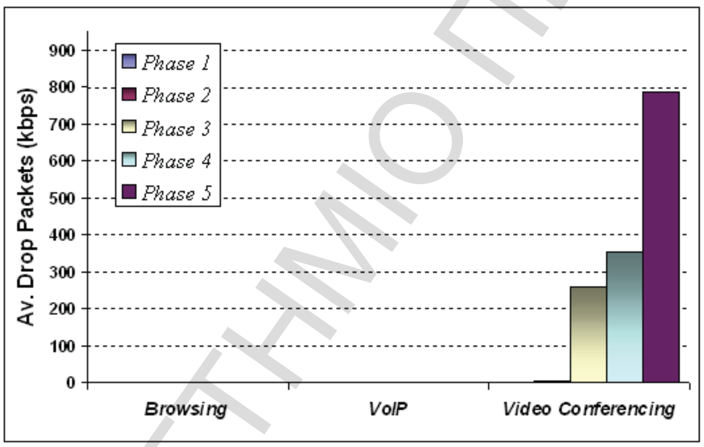
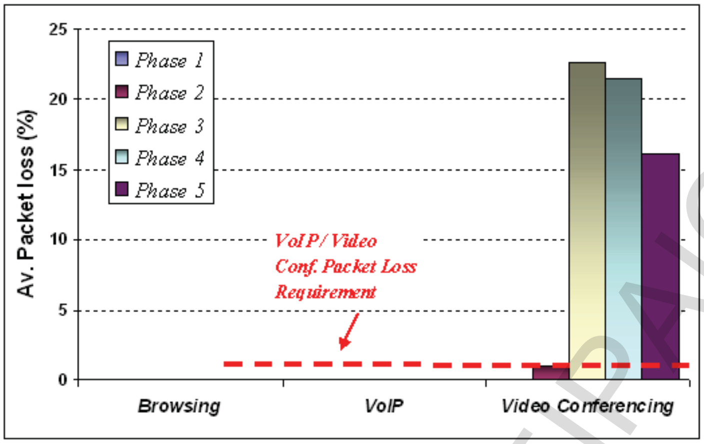


Figure 4-5: Av. Data Dropped per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing Protocol

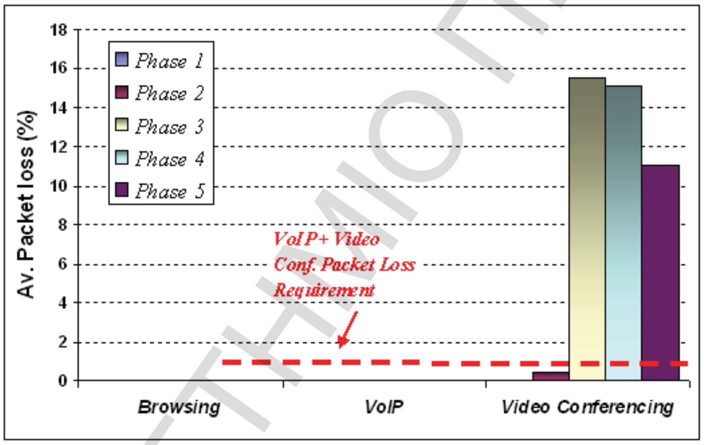
In the same figure, single dotted lines are used to depict the requirements posed for guaranteeing the flawless reception of the application. For both applications, internet browsing and especially for VoIP, packet loss remains at acceptable levels i.e. not exceeding or extremely slightly exceeding a value of 1%, for all the phases of the reduction of the AP's transmission power and for all three routing protocol options. This is not the case for video conferencing. As depicted in Figure 4-6, in the three last phases the average data dropped packets result in a non-acceptable value, which is actually far away from the minimum allowable threshold as defined in Table 4-IV and also depicted as a dotted line in the same figure.

ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

(a)



(b)



(c)

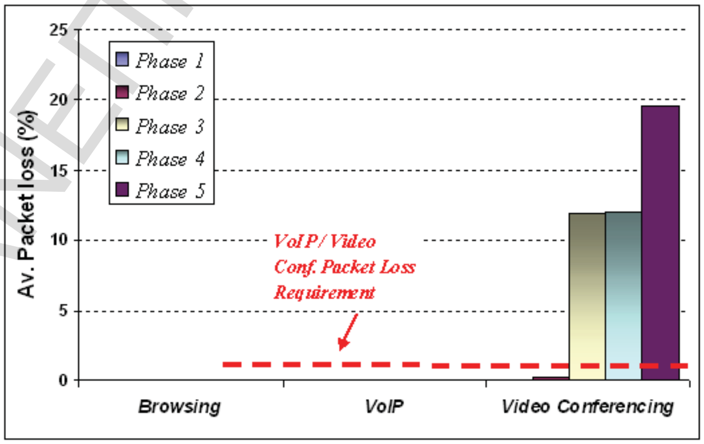


Figure 4-6: Av. Packet Loss per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

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Moreover, similar results can also be derived when examining Figure 4-5 from the used routing protocol perspective. There are minor differences in the data dropped packets for the three protocols, when using the internet browsing and VoIP application, albeit, OLSR seems to clearly win its competitors in the case of video conferencing application giving an average dropped packets (for the 5 phases) of almost 59Kbps and 123Kbps less than the ones taken in the case of GRP and AODV, respectively.

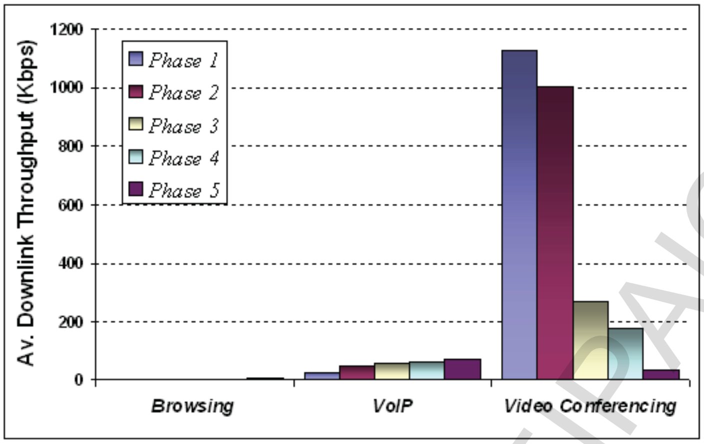
Last but not least, Figure 4-7 depicts the average downlink throughput in Kbps estimated for all terminals, bit infrastructure-based and infrastructure-less. Although the delay in general increases, we observe that in browsing and VoIP applications the average downlink throughput per terminal node increases, even though this happens at non-significant levels. A first, immediate explanation behind this observation would be as follows: In the first phase there are terminals that are in the edge of the cell and the achieved physical data rate is not the maximum supported by the technology i.e. 11Mbps, whereas this is restored with the reduction of the range that causes a corresponding reduction in the average distance among terminals using ad-hoc connections as well. However, the network simulator does not support scaling back of the physical data rate (i.e. among 1, 2, 5,5 and 11Mbps) and as a result, it might be safer to ascribe this throughput increase to the relative increase of the total data received per terminal.

When it comes to video conference application, we observe a significant decrease in the throughput when moving from phase 1 to phase 5. This can be justified if seen in conjunction with the corresponding increase in both the dropped data rate and the end-to-end delay metrics that the application suffers.

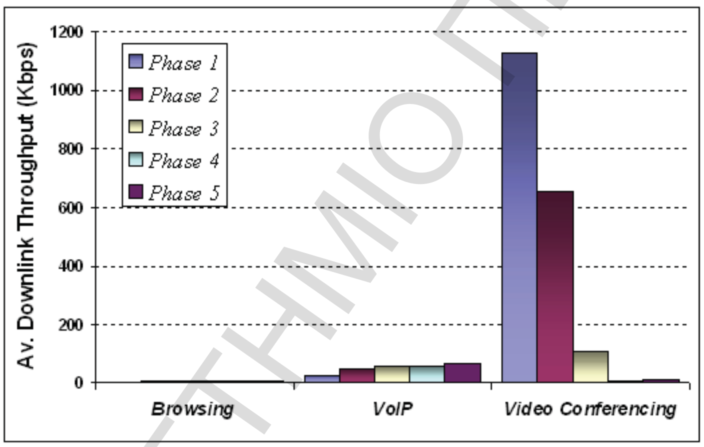
Focusing now is placed on results observed from the Figure 4-7 with respect to the used routing protocol. In the case of internet browsing there are insignificant differences. In the case of VoIP, GRP seems to outperform its competitors, giving an average throughput 28Kbps and 27Kbps more than OLSR and AODV, respectively. Also in case of video conferencing AODV outperforms its counterparts in terms of achieved throughput giving almost 141Kbps and 117Kbps more than OLSR and GRP, respectively.

ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

(a)



(b)



(c)

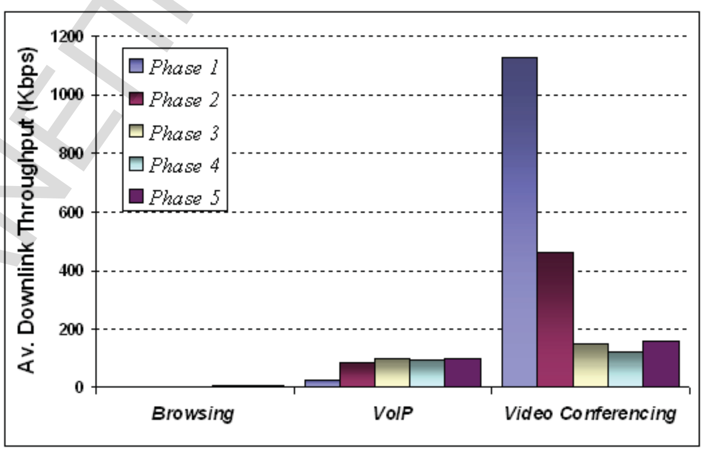


Figure 4-7: Av. Downlink Throughput per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

Apart from the above described results, it should be mentioned here that we have also experimented with another QoS metric, which is judged as rather crucial at least for the two real time applications, namely the “jitter”. What was actually measured was the Instantaneous Packet Delay Variation (IPDV) as defined in IETF RFC 3393 [10] i.e. “the difference in one way delay between successive packets, ignoring any lost packets”. Nevertheless, in all the scenarios examined above, the thresholds appearing in Table 4 IV were not violated and as such, the detailed results and figures are not depicted here for brevity reasons.

Case 2 – Random distribution

Similar analysis was performed for the case of terminals that are distributed in a non-uniform manner around the AP. A brief description of the obtained results follows.

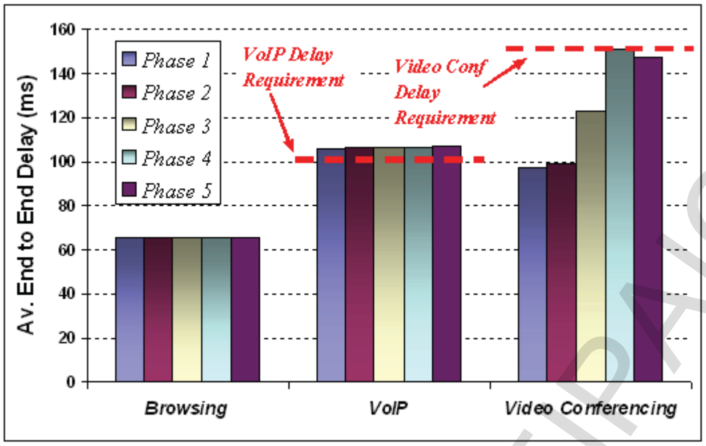
Figure 4-8 depicts the average end-to-end delay which arises as previously described in the uniform case i.e. after doubling the obtained measurement and adding a worst case interim network delay. In the case of Internet browsing application, the average delay (averaged in all phases and routing protocols) is about 65,75ms. For the VoIP application the average value for the delay is about 106,97ms. Moreover the video conferencing exhibits an average delay of about 136,43ms and as the number of the terminals that are out of the range increases, there is a big augment in the delay.

Moreover, when examining Figure 4-8 with respect to the used routing protocol, we observe that there are insignificant differences in the end-to-end delays for the three protocols, when using Internet browsing and VoIP applications. However, AODV seems to clearly outperform its competitors in the case of video conferencing application giving an average delay (for the 5 phases) almost 25ms and 11ms less than the ones collected in the case of OLSR and GRP, respectively.

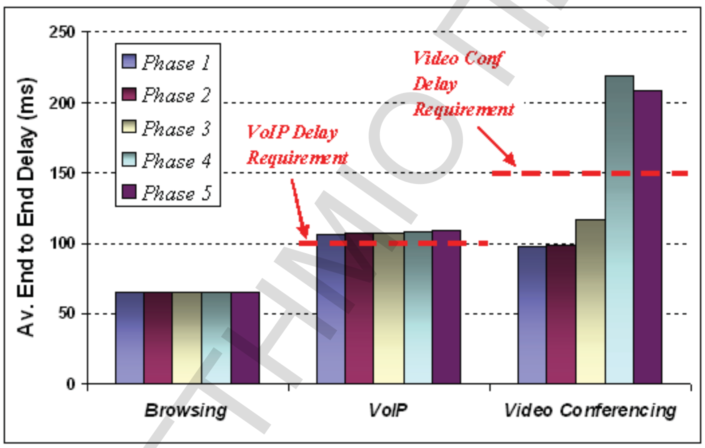
As before, we examine the obtained results against the predefined application requirements given in Table 4-IV, i.e. assuming that the one way acceptable end-to-end delay for VoIP and Video conferencing is 100ms and 150ms, respectively. These thresholds are also depicted in Figure 4-8 for readability purposes.

ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

(a)



(b)



(c)

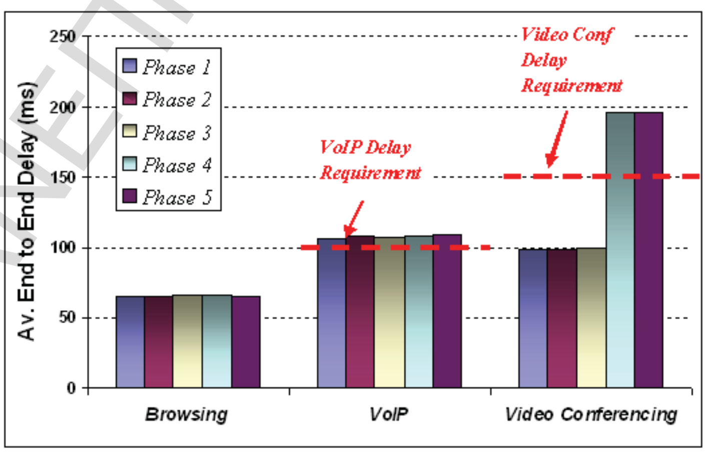


Figure 4-8: Av. End to End Delay per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing Protocol

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For both applications, Internet browsing and VoIP, end-to-end delay remains at acceptable levels with not exceeding the delay requirements of Table 4-IV. In case of Video conferencing only phase 4 and phase 5 have not acceptable values of the metric expect for AODV, which seems to have both phases in acceptable level. Although the delay in general increases in the ranges from R0 to R4 (phase 1 to 5) and for all applications, we observe that while moving from phase 4 to 5 the delay for the video conferencing application does not follow this common trend and it slightly decreases. It should also note here that both phases, 4 and 5, assume the same number of terminals operating in ad-hoc mode (see Table 4-III), however they are differentiated with respect to the TRx power which is 10% less in phase, thus resulting in less data traffic received on average.

Next we focus on the average data traffic (in Kbps) per node (Figure 4-9), which is successfully received by the MAC from the physical layer. As previously observed, the stepwise increase in the number of ad-hoc connections leads to a rise of the total traffic volume passing the nodes of the network. In general we observe that in all applications there is a common tendency towards increasing the number of received data when going from phase 1 to phase 5. For the Internet browsing, the average data received (averaged in all phases and routing protocols) remain in a low level of 16,13Kbps. In the more bandwidth consuming applications, the data received are 685,33Kbps and 1702,47Kbps, respectively.

Results can also be derived with respect to the used routing protocol. As we observe there are little differences in the total data received metric for the internet browsing case. However, the differences become more considerable in VoIP and video conference applications with OLSR leading to clear less average data received per terminal node. In VoIP case, OLSR gives an average data traffic received (for the 5 phases) about 40Kbps and 50Kbps less than the ones collected in the case of AODV and GRP. In the video conference case, these differences are found to be about 89Kbps and 283Kbps, respectively.

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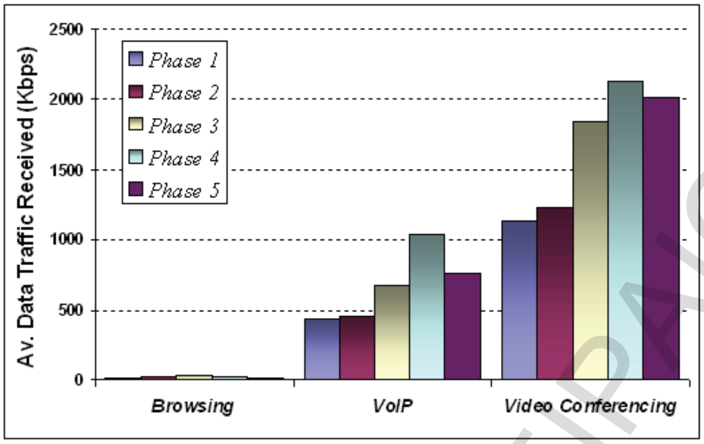
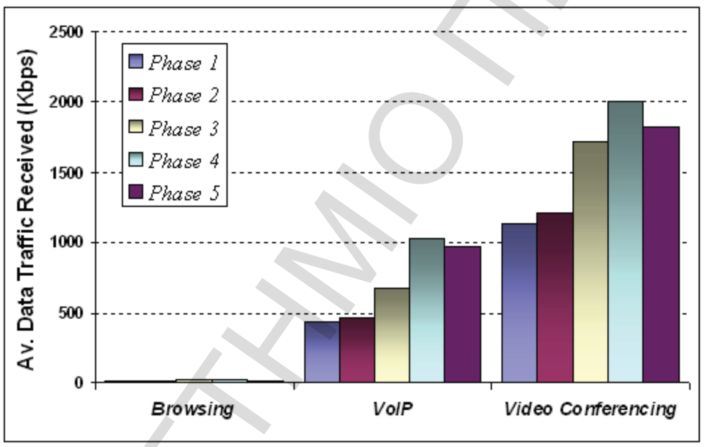
(a)



(b)



(c)

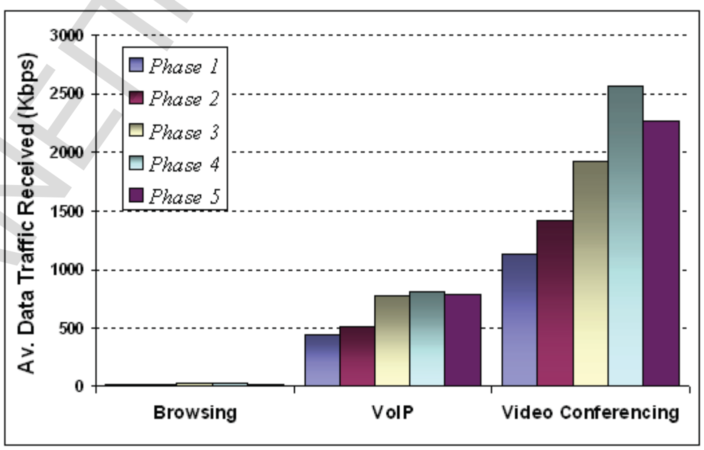
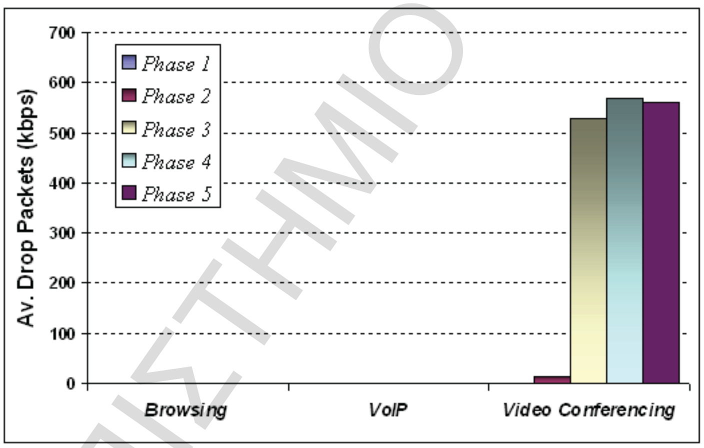


Figure 4-9: Av. Data Received per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

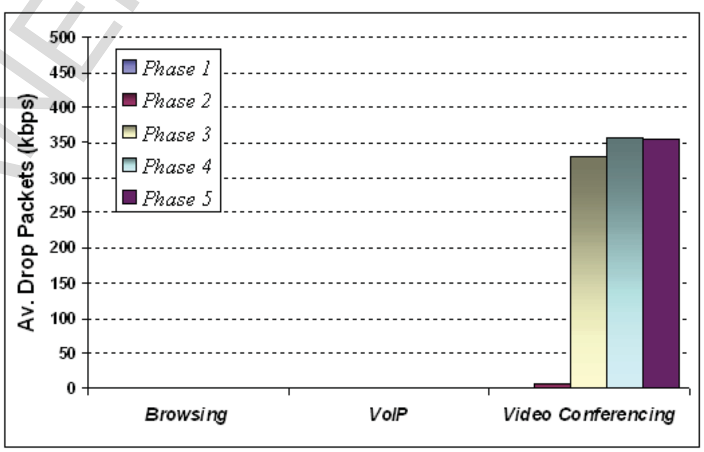
The next set of results focuses first on the average data dropped in Kbps and in effect, to the % percentage of packet loss in the network. Figure 4-10 depicts the former metric. The average value in Kbps for the data dropped (averaged in all phases and routing protocols) is almost zero for the Internet browsing and VoIP applications. In the case of Video conferencing the same value is equal to 245,08Kbps.

Furthermore Figure 4-11 depicts the packet loss rate with single dotted lines corresponding to the packet loss (%) requirements as these are described in Table 4-IV. For both application, Internet browsing and particularly for VoIP, packet loss remains at acceptable levels without exceeding the 1% value. In the case of Video conferencing, in the three last phases the packet loss rate is in a non-acceptable level and in particular away from the minimum 1% threshold.

(a)



(b)



(c)

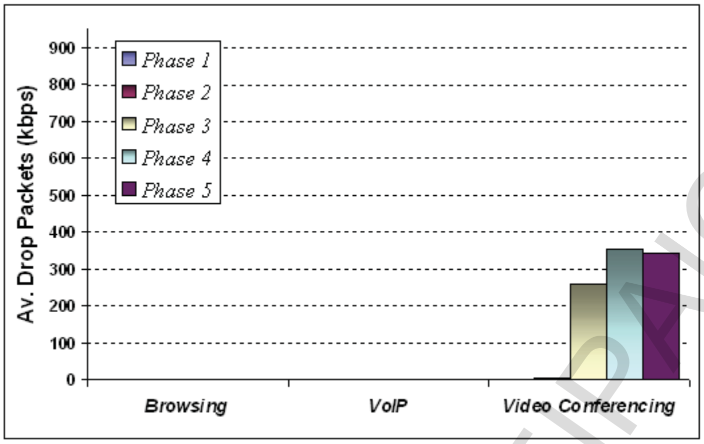
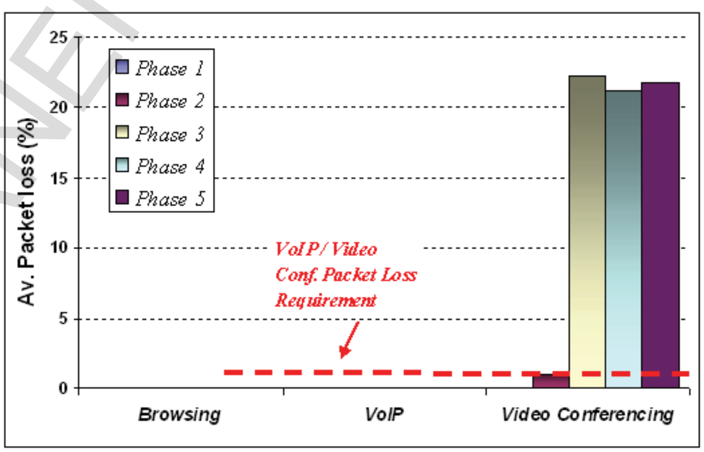


Figure 4-10: Av. Data Dropped per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing Protocol

Similar results can also be derived when examining Figure 4-10 with respect to the used routing protocol. For instance, there are minor differences in the data dropped packets for the three protocols, when using the internet browsing and VoIP application. On the other hand GRP seems to clearly win its competitors in the case of video conferencing application giving average dropped packets (for the 5 phases) almost 17Kbps and 142Kbps less than the ones taken in the case of OLSR and AODV, respectively.

(a)



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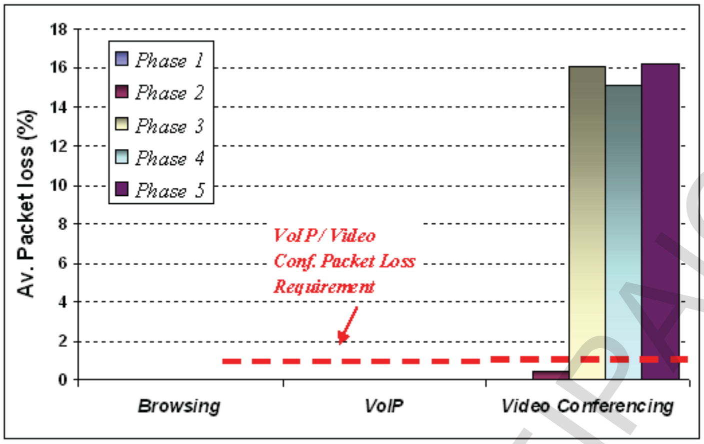
(b)



(c)

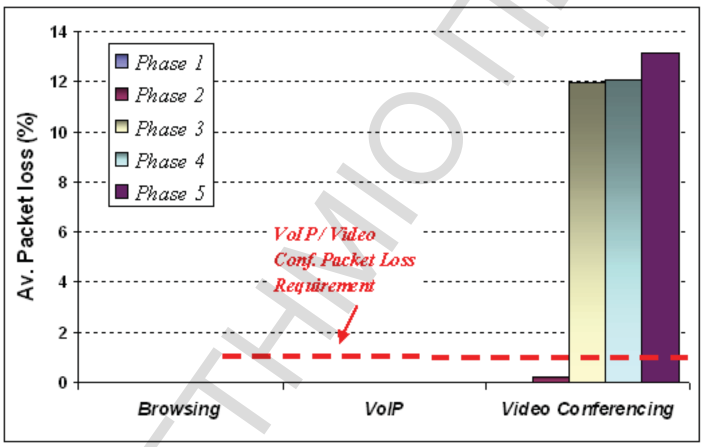


Figure 4-11: Av. Packet Loss per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

Finally, Figure 4-12 depicts the average downlink throughput in Kbps for all the terminal nodes. Even though the average delay increases, we observe that for Internet browsing and VoIP applications this metric also increases. A possible explanation was given previously in the uniform distribution cases, where a similar tendency was observed. For Video conferencing application, we observe a considerable decrease in the average downlink throughput while the AP's range is shrinking from R0 to R4 (phase 1 to 5), which it can also be justified from the increases in packet loss (%) and end-to-end delay.

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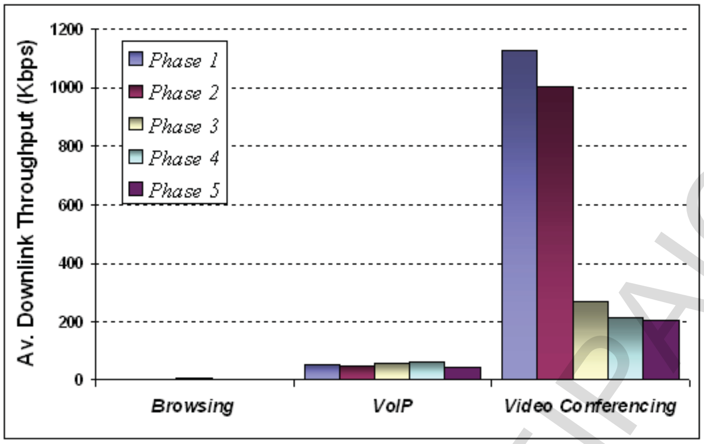
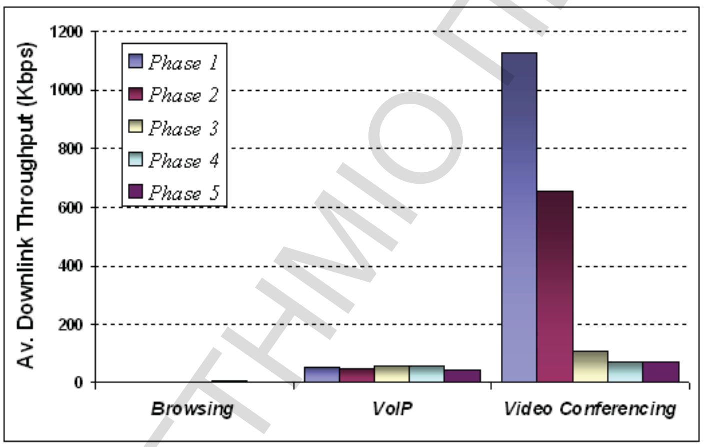
(a)



(b)



(c)

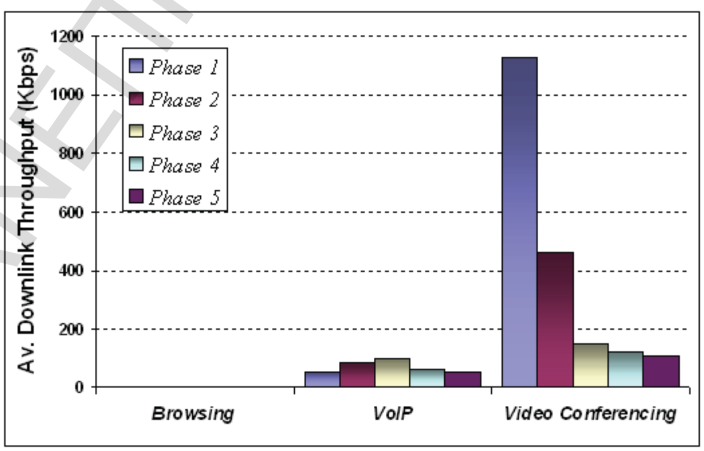


Figure 4-12: Av. Downlink Throughput per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

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Finally we also place focus on results observed from the Figure 4-12 with respect to the used routing protocol AODV outperforms its counterparts in terms of achieved throughput for all the used applications. In particular in the case of video conferencing, AODV gives an average throughput almost 156Kbps and 169Kbps more than OLSR and GRP, respectively.

Case 3 – Business Case

A rather different case in comparison to the ones presented so far is described and examined in this section. The purpose of this case is twofold; first, to showcase and validate the applicability of the proposed scheme (efficient exploitation of infrastructure-less segments (ONs)) in a so called business-case situation, more likely to a in the real-life and second, to experiment on the mobility aspects being absent in the previous two cases. Actually, the described case simulates the situation of an airport lounge where, initially, travelers waiting for their departure announcement are sitting e.g. in a cafe and are being served by an AP located some meters away. At a second step, a set of terminals, simulating the passengers arriving from a just landed flight, pass by in between the sitting travelers and the AP. At the following step, we assume that both the AP and the involved terminals reduce their transmitting powers at the 70% of the initial values. Under these conditions, the only way for the sitting travelers to reach the AP is to proceed with the creation of ONs and receive data through the intermediate nodes. What we want to demonstrate here is the quality level of service provisioning for the sitting travelers, thus paving the way for the development of an algorithm in the management plane that will be able to autonomously take pertinent decisions, whenever new "arriving passengers" appear. The above is schematically given in Figure 4-13, whereas the specific simulation parameters for this test case are summarized in Table 4-V.

The number of sitting terminals (travelers) is four and they may also participate in routing traffic one to another when the ON is created and if commanded by the routing protocol. Moreover, the moving terminals are supposed to move towards the same direction in front of the AP as it is depicted in Figure 4-13. They start moving at the beginning of the simulation and without any interruption during the process and finish with the end of the simulation.

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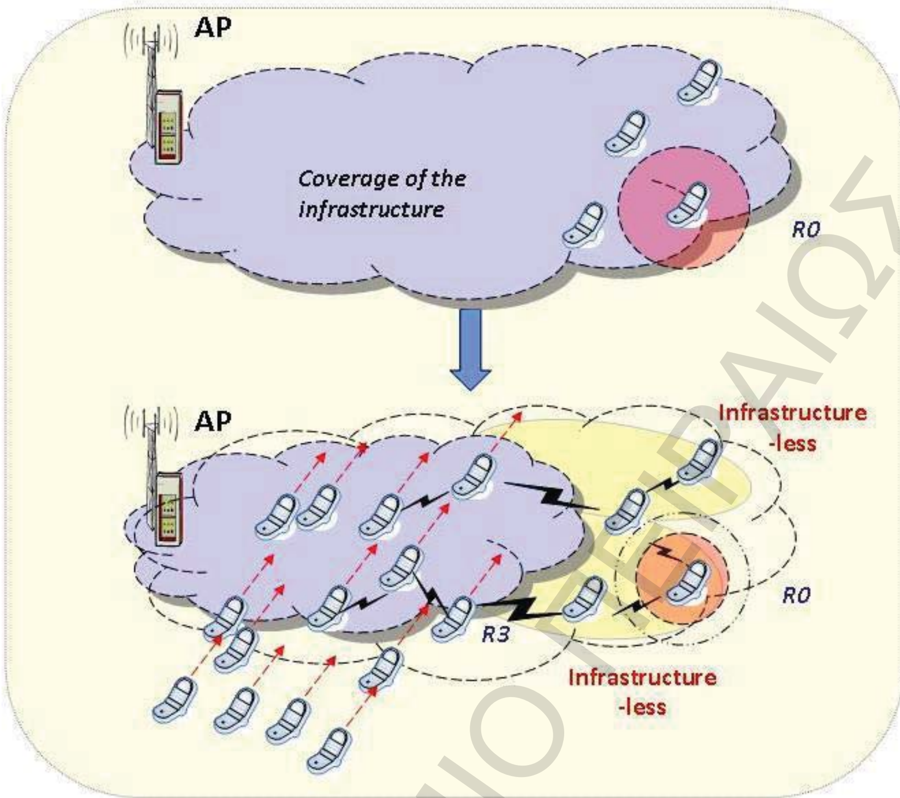

Figure 4-13: Considered Area – Business Case

Table 4-V: General Parameters of the simulation environment – Business Case

Area	*100 x 100 m*
Simulation Time	*10 min*
Physical Characteristics	*802.11g, Extended PHY*
Physical Layer Data Rate	*54Mbps*
Total Number of Terminals	*18*
Total Number of Consumer Terminals	*4 (out of 18)*
Reception Power Threshold	*-95 dbm*
Initial AP Trx Power	*0,03 W*
Terminals Trx Power	*0,02 W*

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In addition, 3 types of applications are considered a) VoIP and b) Video conference and c) Email application. The characteristics and QoS requirements for the two first considered applications have been already given in Table 4-II and Table 4-IV, respectively. As for the Email application, the average e-mail size is assumed equal to 700Bytes and the interarrival time between received e-mails is 5sec. In addition, Email is a type of application that can tolerate delays, however, it is important for the user to expect the e-mail in a logical time. In particular the response time expected by the users is set at 2-5 seconds, while the requirement of the expected network delay is low. Moreover the typical bit rate for this service is less than 10 Kbps and the expected packet loss is zero.

Finally, the QoS metrics used for are the ones defined in sub-Section 4.3.1, plus an additional one, which is more critical in cases with non-zero mobility and refers to the routing traffic namely, the total number of the received routing traffic (in Kbps) by a wireless node for the routing protocol e.g. HELLO and TC messages. Once again, AODV, OLSR and GRP are the tested routing protocols.

Last but not least, in order to study the level of tolerance to mobility as well, we consider three mobility levels for the terminals corresponding to average, common for all, velocities of 1m/sec, 1,5m/sec and 2m/sec, respectively.

Accordingly, Figure 4-14 depicts the average end-to-end delay for the three applications which arises as described in the previous cases. Results can be derived when examining Figure 4-14 with respect to the used routing protocol and mobility level. From the mobility perspective, as the mobility level increases, the overall delay also increases.

From the routing protocol perspective in case of VoIP AODV seems to clearly outperform its competitors giving an average delay (for the 3 mobility levels) almost 49,6ms and 63,6ms less than the ones collected in the case of OLSR and GRP, respectively. Furthermore in case of video conferencing, GRP seems to perform much better than its counterparts, giving delay values 175,4ms and 15ms less than the ones collected in the case of AODV and OLSR respectively.

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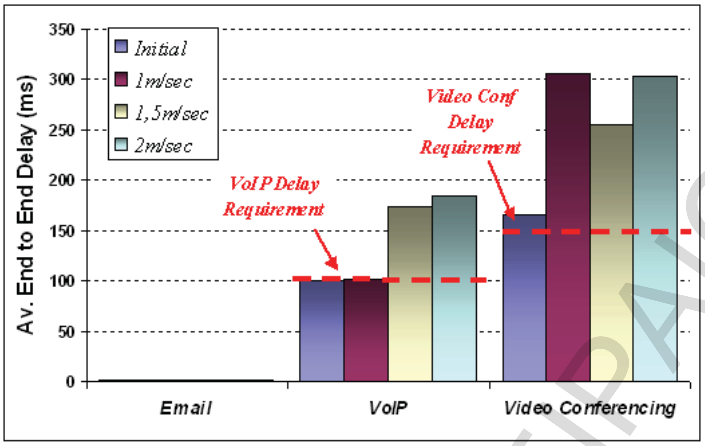
(a)



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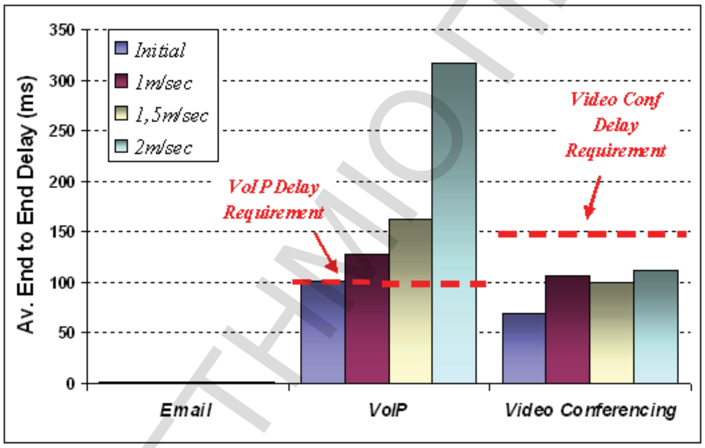

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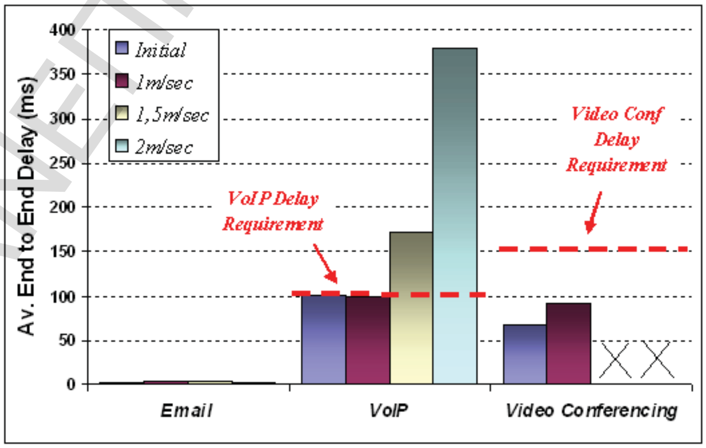

Figure 4-14: Av. End to End Delay per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

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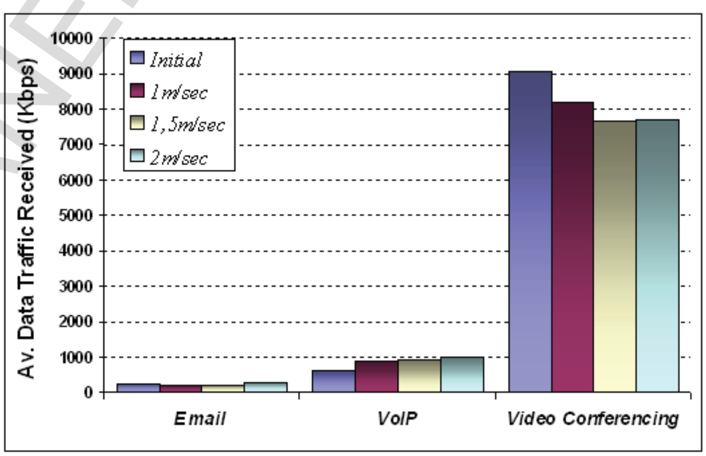
In the same figure, single dotted lines are used to depict the requirements, where for VoIP and Video conferencing applications are 100ms and 150ms, respectively [8]. The delay requirement for email service is not depicted, since remains at low level and it is far away from being violated in all the examined cases. In case of VoIP, two mobility levels i.e. 1,5m/sec and 2m/sec, seem to be clearly prohibitive for the network. Moreover in case of Video conferencing, AODV seems to lead to unacceptable delay values in all mobility levels. Interestingly, the level of 1,5m/sec is the mobility level that gives better performance in terms of delay for the case of Video conference and for both AODV and OLSR protocols.

Figure 4-15 depicts the average data traffic received per node in Kbps. As the mobility increases, this metric also increases for the case of Email and VoIP. On the other hand, there is no such clear tendency in the case of video conference, thus blurring any effort for safe conclusions. When examining Figure 4-15 from the used routing protocol perspective, in case of VoIP, OLSR seems to clearly win its counterparts giving an average data traffic received (for the 3 mobility levels) almost 108,8Kbps and 145,9Kbps less than the ones collected in the case of AODV and GRP, respectively. Furthermore in case of video conferencing, GRP exhibits much less received data traffic when considering the first mobility level (1m/sec), in particular giving 948Kbps and 694Kbps less traffic than the ones collected for AODV and OLSR, respectively. When it comes to 1,5m/sec and 2m/sec mobility levels, AODV gives 389Kbps less data traffic received than those received in OLSR.

(a)



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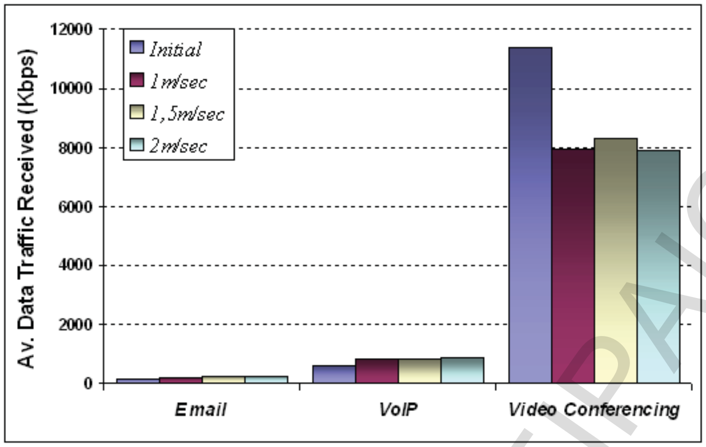

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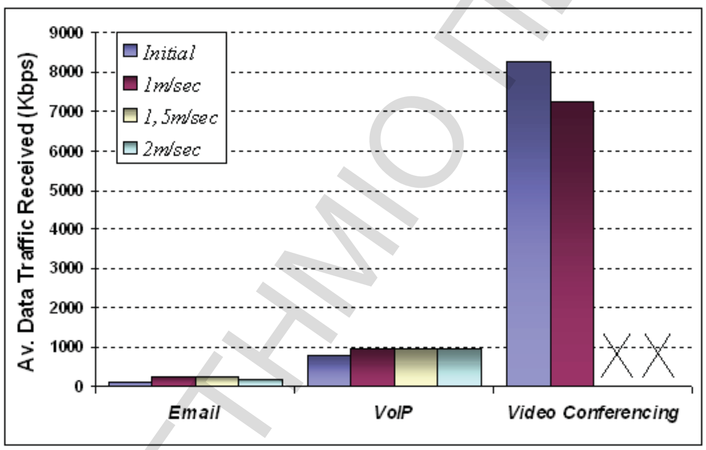

Figure 4-15: Av. Data Traffic Received per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

The next set of results focuses first on the average data dropped in Kbps in Figure 4-16 and thereafter, to the % percentage of packet loss in the network as depicted in Figure 4-17. In general for Email and VoIP, as the mobility level increases from 1m/sec to 2m/sec the average data dropped also increases. However, this does not hold for the case of video conference application. Here once again we observe that the mobility level of 1,5m/sec leads to much less data dropped in the AODV case and almost the same data dropped in the case of OLSR, when compared to the other two mobility levels.

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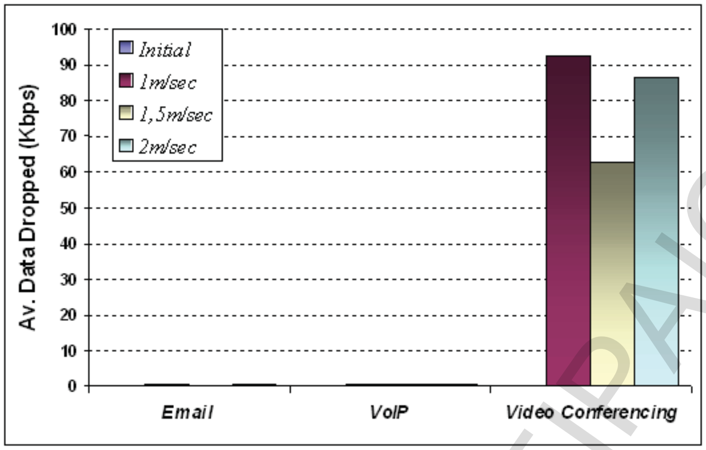
(a)



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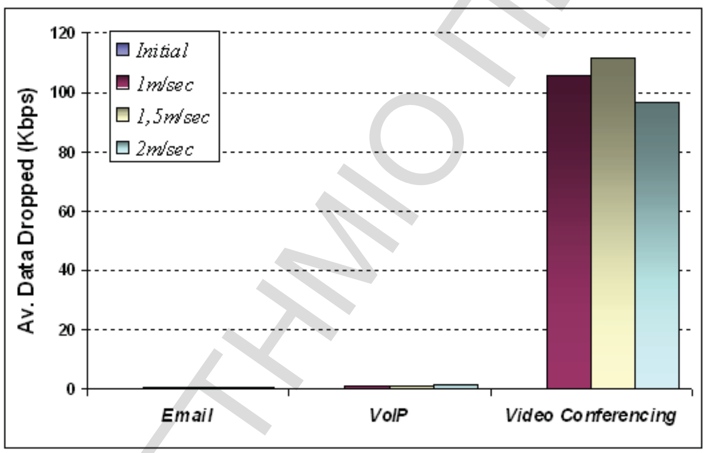

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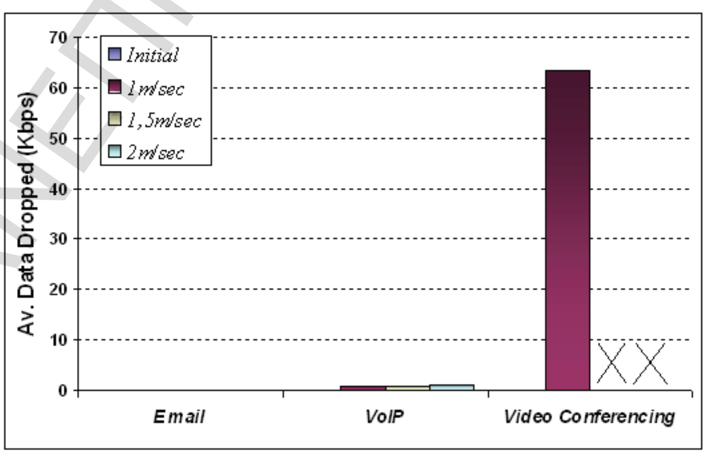

Figure 4-16: Av. Data Dropped per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

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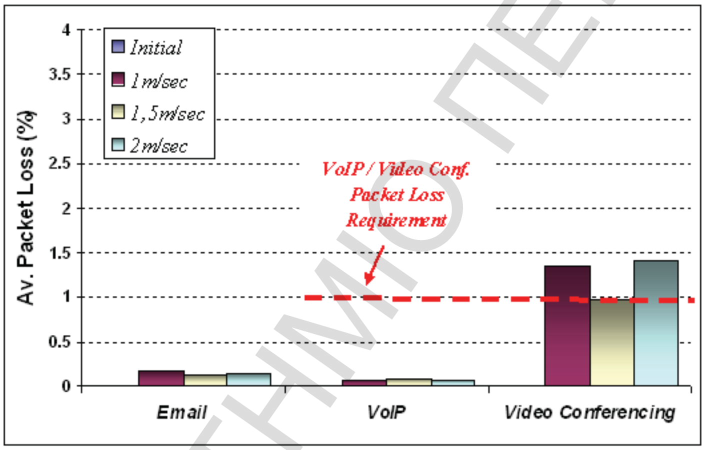
Furthermore, for VoIP application, AODV gives 0,87Kbps and 0,45Kbps less drop data than OLSR and GRP, respectively. In Video conference application AODV seems to win OLSR resulting in 23,9Kbps less dropped data.

When observing Figure 4-17, it can be seen that packet loss remains at acceptable levels i.e. not exceeding a value of 1%, for Email and VoIP applications. In Video conferencing, AODV is the only routing protocol that results in acceptable values. Although this is very clear for the mobility level of 1,5m/sec, there is a slight violation in the other two examined mobility levels, namely 1m/sec and 2m/sec.

(a)



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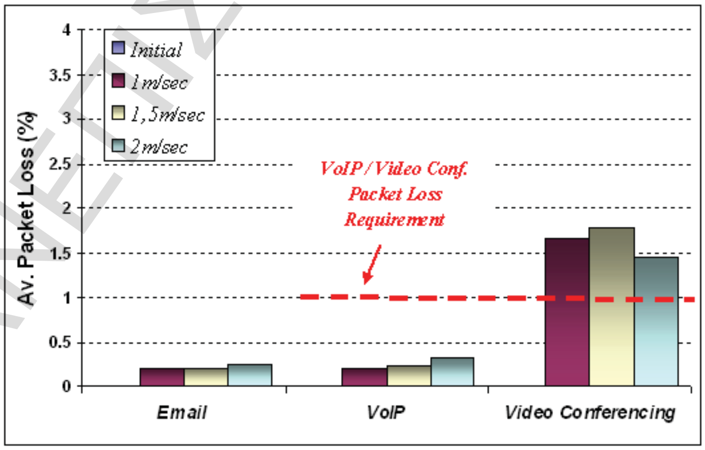

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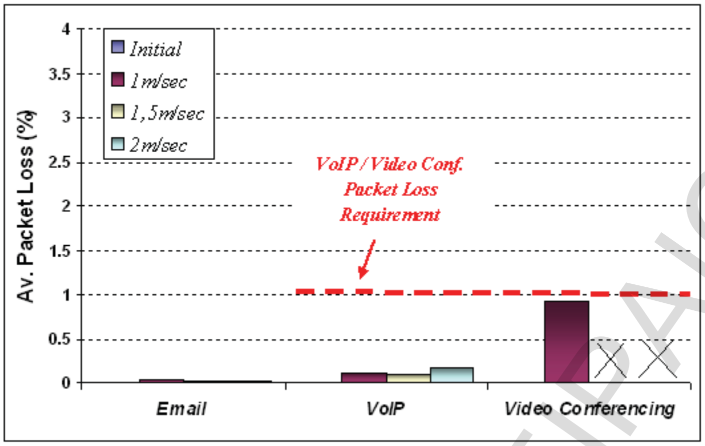
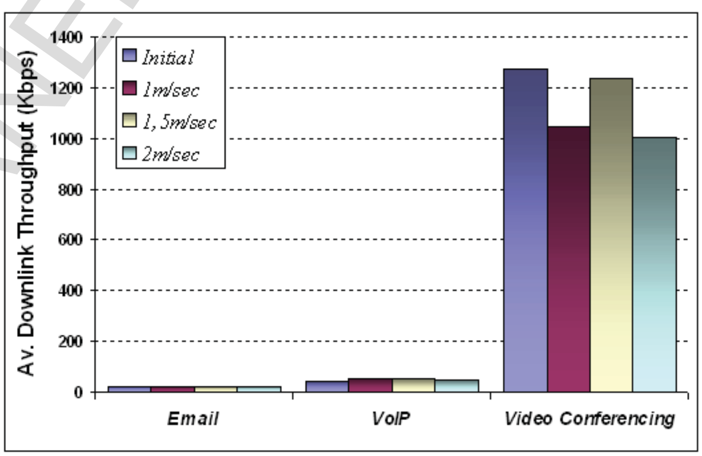


Figure 4-17: Av. Packet Loss per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

Figure 4-18 depicts the downlink throughput in Kbps. What is observed here is that in Email and VoIP applications, the average downlink throughput per terminal node remains stable for all the here protocols, whereas the mobility levels appear not to have a serious effect on that. On the other hand, in case of Video conference we observe that the second level of mobility (1,5m/sec) once again behaves differently than the other two giving the maximum throughput value. This can be justified if seen in conjunction with the dropped data value and the end-to-end delay value that the application has in this mobility level.

(a)



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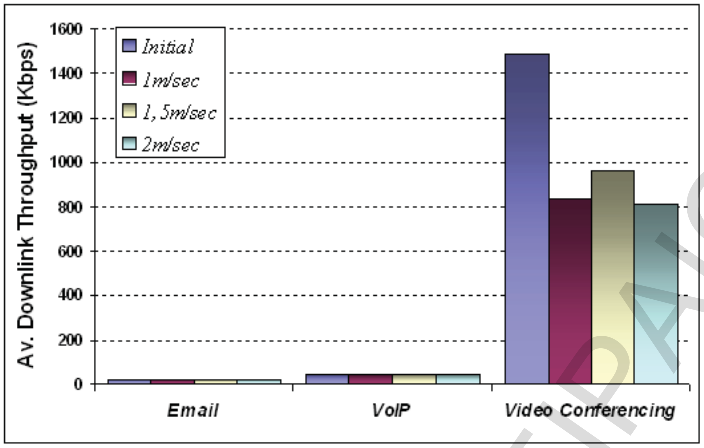

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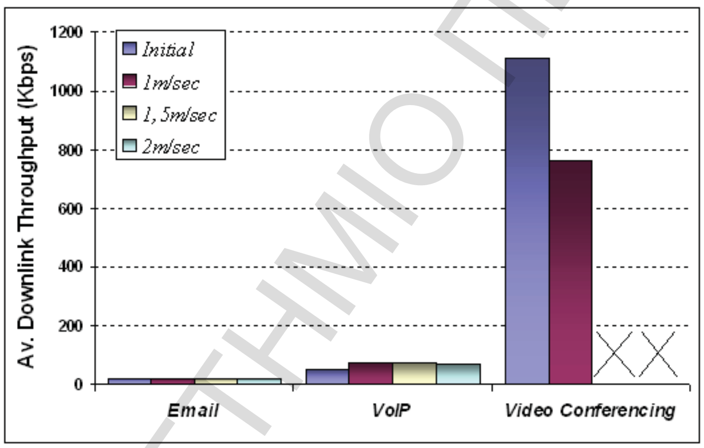

Figure 4-18: Av. Downlink Throughput per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

Finally, Figure 4-19 depicts the average routing data traffic received per node in Kbps. Results can be derived with respect to the used routing protocol and mobility level. Generally speaking, as the mobility level increases, GRP and OLSR seem to have stable routing traffic, which can be justified by their proactive nature strategy. On the other hand, AODV, being a reactive protocol, seems to increase its routing traffic as the mobility increases. From the routing protocol perspective GRP clearly win its competitors in case of VoIP application giving almost 60Kbps less than the ones collected in case of AODV and OLSR respectively.

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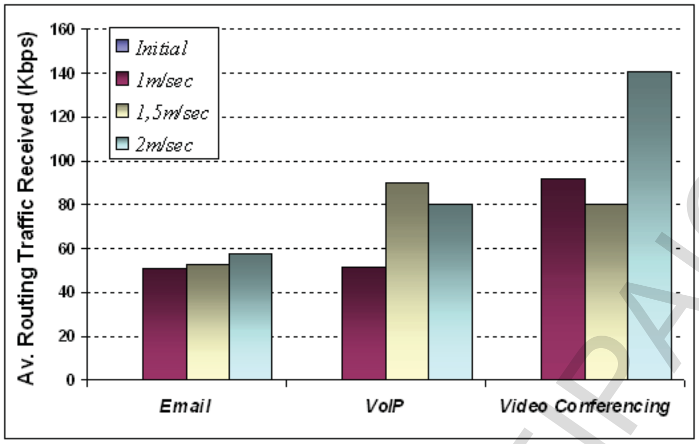
(a)



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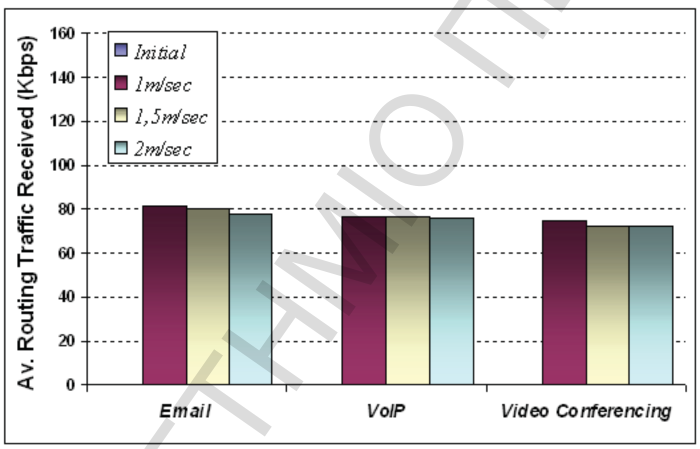

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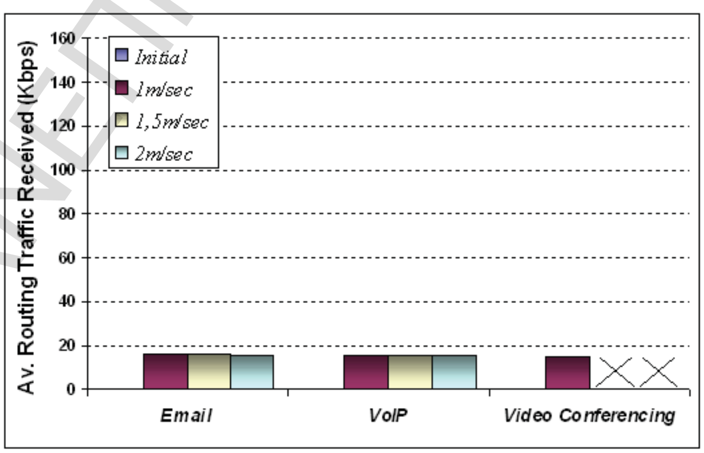

Figure 4-19: Av. Routing Traffic Received per Node vs Application type for *(a)* AODV *(b)* OLSR *(c)* GRP routing protocol

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There are a couple of findings that deserve some attention here. First, the symbols X which replace the value bars in Figure 4-14 to Figure 4-19 are used here to denote that the scheme does not manage to serve all the four sitting (application producer/consumer) users, thus they are omitted from the analysis above. In particular this happens when Video conference and GRP are utilized and for mobility levels equal to 1,5m/sec and 2m/sec, respectively. Secondly, the metrics collected for the mobility level of 1,5m/sec seem to deviate from the trend (increase or decrease), which is almost always observed, when getting from 1m/sec to 2m/sec. This reveals the existence of extremes for the node mobility levels as well, which form the first sight, can be ascribed to the specific topology and environment dimensions considered and in any case, they can be used to drive decisions upon the infrastructure-less network(s) creation, thus certainly calling for more elaboration in the future.

4.4. Summary of discussion and recommendations

Some discussion with respect to the comparison among the uniform and random distribution cases also follows.

When the traffic is uniformly distributed, transmission range reductions of X% (e.g., 70) can be done without impacting too much the service provisioning. In this case a “small” transmission range reduction means that “several” devices are left out of range (see Table 4-III). On the contrary, in case of random distribution the transmission ranges can be reduced even more. For instance in case the randomness lead to “more” terminals close to the AP, the transmission range can be reduced significantly.

In addition, by comparing the obtained results in both cases (uniform and random) and for the whole set of QoS metrics, it is easy to realize that the measured values exhibit big similarities in all phases ranging from 1 to 4. However, this does not happen in phase 5. Going one step further and checking the actual number of terminals that are left outside the range in all these phases (Table 4-III), we may come up with great certainty in the conclusion that the absolute number of terminals which are left out of the range and form the ON is a very crucial factor to take into account and therefore it calls for further investigation.

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In general, what can be deduced from the above scenarios and results is that there appear cut-off levels of the AP transmission power (AP coverage) which if they are not infracted, applications can still be satisfactorily supported and provided at adequate QoS levels, with less AP power resources. In case more devices are concentrated away from the AP, then the cut-off value will be high, near to the default AP transmission range. This will result in small, yet important, savings in the total transmission power. If more devices are concentrated near the AP, then the cut-off value will be significantly lower than the default AP transmission range. This will result in larger savings in the total transmission power.

Of course, there is also the other side of the coin, according to which the cut-off levels designate that below them, some applications cannot be adequately supported. In particular, although an application such as internet browsing can continue to be satisfactorily provided after the reduction steps, this is compromised in the case of applications which are much less tolerable in time slips. This calls for special caution when thinking of the fact that future internet applications are expected to combine high quality video and voice in a real time fashion.

Moreover, one thing that should be realized and should be put into practice while seeking for cut-off levels is that QoS is a rather complex commodity and in most of the cases it cannot be provided after optimizing a single or even a few parameters. Therefore, it is required to take into account the whole or major set of the defined QoS metrics in a joint manner and try to guarantee that they will provide satisfactory values at the same time.

4.5. Conclusions

This chapter has presented a solution that considers the possibility of extending the infrastructure-based composite wireless network, which is owned by a wireless operator and consists of a set of RANs, by network elements and devices that are organized in an infrastructure-less manner, and can be called ONs. The decision of the infrastructure to create or not such an ON needs to be fast and dynamic, it should respect several aspects, including traffic and applications variations, mobility levels and/or energy/power

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consumption levels and it should result in benefits with respect to provisioned QoS for the whole network.

The role of this chapter is to investigate whether and under which conditions, the creation of such an ON will be beneficiary for the overall network as an extension to the infrastructure. For that reason, extensive simulations have been conducted with the aid of network simulations, which revealed that the scheme seems to work and has great potentials to bring about benefits under certain circumstances.

In particular, proper exploitation of the cut-off values identified from the simulation analysis above, can be used to facilitate online, dynamic decisions on whether to boost the creation of the infrastructure-less part or not. The ultimate goal is to use the obtained results for endowing the management plane, in terms of strategies/algorithms, which is responsible for the communication and coordination among infrastructure and the ONs, with proper, advanced functionality that will make timely decisions under preset suitability criteria.

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ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ

5. SUITABILITY DETERMINATION OF OPPORTUNISTIC NETWORKS BASED ON MOBILITY ASPECTS

Chapter Outline

It is common truth that the majority of existing and newly coming applications are more likely to be provided in an extremely high mobility environment with often changes to the network topology. Moreover, as the number of the mobile broadband users is growing rapidly, the communication between them and/or with the infrastructure will significantly impact the provided QoS and finally the QoE of the user. Framed within this statement, this chapter aims at the investigation of those conditions under which the creation of an ON will be beneficiary for the overall network, taking into account mobility and routing aspects. The decision of the wireless network infrastructure to create or not such an ON needs to be fast and dynamic, it should respect several aspects, including traffic/applications variations, mobility levels and/or energy/power consumption levels and it should result in benefits with respect to provisioned QoS for the whole network.

Keywords: Suitability Determination, Network Simulations, Mobility Aspects, Routing Aspects, Indoor – Outdoor Environment

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5.1. Introduction

In the context of the proposed ON-based solution, an operator owning a wireless network infrastructure, can exploit ONs for complementing the infrastructure, e.g., for expanding its coverage or for achieving green targets. Given the existence of opportunities in terms of available nodes and spectrum, the suitability of extending the wireless network infrastructure with an ON can be determined based on the involved applications and mobility levels as well as on the anticipated benefits in terms of adequate QoS level provisioning and energy (power) consumption. In this respect this chapter addresses the following ON suitability determination problem: "Given a wireless network infrastructure, the opportunities in terms of resource situation, the candidate nodes, the applications that should be offered, and the mobility levels of the nodes, should an ON be established"? That is to say, this chapter aims at investigating under which circumstances the creation of such an ON will be beneficiary for the overall network, taking mainly into account mobility and traffic aspects.

This investigation in this chapter is based on network simulations, with the aim to cover a large set of cases in order to increase the validity of the finally extracted conclusions and recommendations. In particular, the impact of mobility and type of applications will be investigated in this study. Ultimately, those recommendations should be used to set up an advanced management plane, to comprise the set of management functions and/or signalling procedures and channels, which are necessary for the integration (communication and coordination) among wireless infrastructure and ONs. In particular, the advanced management plane will incorporate functionalities, such as the Suitability Determination process inside the CSCI management entity, which should be able to reply positively or negatively upon the creation of an ON.

Therefore, the rest of this chapter is structured as follows: A detailed description of the simulation environment, with application, mobility and routing aspects are presented first. Then a great set of the results obtained by simulations is presented in Section 5.3. Section 5.4 presents the summary of discussion and recommendations with an emphasis to the performance and behaviour of the routing protocols in the mobile environment. Finally the chapter is concluded in Section 5.5.

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5.2. Simulation Setup

This section discusses on the simulations that have been setup, in order to validate our concept and give some evidence on the potentials arising from the integration of ONs with the wireless infrastructure. Recall that the impact of specific aspects and particularly mobility and type of applications will be investigated in this integration. Accordingly, a large set of scenarios and test cases were executed in the simulation environment, which was based on the widely used OPNET/OMNeT++ network simulation environments [1], [2] and ran on an Intel Pentium - 4 3.0 GHz with 1.5 GB of RAM and a 32-bit Operating System.

5.2.1. General Setup

The topology comprises a single AP operating at IEEE 802.11g technology with a maximum offering data rate at 54Mbps. The choice of one single AP was made deliberately so as to relax our study from bothering about the interference aspects inherent to a multi AP environment. A total set of 12 Mobile Terminals (MTs) are supposed to exist within the range of the AP, the four of which are selected to be the application consumers. The set of applications offered to those application consumer MTs are analyzed in sub-Section 5.2.3.

Table 5-I summarizes the general input parameters of the considered simulation environment. The selection of 802.11g as the RAT to be used for supporting our validation studies was mainly done for the following reasons: First, because although simpler it is judged as adequate for proving the importance and validity of the concept. In addition, the wide and unlicensed usage of 802.11 family strengthens the applicability of the proposed scheme in real scenarios and short term deployments. Last but not least, the availability of this technology in a great variety of costless but also widely used simulation tools. Of course, our scheme can be extended towards cellular RATs, in particular towards the latest advancements of 3GPP LTE and LTE-advanced and this will comprise part of our future study provided that there will be concrete steps towards the standardization of machine to machine communications (being a prerequisite and enabling technology in our scheme) and also towards the respective supporting LTE simulation platforms.

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Table 5-I: General parameters of the simulation environment

Area	*300 x 300 m*
Simulation Time	*60min*
Physical Characteristics	*802.11g*
Physical Layer Data Rate (Max)	*54Mbps*
Number of users	*12 (4 application users)*
Reception Power Threshold	*-95 dbm*

5.2.2. Definition of Scenarios

Two main cases are considered which are differentiated with respect to the environment of the topology. In the first case, the AP is placed in an outdoor environment with Free Space propagation model, whereas the second case assumes an indoor environment with Rayleigh propagation model [3]. The examined simulation scenarios evolve as follows. The initial TRx power of the AP is gradually decreased. As it is depicted in Figure 5-1 and summarized in Table 5-II four steps (phases) are considered, each one corresponding to a specific percentage of the initial TRx power of the AP/MTs, namely: 100% (initial) / 100% (initial), 80% / 100%, 60% / 100% and 60% / 60% thus resulting in ranges R0 (initial) /T0 (initial), R1/T0, R2/T0 and R2/T1, respectively.

As it can be seen, in the last phase, a reduction of the initial TRx power of the MTs to 60% takes place as well, as it is depicted in Figure 5-1 (a cycle around the MT). In general, during the reduction of the AP's TRx power, a number of MTs are left out of the APs' range. These MTs are then supposed to create ONs with intermediate MTs in an ad-hoc manner and operate in WLAN 802.11g, as well. In particular, the initial transmission power of the AP for both cases is set equal to 0.03W, thus resulting in a cell with a radius equal to about 140m and 30m for Outdoor and Indoor environment, respectively. The respective default MT transmission power is set equal to 0.02W. Further details for the phases of the considered scenarios are summarized in Table 5-II.

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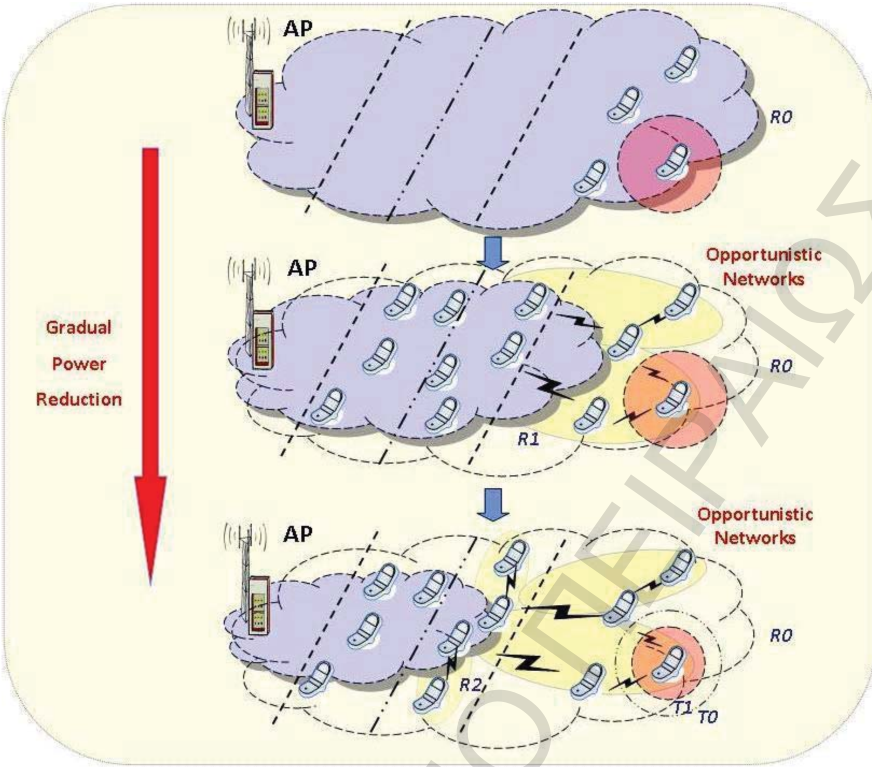

Figure 5-1: Considered scenarios

Table 5-II: Parameters of each phase

Phases	Environment	Range	Trx AP (W)	Trx MTs (W)	Mobility Profile	Routing Protocols	Services
First	*Indoor, Outdoor*	*100% / 100% (R0/T0)*	*0,03*	*0,02*	*No mobility*	*AODV, DSR OLSR, GRP*	*VoIP, Video Conferencing*
Second	*Indoor, Outdoor*	*80% / 100% (R1/T0)*	*0,024*	*0,02*	*Random Waypoint*	*AODV, DSR OLSR, GRP*	*VoIP, Video Conferencing*
Third	*Indoor, Outdoor*	*60% / 100% (R2/T0)*	*0,018*	*0,02*	*Random Waypoint*	*AODV, DSR OLSR, GRP*	*VoIP, Video Conferencing*
Fourth	*Indoor, Outdoor*	*60% / 60% (R2/T1)*	*0,018*	*0,012*	*Random Waypoint*	*AODV, DSR OLSR, GRP*	*VoIP, Video Conferencing*

Furthermore, each phase evolves also sub-phases depending on the mobility level of the intermediate MTs that are inside a predefined mobility domain. For the first case of outdoor environment we assumed 7 mobility levels (0m/sec – 15m/sec), while 6 mobility levels (0m/sec – 3m/sec) were assumed for the indoor environment. More details about the mobility domain and mobility levels assumed in each phase are presented in sub-Section 5.2.4. Once again, it should be noted that the issue of interference between the transmitting MTs is not taken into account and is left out for future study.

Finally, we also experiment on the routing protocol, which will be used to route traffic to MTs that are found out of range during the AP's and MTs' transmission power reduction.

In this paper, we conduct also all the simulation scenarios assuming 4 ad-hoc routing protocols in total [4], both proactive, namely, OLSR [5] and GRP [6] and reactive ones namely, Dynamic Source Routing (DSR) [7] and AODV [8]. Further details about the routing protocols are presented in sub-Section 5.2.5.

5.2.3. Application Aspects

Two types of real-time applications are considered in the simulation scenarios, which were selected so as to exhibit varying and scalable resource requirements and sensitivity e.g. with respect to bandwidth, delays, jitter, packet loss etc. These are a) VoIP and b) Video Conference. The study could be extended to include non-real time applications, as well, however we select here to evaluate the proposed ON creation in more stringent situations. Furthermore, Web–browsing has been already studied and simulated in our previous work in [9] and presented in Chapter 4, where it is demonstrated that this application can be still supported without any problem after the creation of an infrastructure-less network.

The VoIP application is based on the G.711 [10] voice encoding scheme for both the caller and the callee. Further values for the attributes of the modeled VoIP application are given in Table 5-III.

Furthermore, a Video Conferencing application is considered for the transfer of video streaming frames between the MTs of the network. Once again, the details for the assumed values for some important Video Conference attributes are also summarized in Table 5-III.

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It should be noted that the type of service for all the two assumed applications is set to BE. This is quite fair, since we are not interested in giving priority to the traffic of a specific application against another. Actually, as revealed in the sequel, the simulations were run assuming one application each time. A mixing of application traffic and the inclusion of service type related priorities is also of high importance from QoS perspective, but it will comprise subject of our future study.

Table 5-III: Traffic Input Parameters

VoIP	*Encoder Scheme G.711*
	1 voice frame per packet
	No control signalling(e.g. for setup/release) included
Video Conferencing	*Low Resolution Video :* *128X120 pixels, 9 bits/pixel*
	10 frames/sec

5.2.4. Mobility Aspects

We consider a mobility domain inside the range of the AP, in which the MTs are moving assuming a random waypoint mobility model [11]. The Random waypoint model is one of the most commonly used mobility models in the research area of mobile ad-hoc networks. The characteristics of this model, as depicted also in Figure 5-2, is that at every instant, each one of the mobile nodes chooses a random destination inside the mobility domain A and moves towards (from waypoint Pi to waypoint Pi+1) with a speed distributed in [0, Smax], where Smax is the maximum speed of each node. When the node arrives at the destination, stops for a defined duration time called "pause time". After this "pause time", it chooses again another random destination and this it is repeating until the simulation ends.

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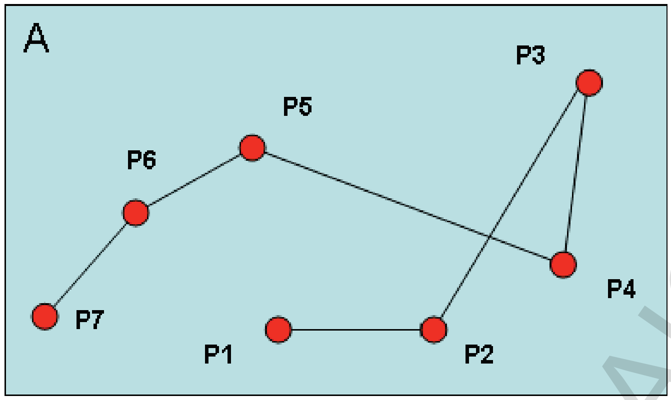

Figure 5-2: Random Waypoint model

The MTs inside the domain are serving those that are out of the range using ad-hoc connections and creating ONs. The mobility of the MTs in the domain starts at the beginning of the simulation without any interruption during the process and finishes with the end of the scenario. Recall that, in the first case of the Outdoor environment 7 mobility levels (0m/sec – 15m/sec) are considered while in the Indoor 6 (0m/sec – 3m/sec). Table 5-IV summarizes the levels of each case of the considered simulation environment. The maximum speed of the random waypoint model is the same for all the MTs that are inside the mobile domain.

Table 5-IV: Mobility Parameters

Mobility Model	*Random Waypoint*
Mobility Domain Range (m)	*Indoor :30*
	Outdoor :120
Max Speed (m/sec)	***Indoor*** *: 0 - 0,25 - 0,5 – 1 - 1,5 - 3*
	Outdoor *: 0 – 1 – 1,5 – 3 – 5 – 10 – 15*
Pause Time (sec)	*None*
Start Time (sec)	*1*
Stop Time (sec)	*End of Simulation*

It should be note here that although the random waypoint model is broadly accepted because of its simplicity and wide availability, in many cases it is insufficient to come up

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with some mobility aspects such as the temporal dependency of movement node over time, spatial dependency of the movement among the nodes and geographic restrictions from barriers or obstacles [12].

5.2.5. Routing Aspects

As already written, we simulate all the scenarios assuming 4 ad-hoc routing protocols, which will be used to route traffic to MTs that are found out of range during the AP's and MTs' transmission power reduction. Therefore the first intention of the routing protocol is the correct route establishment among the nodes, which is constructed by the use of minimum overhead and bandwidth consumption.

Figure 5-3 depicts the main classification of key routing protocols for a mobile ad-hoc network. Firstly, flat routing which is further categorized in proactive and reactive, then hierarchical routing and finally geographic position assisted routing [13]. Proactive protocols (OLSR - GRP) maintain periodically routing information, such as destinations and routes, before it is needed [8]. Particularly OLSR performs hop-by-hop routing, where each node uses recent routing information, in order to route packets. Therefore, each node, selects a set of nodes, with the use of HELLO messages, from its one hop neighbors in order to act as Multipoint Relays (MPRs). MPRs are intermediate nodes that relaying messages between source and destination. Finally MPRs are responsible for the transmission of Topology Control (TC) messages that are used for the communication between neighbors. Moreover GRP is a routing protocol that relies on geographic position information. However it has a proactive routing strategy and each node maintains its current geographic location. A HELLO message is exchanged between nodes to identify their neighbors and their positions. With this information the traffic can be routed from the source to the destination without any route discovery process or any knowledge of the network topology.

On the other hand, reactive protocols (DSR – AODV) are searching for the route, when there is the need for the communication and then they are establishing the connection. However, AODV is based on a different technique in order to maintain routing information that uses traditional routing tables (one entry per each destination). Route Request (RREQ) messages are used by nodes in order to find a route to its neighbors.

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The RREQ message is transmitted in the network until it reaches the final destination. Finally the route is established with the use of Route Replies messages (RREP), back to the source. This mechanism is different from DSR's, which can maintain multiple routes for each destination. That is, source knows the complete hop-by-hop route to the destination. Further details, with the characteristics of the used routing protocols, are summarized in Table 5-V.

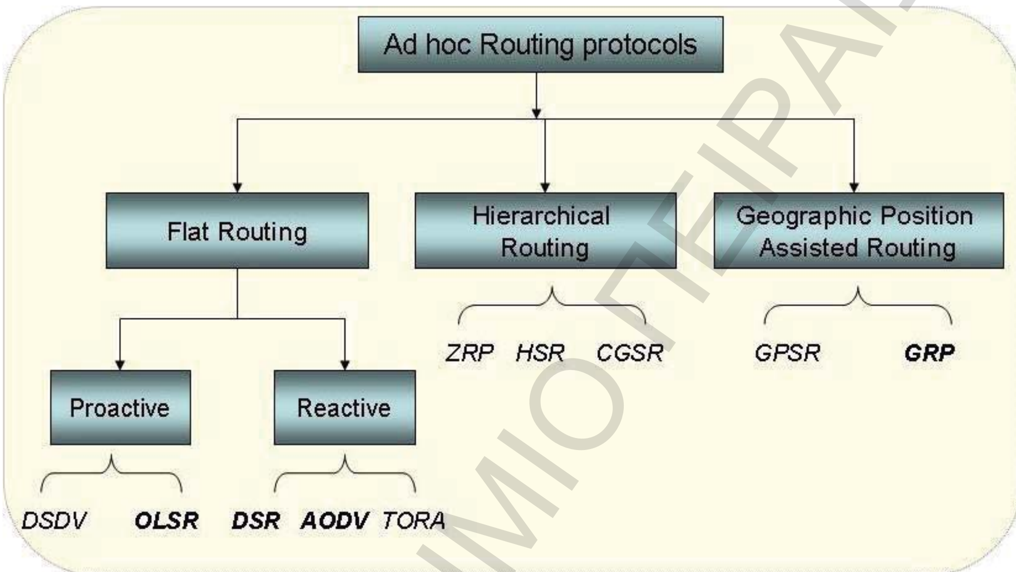

Figure 5-3: Classification of ad-hoc routing protocols [13]

Table 5-V: Features of Routing Protocols

Characteristics	Routing Protocols			
	AODV	*OLSR*	*GRP*	*DSR*
Routing strategy	*Reactive*	*Proactive*	*Proactive*	*Reactive*
Routing Type	*Hop-by-hop*	*Hop-by-hop*	*Hop-by-hop*	*Source routing*
Frequency of Updates	*As needed*	*Periodically*	*Periodically*	*As needed*
Worst case	*Full flooding*	*Pure link state*	*Full flooding*	*Full flooding*
Use of Multiple routes	*No*	*No*	*No*	*Yes*

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5.3. Results and Analysis

In this section, the QoS metrics that have been used for the evaluation of the ON-based solution are presented, along with the results conducted from the simulations.

5.3.1. Qos Metrics

The study of the feasibility of such integration of ONs with wireless network infrastructure requires the investigation of the potentials of adequate QoS provision under such schemes. Accordingly, in this simulation study we focus on specific QoS metrics, which are used to evaluate conditions and assist in coming up with useful recommendations with respect to the creation of the ONs. Above all, in this simulation study, QoS evaluation is carried out by the following performance metrics:

a) Application End to End Delay (sec): which is the one way, end to end delay of application packets from the sending to the receiving node. It includes a) processing delays e.g. voice packet compression/decompression, packetization etc. b) queuing and medium access delays in the AP as well as in the intermediate nodes, c) TRx delay of the AP and the intermediate nodes and d) the propagation delay for each connection between the AP and the destination node.

b) Data received (Kbps): which corresponds to the total number of the successfully received packets (including PHY/MAC headers) by a wireless node, regardless of the destination of the received frames.

c) Packet Loss (%): which is defined as the percentage in which data is dropped due to full higher layer data buffers or because of too many retransmission attempts.

d) Throughput (Kbps): which corresponds to the total data traffic in bits per sec, successfully received by the destination excluding packets for other destination MACs, duplicate and incomplete frames.

e) MOS Value (Mean Opinion Score), which corresponds to a numerical indication, range 1(worst) to 5(best) expressing the quality of the voice telephony or audio [14].

f) Routing Traffic received (Kbps): which corresponds to the total number of the received routing traffic by a wireless node for the routing protocol e.g. Hello messages, RREQ and RREP messages.

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g) Jitter (sec), which is used to denote the average time difference between the arrivals of two consecutive packets at any destination node.

All the above metrics are averaged to the set of 4 application MTs in the simulated network, except from Data and Routing traffic received respectively, which are measured in the entire network. Moreover, Table 5-VI summarizes the requirements for specific QoS metrics [15], [16] and for each of the considered applications. This table will be used as a reference throughout the rest of this chapter and will assist in extracting conclusions and recommendations from the derived statistics.

In the sequel, the possible QoS provision potentials from the exploitation of the ONs by the infrastructure-based part during the defined phases in outdoor and indoor environments will be investigated. Specifically, comprehensive results from the execution of various test cases differentiated with respect to the mobility levels of MTs, the type of application offered and the deployed ad-hoc routing protocol follow.

Table 5-VI: QoS requirements per application type [15], [16]

Applications	**Technology**	**QoS Metrics**				
		Delay (ms)	*Jitter (ms)*	*MOS*	*Bit Rate (Kbps)*	*Packet Loss*
VoIP	Real Time and Symmetric	<200	<400	>3,5	60	<1% (lasting 2-3 sec)
Video Conferencing	Real Time and Symmetric	<150	<150	n/a	>80	<1%

5.3.2. Outdoor Environment

A brief description of the obtained results for VoIP and Video Conferencing application in the outdoor environment, with the properties appearing in Table 5-I and Table 5-II, follows.

Figure 5-4 *(a), (b)* depicts the average application delay of each MT node for the VoIP and Video Conferencing application. It should be noted here that the end-to-end delay that is measured by the network simulator, actually assumes a MT node in the one end and the AP in the other end.

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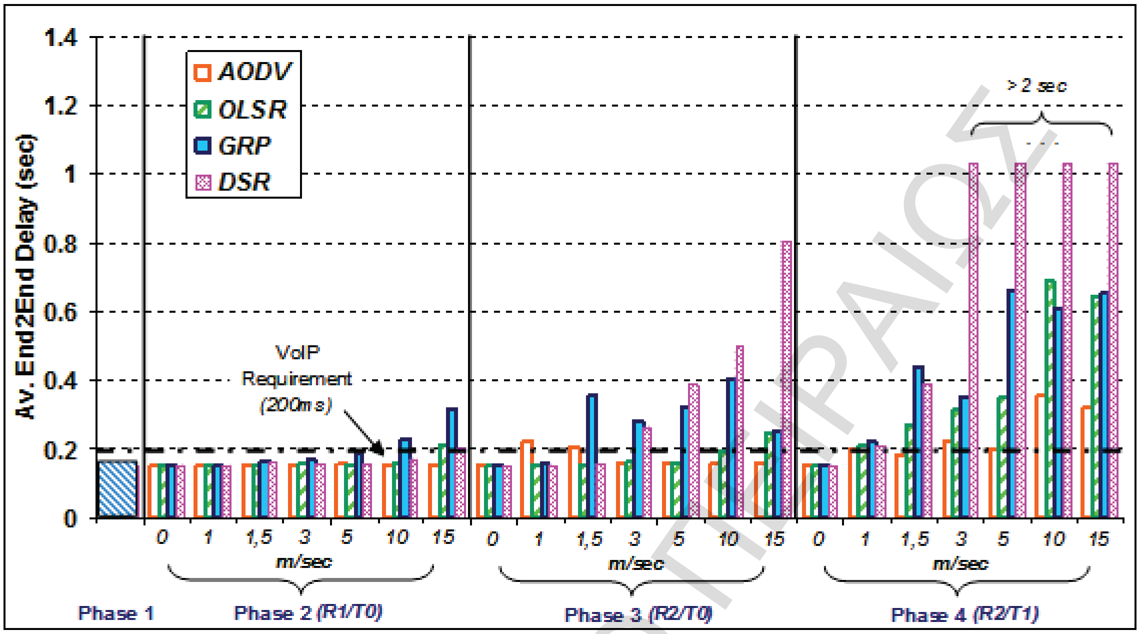
(a)



(b)

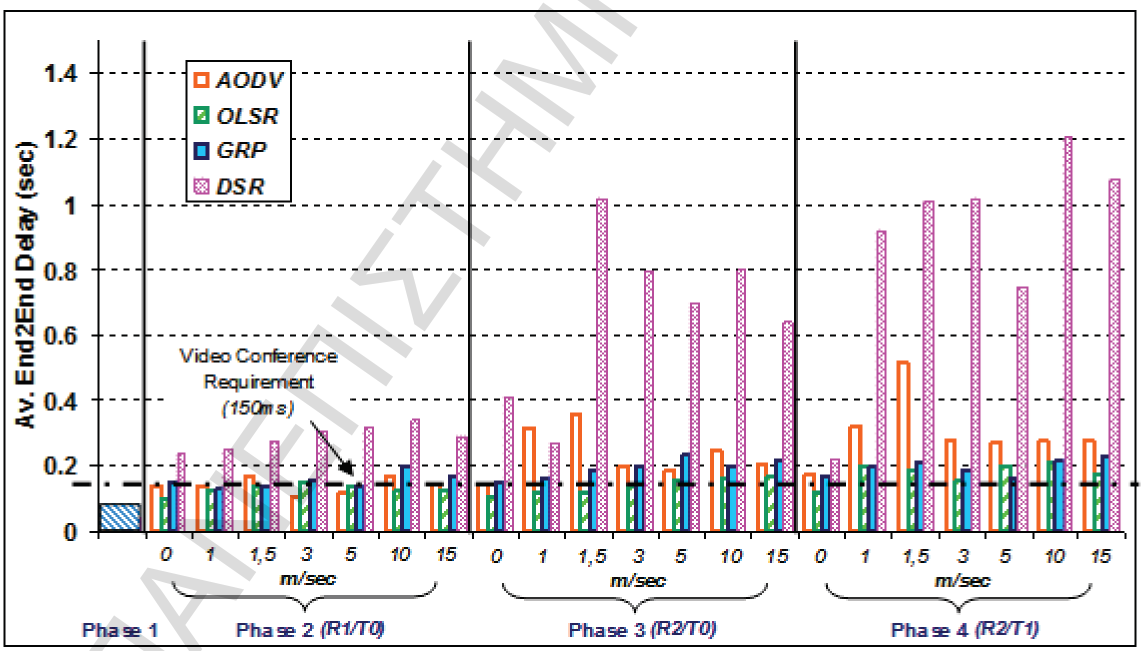


Figure 5-4: Av. End to End Delay (sec) per Application Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

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That is to say, in order to obtain the actual end to end values, we should first double the obtained simulation measurement (reach the other MT node) and add a worst case delay of about 65ms [17] corresponding to the extra delay due to the packets traversing the backbone part. Therefore, Figure 5-4 *(a), (b)* depicts exactly these elaborated results.

As a general observation, as the mobility level is increasing in all phases, the overall delay is also increasing. This is due to the fact that the mobility in the intermediate nodes, can significantly impact the performance of the ad-hoc routing protocols, including the packet delivery ratio, the control overhead and the data packet delay [18].

Moreover as it is depicted in Figure 5-4 *(a), (b)* in all phases, the decrease of the initial transmission power of AP/MTs, leads to a more serious increase of the delay in VoIP and Video Conferencing application. As the number of the intermediate, out of range nodes is increasing, while the AP's range is shrinking from R0 to R2 (phase 1 to 4), the overall delay is also increased as more MTs are responsible for routing and forwarding the received packets. In particular in VoIP application, this increase is almost inexistent in the Phase 2, keeping the delay values negligible in almost all mobility levels, whereas in Phase 3 and 4 there is not the same tendency. On the other hand in Video Conferencing application there are appreciable differences through the routing protocols.

Similar results can be derived when examining Figure 5-4 *(a), (b)* with respect to the used routing protocol. For instance when considering VoIP, in Phase 2 and 3 there are negligible differences in the produced delays for AODV and OLSR. However AODV seems to have better performance in high mobility levels. On the contrary, this does not happen with GRP and DSR, leading to an increase of the overall delay especially in the last three mobility levels (5m/sec - 10m/sec - 15m/sec). A quite similar situation appears in the Video Conference application, but with the OLSR being the winner this time, resulting in 0,07sec, 0,02sec and 0,44sec less in average delay values compared with the AODV, GRP, and DSR respectively.

In the sequel, we examine the obtained results against the set of predefined application requirements given in Table 5-VI. By advising the table, it is assumed that the one way acceptable end-to-end delay for VoIP and Video Conferencing applications is 200ms and 150ms, respectively [14], [15]. The result is also depicted in Figure 5-4 *(a), (b)*, where

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single dotted lines corresponding to the delay requirement for the time-sensitive application is also drawn for readiness purposes. Phase 4 seems to be a prohibitive state for the network, when considering both applications for all routing protocols, except the first sub-case where there is no mobility in the intermediate MTs. Moreover, phase 3 can also result in intolerable delays for high mobility levels e.g. when DSR and GRP routing are deployed.

The next set of results focuses on the total received data traffic metric in the network. Particularly, Figure 5-5 *(a), (b)* depicts the average data traffic per node, which is successfully received by the MAC from the physical layer in Kbps.

In general as the number of the ad-hoc connections increases from phase 1 (0 ad-hoc) to phase 2 ($\geq$1 ad-hoc), the average number of control and data packets circulating in the network, also increases. This can be justified by the fact that, as the AP’s coverage is reduced, the number of MTs that are forced to route traffic to other MT nodes increases and thus, more traffic traverses each node in average. From the mobility perspective, when considering Video conferencing, we observe a common tendency towards decreasing the number of data traffic received, while this does seem to occur in VoIP application.

In addition, when examining Figure 5-5 *(a)* with respect to the used routing protocol, we observe that there are small differences in the total data received metric for AODV and OLSR. On the other hand in Video Conference there are small differences in the values for the four routing protocols. However GRP exhibits more received data traffic when considering both applications.

Figure 5-6 *(a), (b)* depicts the % percentage of Packet Loss which arises after dividing the number of dropped data (as a result of either buffer overflows or exceeds in retry thresholds) with the data sent to all application MTs. The maximum acceptable loss for each application is also depicted with dotted line.

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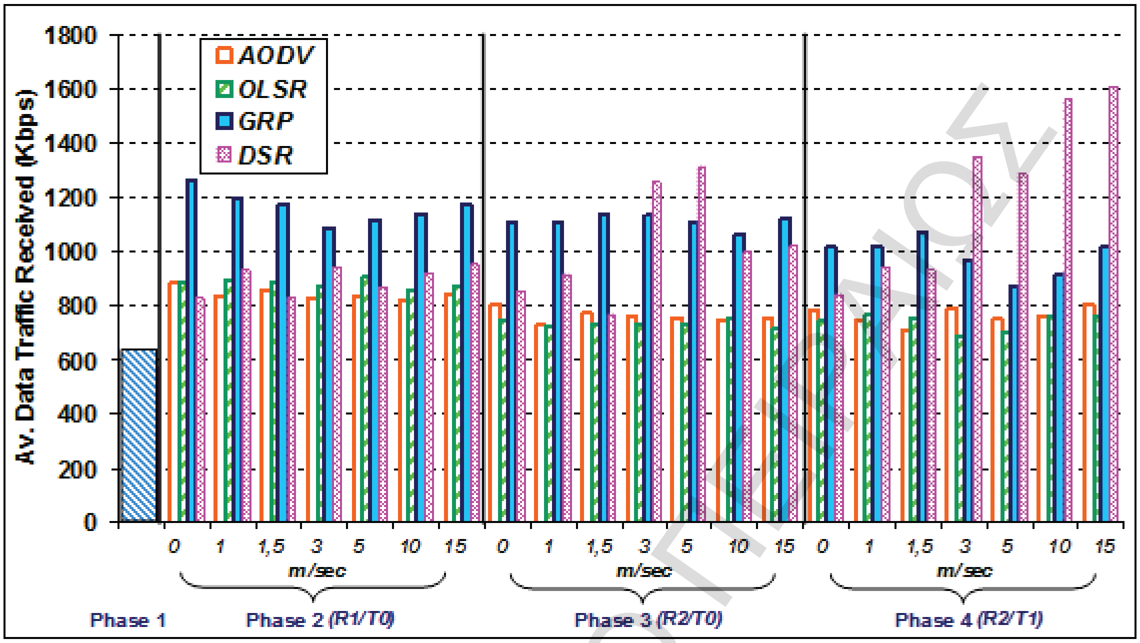
(a)



(b)

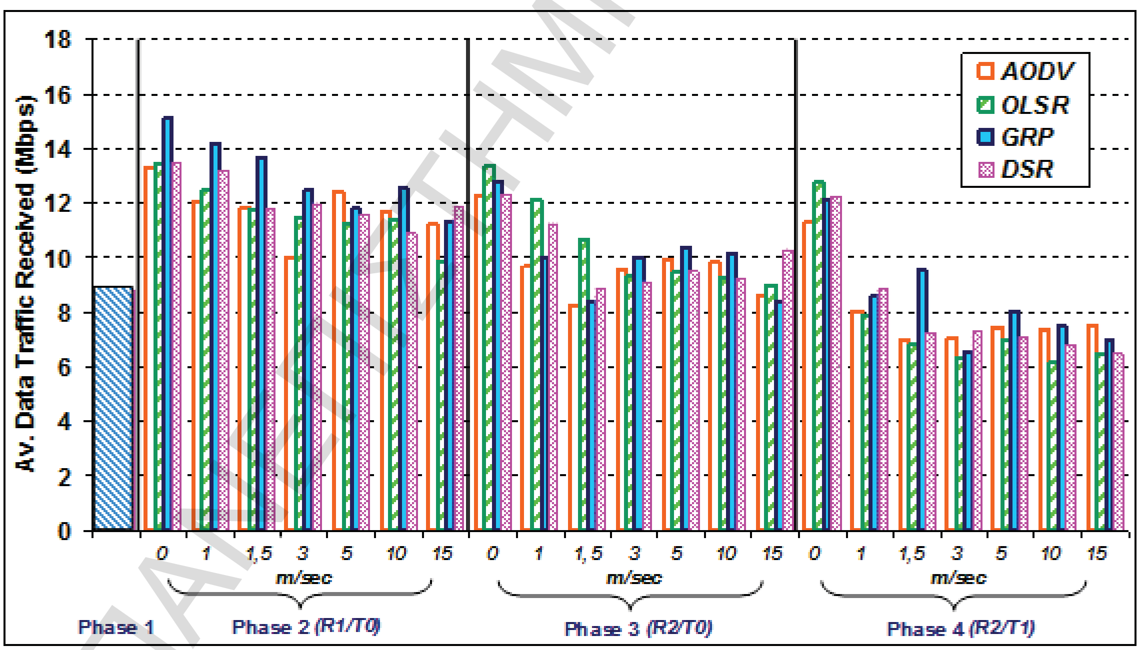
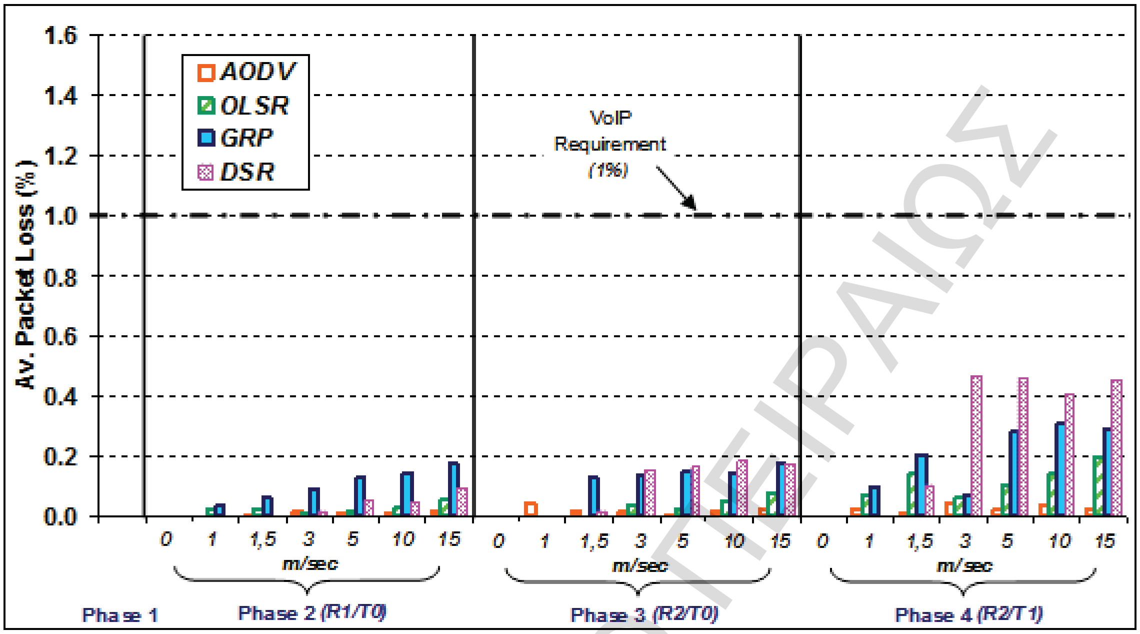


Figure 5-5: Av Data Traffic Received (Kbps) per Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

(a)



(b)

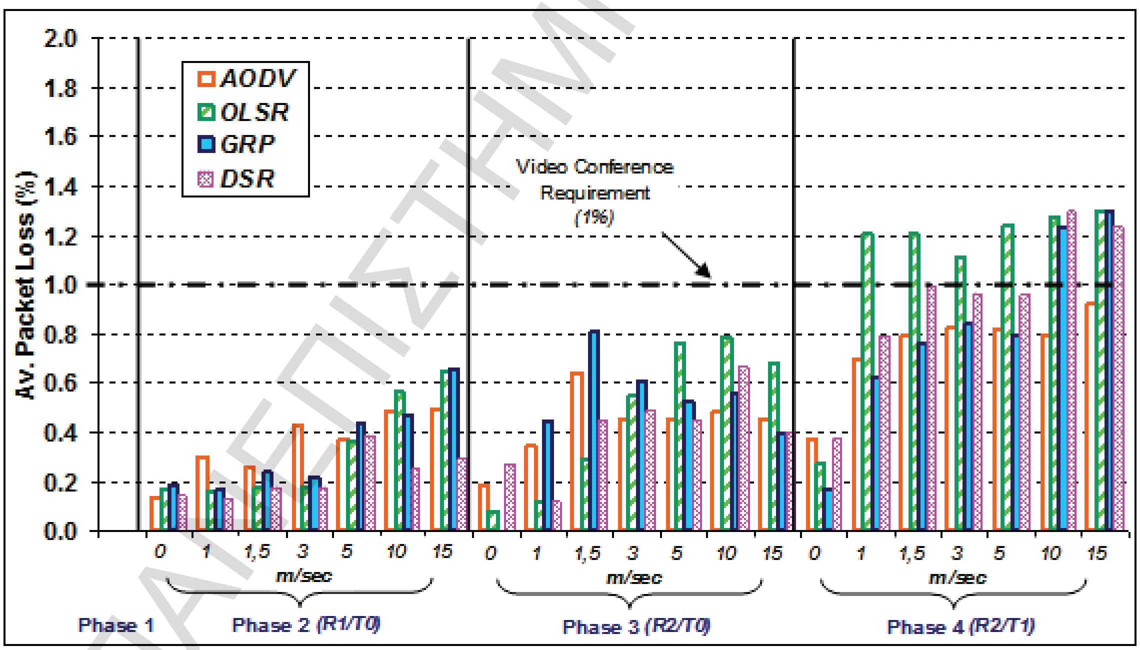


Figure 5-6: Av. Packet Loss (%) per Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

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In general as the mobility level increases the average data dropped also increases and this is more apparent in phase 4, where both the AP's and MTs' initial transmission power decreases. This happens due to the fact that, when there is an increasing in the mobility level of the MTs, there is higher rate of disconnections in the network, which produces more route errors and thereafter dropped packets.

In the same figure, single dotted lines are used to depict the requirements posed for guaranteeing the flawless reception of the application. When considering VoIP, packet loss remains at acceptable levels i.e. not exceeding a value of 1%, for all the phases of the reduction of the AP's/MTs' transmission power and for all four routing protocol options. In Video Conference application and for phase 2 and 3, packet loss remains at acceptable levels without exceeding the 1% value. Finally, in phase 4 the packet loss rate has acceptable values in the first five mobility levels (0 to 5m/sec), for all routing protocols except OLSR.

The next set of results focuses on the total received routing data metric. In particular, Figure 5-7 *(a), (b)* depict the average routing data traffic received per node in Kbps that comprises all the control traffic received. Generally speaking, when there is an increasing in the mobility level of the MTs, the rate of disconnections is higher. This creates more route errors and there is more frequently need for re-initialization of route discovery process.

In particular, as the mobility level increases, GRP and OLSR seem to have stable routing traffic, which can be justified by their proactive nature strategy. On the other hand, DSR, being a reactive protocol, seems to increase its routing traffic as the mobility increases. This does not seem to exist in case of AODV, whereas in general the high mobility levels appear not to have a serious effect on that. Moreover comparing the reactive protocols, DSR almost always has lower routing traffic than AODV. This happens due to the fact that DSR uses caching [7]. It is more likely for DSR to find a route in cache and perform the process of route discovery less frequently than AODV. From the routing protocol perspective GRP clearly win its competitors in both applications.

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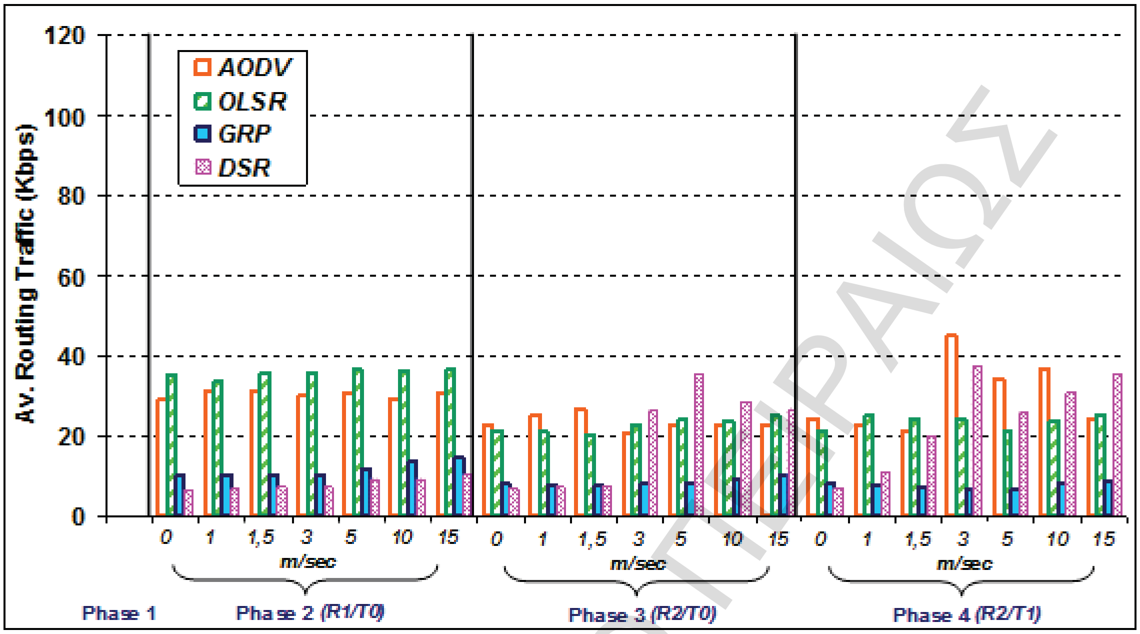
(a)



(b)

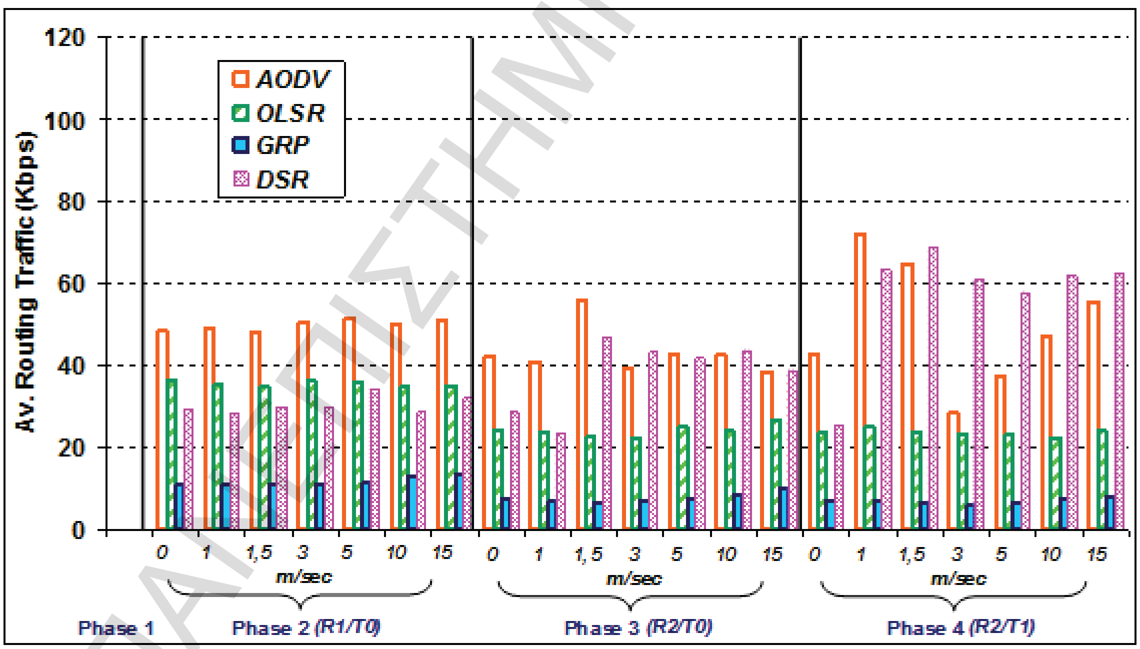


Figure 5-7: Av Routing Traffic (Kbps) per Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

In addition, Figure 5-8 *(a), (b)* depicts the average downlink throughput in Kbps estimated for application MTs. Although the delay in general increases, we observe that in VoIP application the average downlink throughput per MT node increases, even though this happens at non-significant levels. A first, immediate explanation behind this observation would be as follows: In the first phase there are MTs that are in the edge of the cell and the achieved physical data rate is not the maximum supported by the technology i.e. 54Mbps, whereas this is restored with the reduction of the range that causes a corresponding reduction in the average distance among MTs using ad-hoc connections as well.

Furthermore, under the same spirit, in ad-hoc networks a multi-path route can achieve higher throughput than in direct route between the source and the destination [19]. An explanation is that, the longer in distance it takes a packet to transmit, the less time is available to other nodes for transmission. Due to this fact, there is an increase of the overall downlink throughput in the network. Moreover, we observe that the increase of the mobility to a specific level, can give better downlink throughput. This is more obvious in case of reactive routing protocols, DSR and AODV. This happens due to the fact that the mobility in the intermediate nodes creates additional routes between the source and the destinations, leading to a better performance of the network [20].

When it comes to Video Conference application, we observe a significant decrease in the throughput when moving from phase 1 to phase 4. This can be justified if seen in conjunction with the corresponding increase in both the dropped data rate and the end-to-end delay metrics that the application suffers.

Focus is now placed on results observed from the Figure 5-8 *(a), (b)* with respect to the used routing protocol. In the case of VoIP application GRP outperforms its counterparts in terms of achieved throughput, as none of the other three protocols achieves the requirement bit rate, depicted in Table 5-VI. Also in case of Video Conferencing, AODV outperforms its counterparts in terms of achieved throughput giving almost 184,9Kbps, 49,5Kbps and 164,2Kbps more than OLSR, GRP and DSR respectively.

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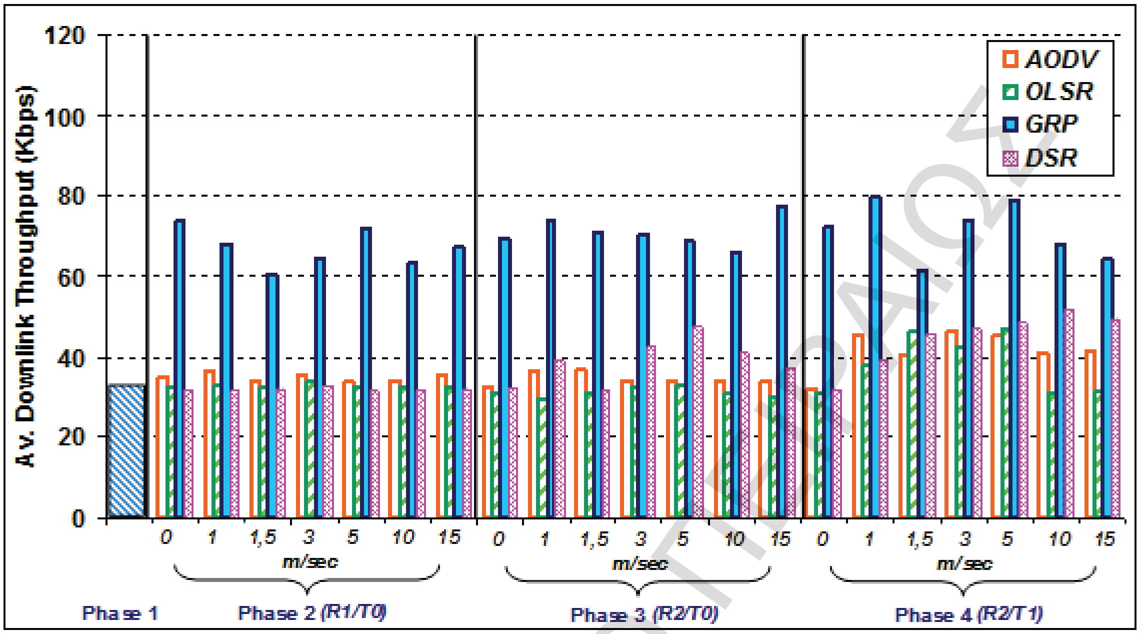
(a)



(b)

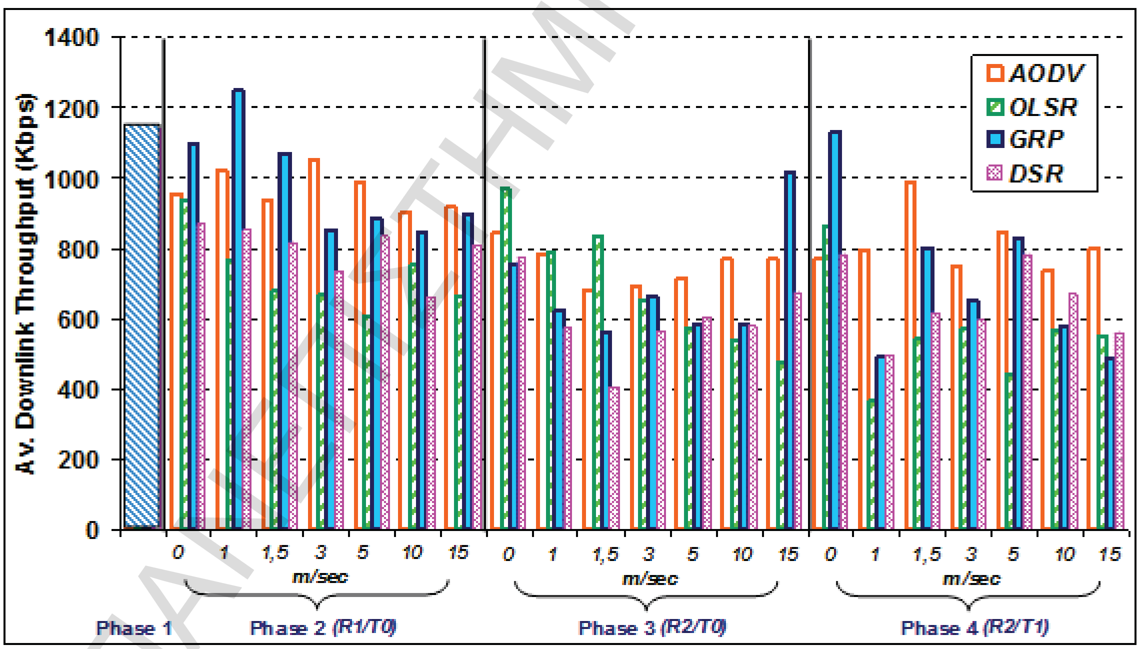


Figure 5-8: Av Downlink Throughput per Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

Figure 5-9 depicts the average MOS value of each MT node for the VoIP application. The MOS value is based on the impairment calculated planning impairment factor (ICPIF), which in an IP network is also based in delay and equipment effects such as the type of codec used for the call and the packet loss [21]. We observe a significant decrease of the MOS Value as the mobility level increases. Additionally, the decrease of the initial transmission power of AP/MTs, leads to a more serious decrease of this metric.

In the same figure, single dotted lines are used to depict the requirements posed for guaranteeing the flawless reception of the application. Phase 4 seems to be an inhibitive state for the network for all routing protocols except the first mobility level, where there is no mobility in the MTs. Moreover, phase 3 can also result acceptable values for MOS in low mobility levels e.g. when AODV and DSR routing are deployed. In Phase 2 almost all the routing protocols are over the MOS value requirement except from the last mobility level (15m/sec) where OLSR, GRP and DSR cannot reach it.

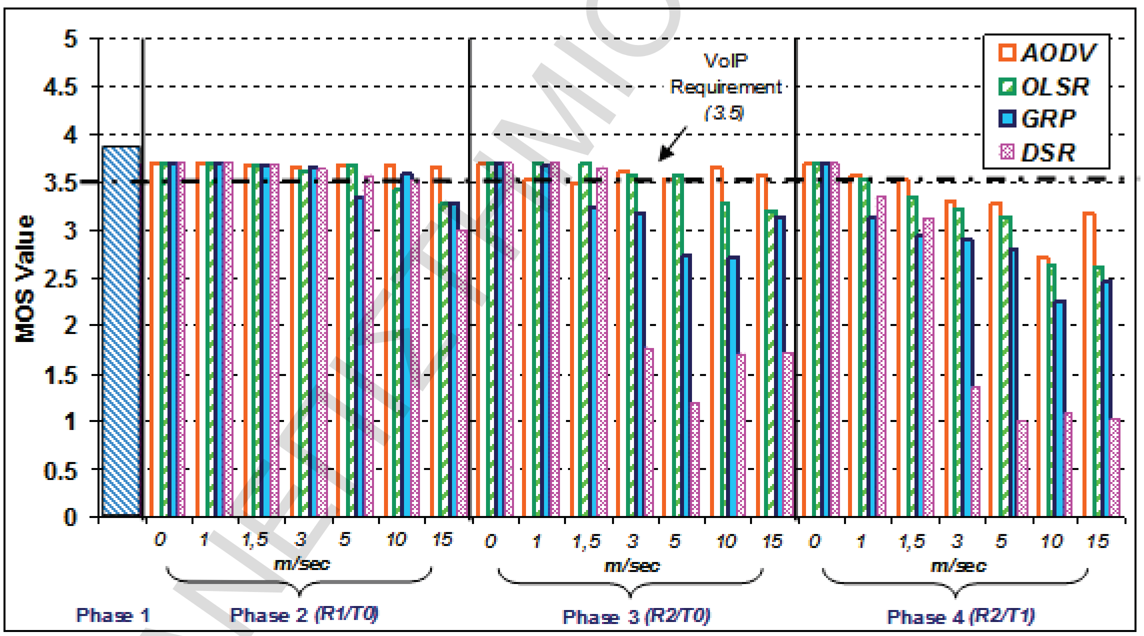


Figure 5-9: MOS Value per Node in 4 Phases for VoIP for AODV, OLSR, GRP and DSR routing Protocol

Apart from the above described results, it should be mentioned here that we have also experimented with another QoS metric, which is judged as rather crucial at least for the two real time applications, namely the "jitter". What is actually measured for jitter is the

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IPDV as defined in IETF RFC 3393 [22] i.e. "the difference in one way delay between successive packets, ignoring any lost packets". However, in all the scenarios examined above, the thresholds appearing in Table 5-VI were not violated and as such, the detailed results and figures are not depicted here for brevity reasons.

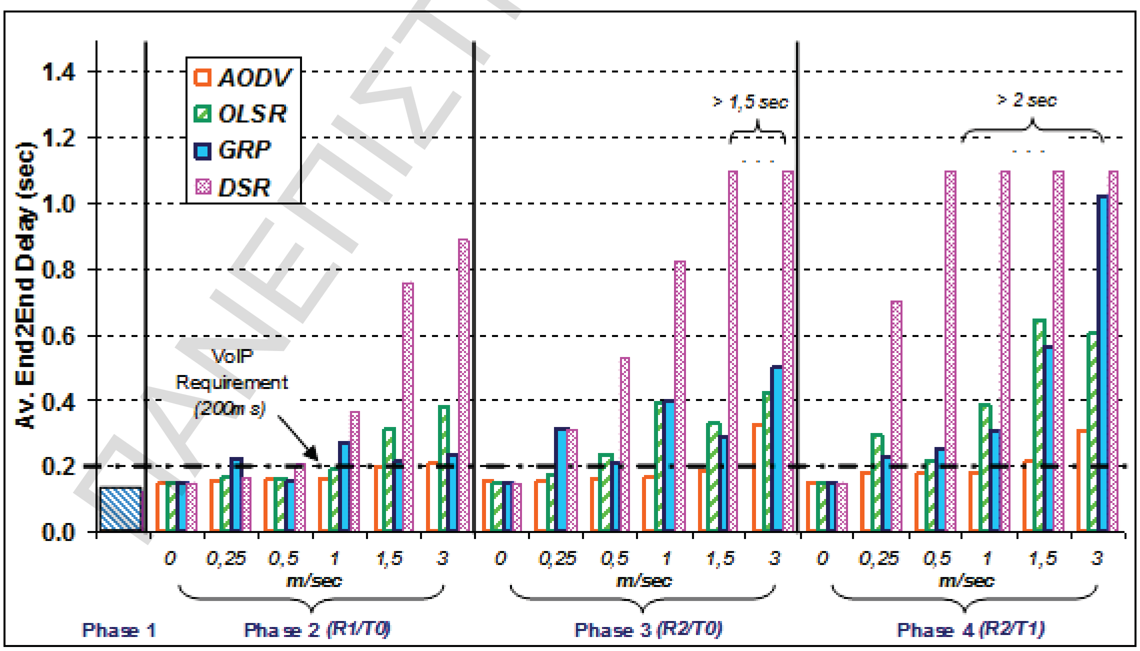
5.3.3. Indoor Environment

Similar analysis was performed for VoIP and Video conferencing application in case of indoor environment. A short description of the obtained results follows.

Figure 5-10 *(a), (b)* depicts the average end-to-end delay which arises as previously described in both applications i.e. after doubling the obtained measurement and adding a worst case interim network delay. Generally as the number of the ad-hoc connections increases from phase to phase, the average end to end delay in the network, also increases.

In case of the VoIP application, AODV seems to have less average delays than the other routing protocols, whereas OLSR seems to clearly outperform its counterparts when considering Video Conferencing application.

(a)



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(b)

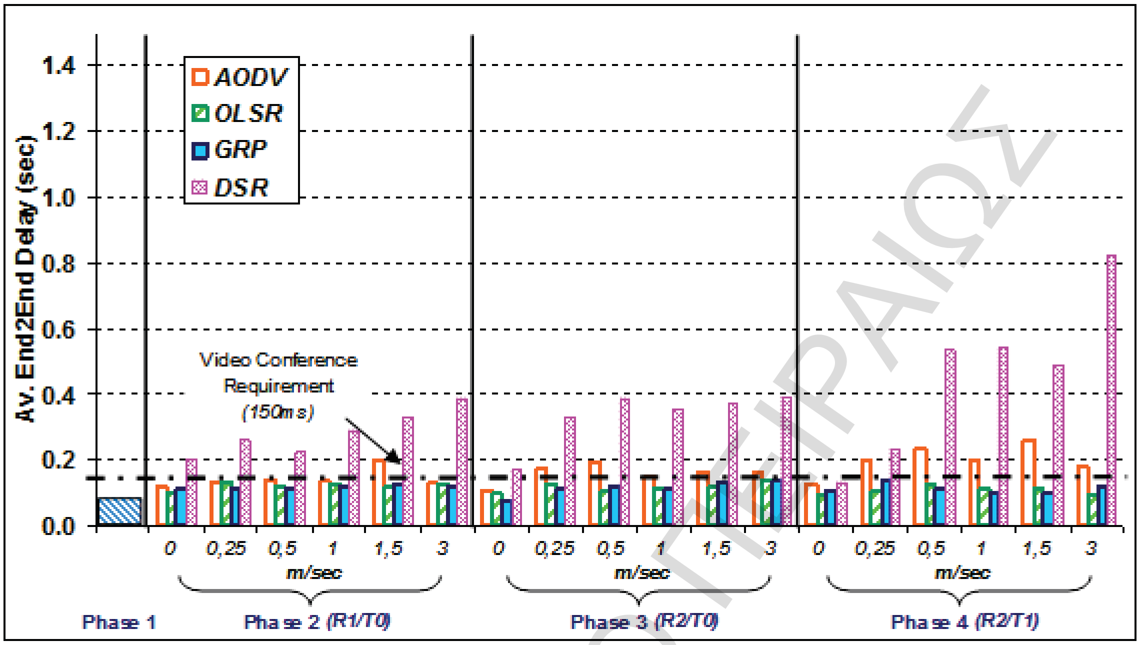

Figure 5-10: Av. End to End Delay (sec) per Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

As before, we examine the obtained results against the predefined application requirements given in Table 5-VI. For the VoIP application in phase 2, end-to-end delay remains at acceptable levels without exceeding the delay requirements of Table 5-VI for the first three mobility levels (0 – 0,5m/sec). Additionally, in phase 3 and 4, except the first mobility level with no mobility at all, all the routing protocols expect AODV seems to exceed the given requirement. In case of Video Conferencing only DSR has not acceptable values of the metric in all phases and mobility levels. In addition AODV in some mobility levels especially in phase 4 seems to be a prohibitive state for the network.

Next we focus on the average data traffic per node (Figure 5-11), which is successfully received by the MAC from the physical layer. As previously observed, the stepwise increase in the number of ad-hoc connections, from phase 1 to phase 2, leads to a rise of the total traffic volume passing the nodes of the network. In case of Video Conferencing we observe that there is a common tendency towards decreasing the

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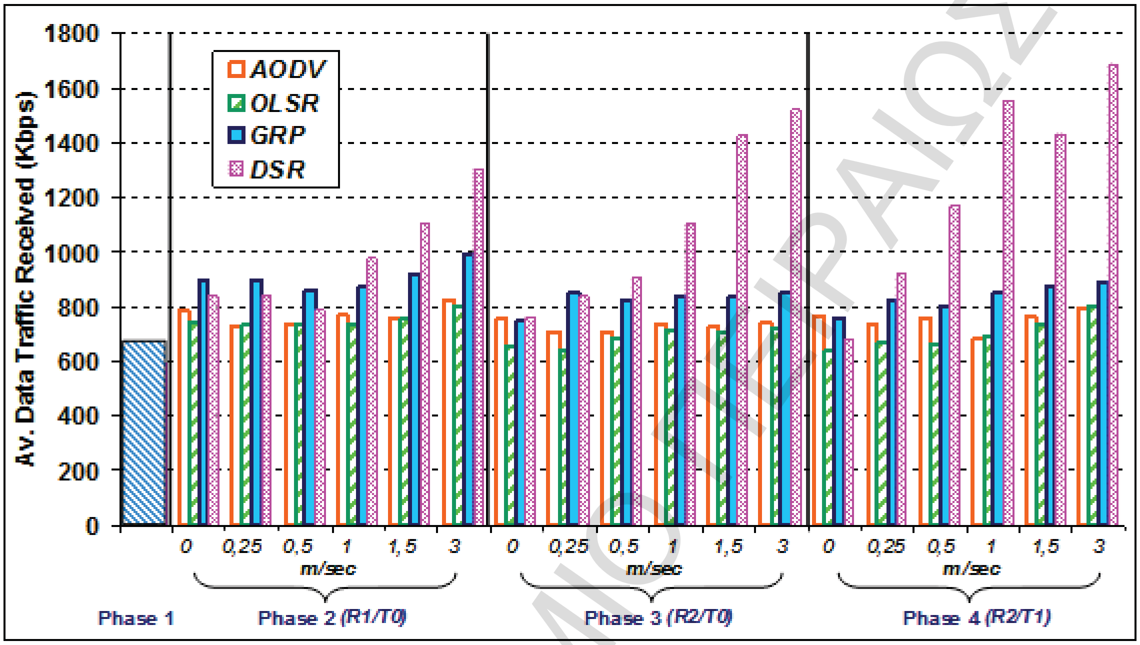
number of received data when going from phase 2 to phase 4 and as the mobility increases.

(a)



(b)

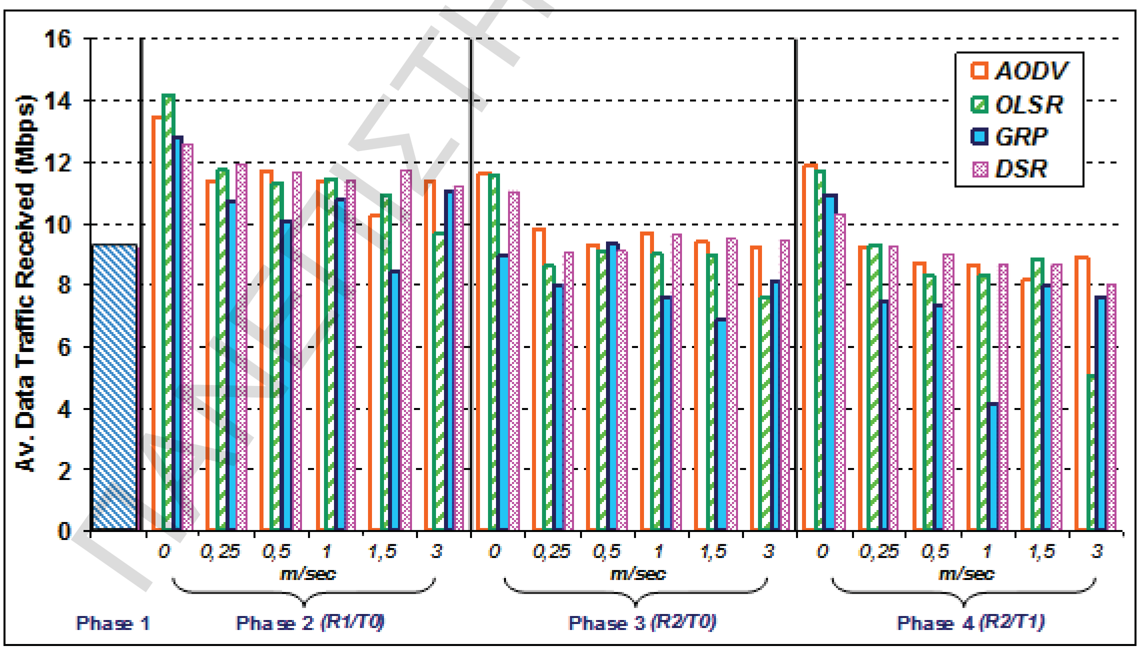


Figure 5-11: Av. Data Traffic Received (Kbps) per Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

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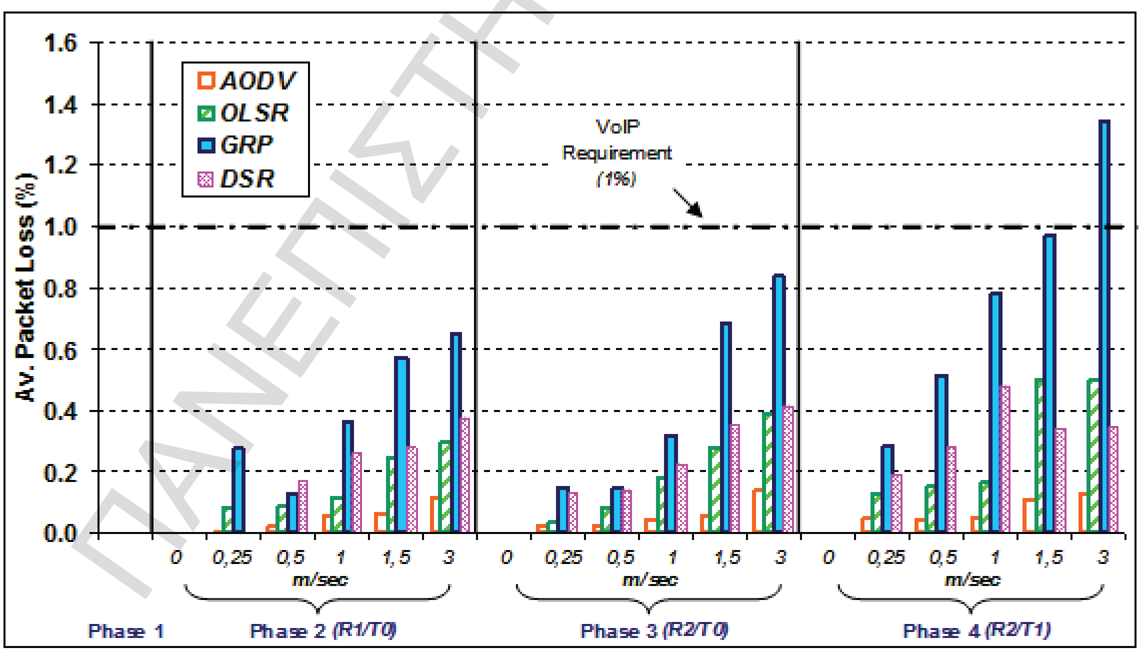
On the other hand, in VoIP application we observe that there are small differences from phase to phase. Additionally with respect to the mobility level, DSR seems to increase its data traffic as the speed of the MTs also increases.

Results can also be derived with respect to the used routing protocol. As we observe there are little differences in the total data received metric in each phase. However, in VoIP application some differences become more considerable in phase 2 with OLSR leading to clear less average data received per MT node. OLSR gives an average data traffic received (for all phases and mobility levels) about 35,4Kbps, 141,3Kbps and 389,2Kbps less than the ones collected in the case of AODV, GRP and DSR respectively. Moreover in Video conference application GRP give about 1,44Mbps, 0,96Mbps and 1,33Mbps less than the ones collected in the case of AODV, OLSR and DSR respectively.

Figure 5-12 *(a), (b)* depicts the packet loss rate with single dotted lines corresponding to the packet loss (%) requirements as these are described in Table 5-VI. In case of VoIP, packet loss remains at acceptable levels in most phases without exceeding the 1% value, except from GRP in the last mobility level (3m/sec) of phase 4.

(a)



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(b)

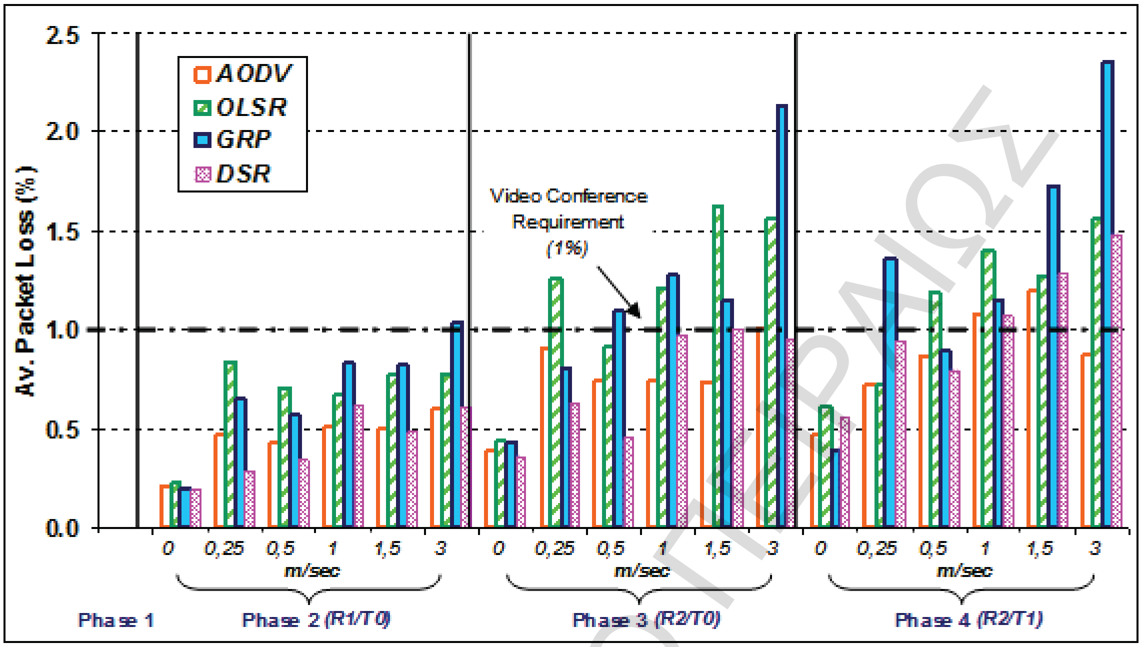

Figure 5-12: Av. Packet Loss (%) per Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

In contrast, when considering Video Conferencing, phase 2 seems to have acceptable values for all routing protocols, whereas phase 3 and 4 only AODV has values under the requirement for all mobility levels except the last three of phase 4 (1 - 3m/sec).

The next set of results focuses on the total received routing data metric. Above all, Figure 5-13 *(a), (b)* depicts the average routing data traffic received per node in Kbps and comprises all the routing traffic as previously described. Generally we observe that there is a common stable tendency in the number of routing data in all phases and for both applications for proactive protocol such as OLSR and for geographic like GRP. On the contrary, in reactive routing protocols (AODV and DSR), we observe that the mobility level of each MT affects this metric. In particular, there is an increase in the routing traffic as the speed of the MT also increases. From the routing protocol perspective GRP, as also depicted in Figure 5-13 *(a), (b)*, clearly win its competitors in both applications.

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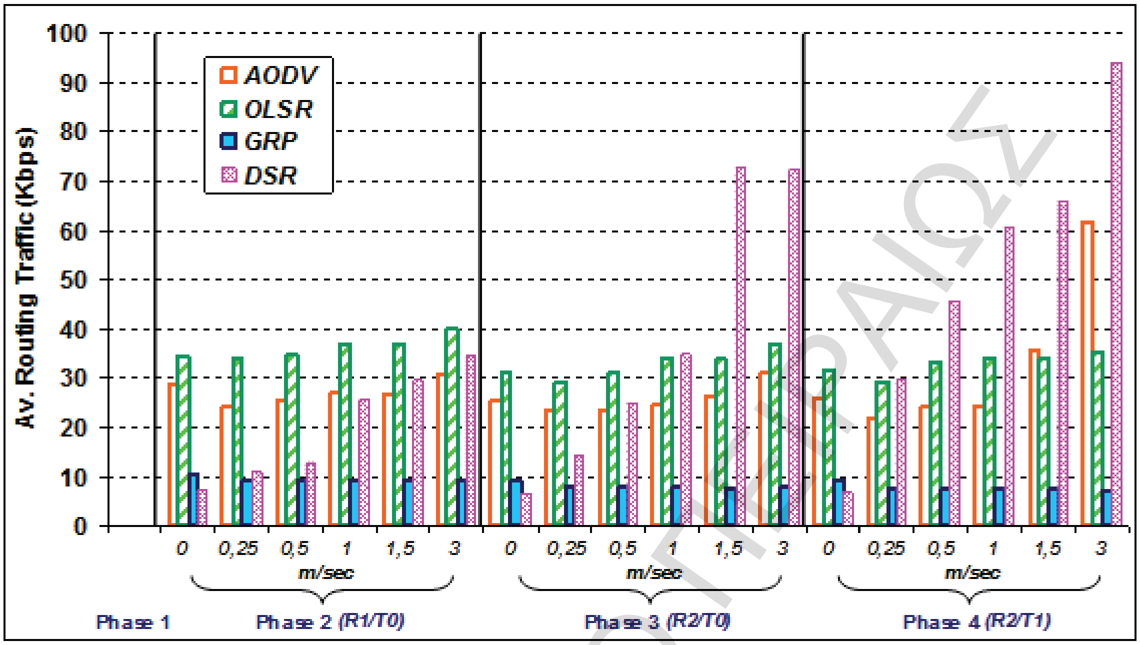
(a)



(b)

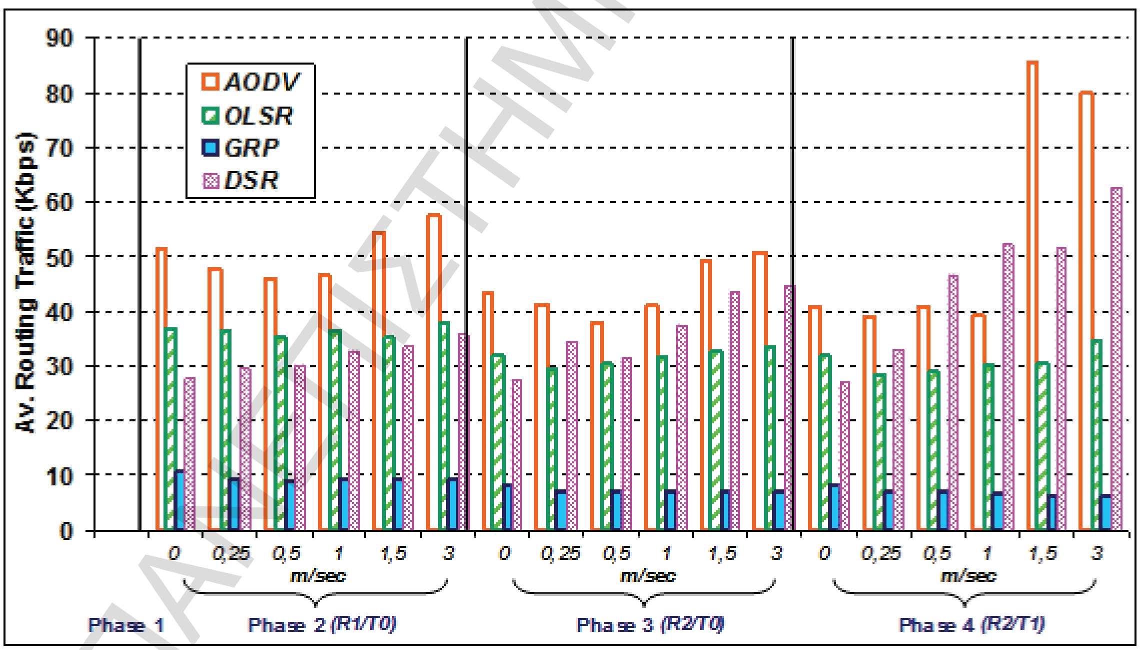
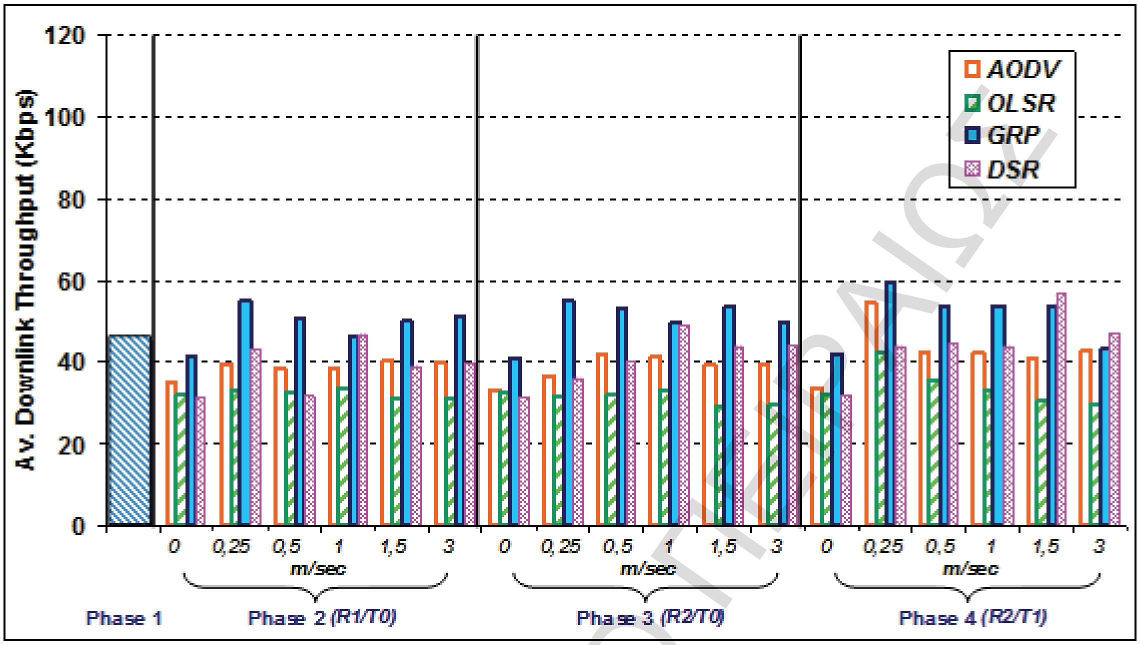


Figure 5-13: Av. Routing Traffic (Kbps) per Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

(a)



(b)

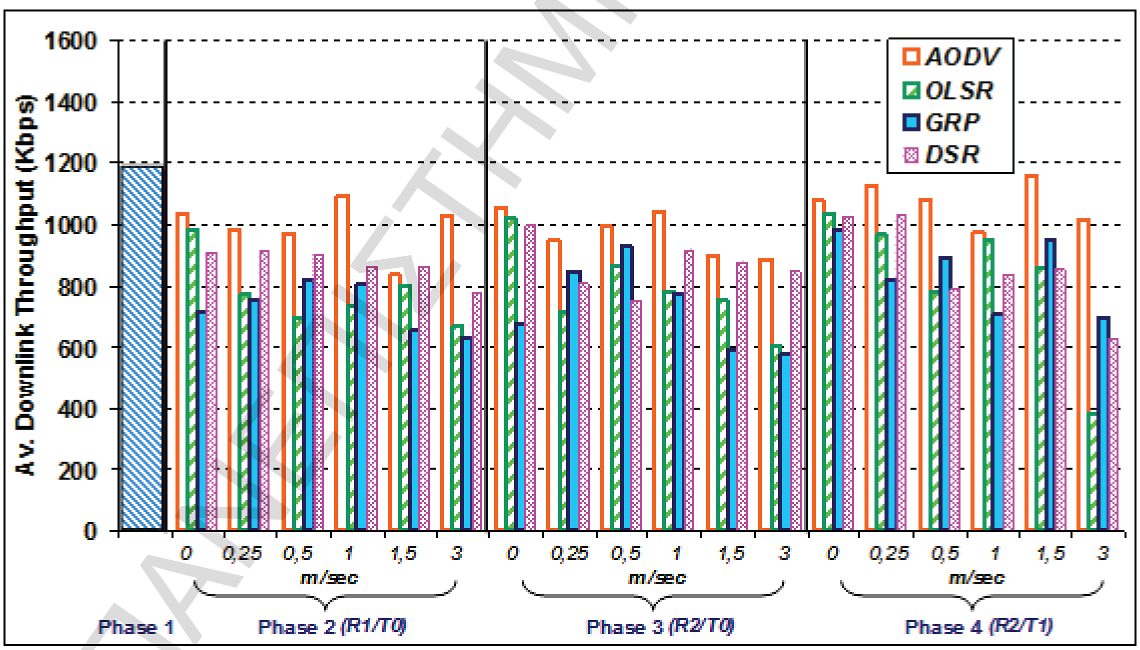


Figure 5-14: Av. Downlink Throughput (Kbps) per Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

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Figure 5-14 *(a), (b)* depicts the average downlink throughput in Kbps for all the MT nodes. Even though the average delay increases, we observe that in VoIP application and for some mobility levels this metric also increases. A possible explanation for both applications was given previously in the outdoor environment, where a similar tendency was observed. We also place focus on results observed from the Figure 5-14 with respect to the used routing protocol. We have to mention that, none of the 4 routing protocols achieves the requirement bit rate in VoIP application, as it is depicted in Table 5-VI. Finally in the case of Video Conferencing, AODV gives an average throughput almost 213,3Kbps, 243,4Kbps and 145,6Kbps more than OLSR, GRP and DSR, respectively.

Finally, Figure 5-15 depicts the average MOS value of each MT node as previously described in outdoor environment for the VoIP application. As previously observed, since the end to end delay is increasing the average MOS value has a decreasing trend. Also single dotted lines are used to depict the requirements given in Table 5-VI. Phase 3 and phase 4 seem to be an inhibitive state for the network for all routing protocols except the first mobility level. Finally, we observe that in Phase 2 only the three first mobility levels (0m/sec, 0,25m/sec and 0,5m/sec) have acceptable values.

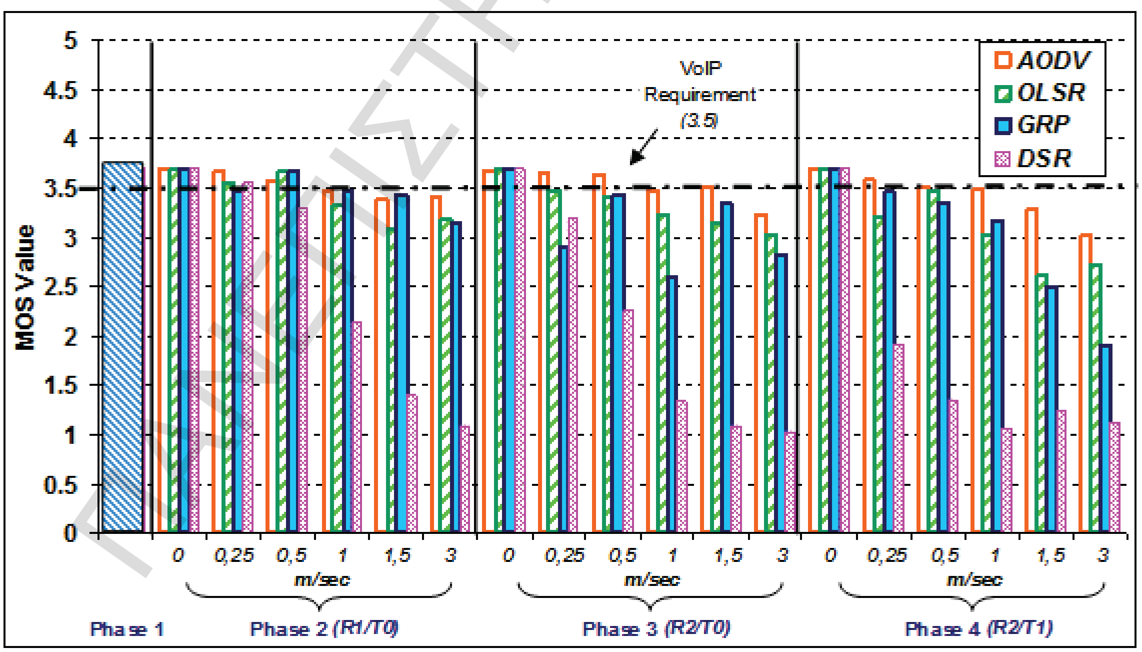

Figure 5-15: MOS Value per Node in 4 Phases for *(a)* VoIP *(b)* Video Conferencing for AODV, OLSR, GRP and DSR routing Protocol

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5.4. Summary of discussion and recommendations

Typically within the users' conscience, the infrastructure side is connected with cellular-based technologies. The infrastructure side has a certain configuration such as topology, network and radio operation parameters. However, the reduction of BS's power can lead to more energy efficient operation points, which at the same time can prove to provide comparable performance to the initial state. As a result, nodes will be found outside the coverage of the infrastructure transmitter(s), but hopefully within the coverage of at least one intermediate, terminal node. Such nodes can be exploited by an ON so as to relay data traffic to application consumers not covered by the infrastructure trying to preserve the obtained network QoS at adequate levels. As already said, one of the main goals is to study the impact of the proposed integration scheme to the reduction of the transmission power for both wireless infrastructure and terminal nodes, while achieving, at the same time, the same or even better results in terms of QoS levels. The reduction of the transmission power of the AP will not only have benefits for the AP itself, but also for the terminals as they will not communicate any more with the AP which is far away, thus consuming a large amount of energy, but with an intermediate node in a short distance that results in less energy consumption and vice versa.

In general, as simulations showed, AP/MTs transmission power reductions of X% (e.g., 60) can be done without impacting too much the service provisioning. This means that the supported application remains at acceptable QoS levels with less AP/MT power resources. Therefore this reduction will result important, savings in the total transmission power in the network.

Additionally, although not directly seen, the measured total "data received" is the metric that reflects the energy consumption of the MT, mainly due to requirement for processing and forwarding extra packets from phase to phase. Of course, if we go one step further, this might be prohibitive for a MT, because this operation is purely based on its battery level. In fact, there exists an interesting trade off among the AP power and the power consumed by each MT as a result of this gradual decrease of the AP. The proper handling of this trade off can be used to set suitability criteria that will boost ONs creation decisions with a "green" footprint.

Moreover, some or the above nodes may be mobile. In general, terminals' mobility level seems to be a very crucial factor to take into account. Particularly, what can be deduced from the above scenarios and results is that there appear cut-off values of the speed which if they are not violated, applications can still be satisfactorily supported and provided at adequate QoS levels. On the other hand, in some mobility levels the applications cannot be fully supported. Interestingly, mobility can be also seen both as a constraint that restrains application users from being served at adequate levels and as an enabler that might yield more opportunities in traffic servicing, that otherwise might be inexistent. However, it is observed that in case of static nodes, where there is no mobility, the applications can be more adequately supported than in case of mobile nodes.

Additionally, we observe that the increase of the terminal's mobility increases the rate of disconnections between the terminals in the network resulting in more route errors and thereafter dropped packets. Therefore the increase can considerably impact the performance of the routing protocols, including the packet loss, the routing traffic, the data packet delay and throughput.

From the QoS perspective, the mobility level seems to significantly affect the overall performance of the network. As a general observation the higher speed, increases also the overall delay and drop packets, as more MTs are responsible for routing and forwarding the received packets. However what it can be observed in many cases is that, the increase of the mobility up to a specific level can lead to a better performance, as the speed can create additional routes in the network between the terminals, and therefore maximize the possibility for a success communication between source and destination.

5.4.1. Performance and Behaviour of Routing Protocols

In the sequel, an explanation of the observed behaviour based on the inner workings (design and metrics e.g. mobility level, routing traffic) of each routing protocol is presented.

The results from the conducted simulations, showed that as the mobility level increases, GRP and OLSR seem to have stable routing traffic, which can be justified by their

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proactive nature strategy. The update of the routing information occurs periodically, resulting in constant overhead created by control traffic. Furthermore OLSR seems to generate higher overhead, due to the generation of HELLO messages for the creation of MPRs nodes and TC messages, in order to disseminate link state information through the network.

On the other hand, DSR, being a reactive protocol, seems to increase its routing traffic as the mobility increases. This does not seem to hold in case of AODV, whereas in general the high mobility levels appear not to have a serious effect on the routing traffic. Moreover comparing the reactive protocols, DSR almost always has lower routing traffic than AODV. This happens due to the fact that DSR uses caching. It is more likely for DSR to find a route in cache and perform the process of route discovery less frequently than AODV. Furthermore DSR's routing traffic is dominated by route replies (e.g. unicast packets - RREP), while AODV's routing load by route requests (e.g. broadcast packets - RREQ). DSR generates more RREP and RERR packets than AODV, but significantly fewer RREQ packets. Therefore, all the routing load savings for DSR came from the fact that transmits fewer RREQ packets. As a result, DSR performs very well when looking at the routing overhead [23], [24].

Furthermore in reactive protocols, DSR has the higher average packet loss (%) in the simulation results. Although it is more likely for DSR to find a route in cache and perform the process of route discovery, these routes are most often not valid anymore and a lot of packets get dropped. Moreover as the mobility level increases the average packet Loss (%) also increases. This happens due to the fact that, when there is an increasing in the mobility level of the nodes, there is higher rate of disconnections in the network, which produces more route errors and thereafter dropped packets. On the contrary, in proactive protocols it is observed that GRP has the higher average packet loss (%) in high mobility environment due to the fact that the routing strategy depends from the geographical location of the node.

Considering users' QoS experience, it is observed that DSR suffers from higher delay than AODV, especially when the mobile node speed increases. However for lower speed, AODV suffers from higher delay, due to the fact that it has periodic exchanges of HELLO messages and it has no cache mechanisms in order to store the route. On the contrary,

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when there is an increase in the speed, the routes change more frequently and DSR needs to find new routes. In that case, the presence of cache can lead to insufficient situations, with high delays and dropped packets. Moreover, it is observed that GRP results in a higher average end-to-end delay than OLSR does in high mobility environment, due to the fact that the discovery process depends from the location of the node, which constantly changes.

5.5. Conclusions

The aim of this chapter was to study the feasibility of extending the infrastructure with an ON (why, where and when) i.e. to find the conditions under which it will be beneficiary for the overall network. The study was mainly based on extensive network simulations, which revealed that the scheme seems to work and has great potentials to bring about benefits under certain circumstances. Moreover, the decision of the wireless network infrastructure to create or not an ON needs to be fast and dynamic, and it should respect several aspects, including traffic/applications variations, mobility levels and/or energy/power consumption levels and it should result in benefits with respect to provisioned QoS for the whole network. Furthermore, the appropriate exploitation of the cut-off values identified from the comprehensive simulation analysis above, can be used to extract policies in Chapter 6, in order to facilitate online, dynamic decisions on whether to boost the creation of the ONs or not.

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6. POLICY DERIVATION BASED ON THE SUITABILITY DETERMINATION OF ONS

Chapter Outline

An important goal of this dissertation is the properly exploitation of the extracted simulation results so as to derive policies that can be used by the operator of the wireless infrastructure to control the decision upon forming the ONs, while in operation or even in a proactive manner. In this respect the Knowledge-Based Suitability Determination Algorithm is considered responsible for making decision upon the feasibility of the creation of ONs when judged as appropriate. The algorithm collects context/profile information and knowledge in order to provide a proper policy, for the actual creation of the ON. Finally a validation platform is presented in order to give a proof of concept of the functionalities for the ON management in different indicative scenarios. The ON-based solution has benefits in terms of adequate QoS level provisioning and energy (power) consumption.

Keywords: Policy derivation, Knowledge-Based Suitability Determination Algorithm, Exploitation of Results, Green Footprint, Validation Platform, Proof of Concept

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6.1. Introduction

As already presented, the suitability of extending the infrastructure with the use of ONs can be determined based on the involved parameters, such as type of applications, mobility etc., as well as on the anticipated benefits in terms of adequate QoS level provisioning and energy consumption. The decision of the wireless network infrastructure to create or not such an ON needs to be fast and dynamic and will be provided by means of proper policies by the management entities (e.g. CSCI, CMON). In this respect this chapter presents the policy derivation process and particular the Knowledge-based Suitability Determination Algorithm, considering specific simulation parameters used in Chapters 4 and 5.

Therefore, the rest of this chapter is structured as follows: A detailed description of the algorithm, for the policy derivation is presented first in Section 6.2. Moreover, indicative results will reveal the benefits from the creation of ONs in terms of energy consumption. The validation platform is presented in Section 6.3, with the functionalities of the management entities, in order to provide a proof of concept of the ON-based approach. Finally the chapter is concluded in Section 6.4.

6.2. Policy derivation

As already stated, an important step in this dissertation is to utilize the results derived from the simulations in order to design and develop proper algorithms/strategies for the CSCI entity (Suitability Determination process) that will be able to decide on the feasibility of creating the ON when required, while in operation or even in a proactive manner. Moreover the decision of the CSCI will be provided by means of proper policies to the CMON functional entity which will handle the actual creation of the ONs.

The description of the CSCI functionality and particular the Knowledge-based Suitability Determination Algorithm is presented in this section, considering specific parameters used in the simulation environment. In the following is presented an example of how the policies can be derived from the decision process with the use of the results of the offline-simulations, conducted in Chapter 4 and 5.

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6.2.1. Knowledge-based Suitability Determination Algorithm

As already presented, the CSCI is responsible for making decision upon the feasibility of the creation of ONs when judged as appropriate. Principally, the CSCI is responsible for the detection of situations where an ON may be useful as part of the ON suitability determination phase. The suitability determination is a centralized process, with the decision making located typically in the infrastructure. The decision making is based on infrastructure-level information provided by functional entities in the network and user/device-level information provided by the CSCI entities from a selected set of devices. The suitability determination runs before the creation of an ON but also during the lifetime of the ON in order to check that context changes and ON reconfigurations (information from CMON) have not cancelled the suitability of the ON.

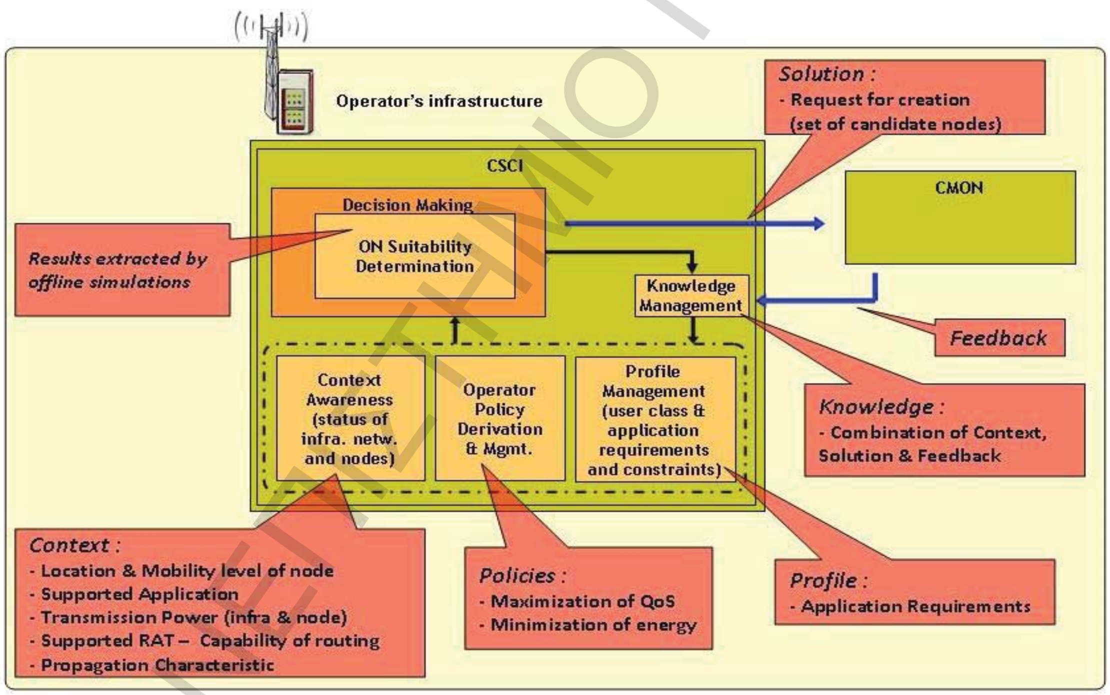

Figure 6-1: CSCI functional blocks

The CSCI, as also depicted in Figure 6-1, comprises context awareness, operator policy derivation and management, profile management and knowledge management which provide the input to the decision making mechanism for the ON suitability determination. Moreover, depending on the results extracted from the offline simulations the

Knowledge-based Suitability Determination Algorithm will provide solution(s) for the actual creation of ONs.

Furthermore, cognition relies on the fact that knowledge management encompasses mechanisms for learning on context, profiles, policies and decision making in order to reach better decisions in the future, and faster according to the learned results. The CSCI delegates the actual creation, maintenance and termination of a given ON to the associated CMON functional entity and it is located in both the operators' infrastructure and the terminal side, respectively.

In particular, according to the analysis in previous chapters (Chapter 4 and 5), the context information comprises (i) location and mobility level of nodes, (ii) supported applications for each node, (iii) AP and terminal capabilities and characteristics (such as transmission power, supported RATs and routing capabilities) and (iv), environment characteristics (such as propagation model). Moreover the policy information contains rules (high level policies) such as (i) the maximization of the QoS levels to applications/users and (ii) the decrease of the transmission powers, which can also mean lower energy consumption. Finally the profile information contains the QoS requirements per application type, based on specific QoS metrics (such as delay, drop packet, etc.), which are used to evaluate specific conditions.

The process of the Knowledge-based Suitability Determination Algorithm is presented in the following and depicted in Figure 6-2. Initially, a monitoring process is taking place in the network so that the decision maker (the operator) will be aware of the nodes' related information and the current situation of the network. Under certain circumstances/criteria, the suitability determination process will be triggered. Such criteria could be the bad coverage of nodes inside the cell or in order to target specific rules (high level policies) such as lower energy consumption. Second, there is the perception of the situation encountered, in terms of the factors identified above (context and profiles). Then the process loads the data from the off-line simulations, which were conducted a priori and presented in Chapter 4 and 5.

Based on the perceived situation and the information recorded (off-line simulations), there is concrete indication of the best acceptable decision pairs, of terminals/AP transmission powers (ranges) and corresponding routing protocols, leading to

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acceptable QoS. Finally, the definition of the policies with the use of a pseudo-code language is taken place, mainly for the communication with the CMON functional block and for illustration purposes.

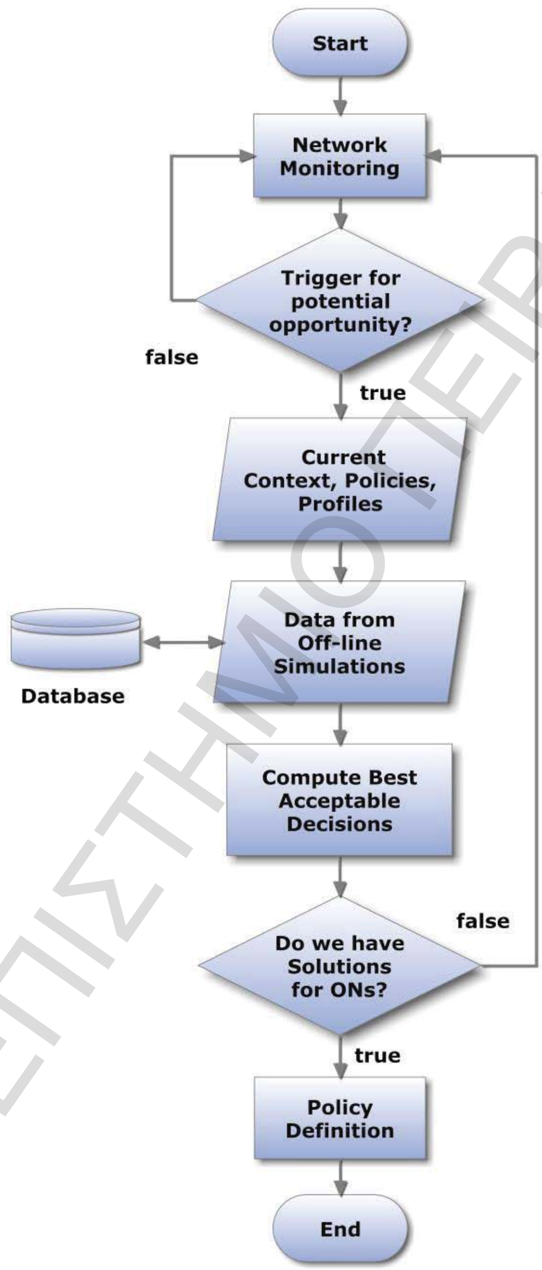

Figure 6-2: Flowchart for the Knowledge-based Suitability Determination Algorithm

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In the output, the Knowledge-based Suitability Determination Algorithm, depending on the results extracted from the offline simulations, will provide solution(s) for the creation of ONs. Particularly the solution comprises *(i)* the candidate terminals, *(ii)* the transmission power of APs/BSs and terminals and *(iii)* the ad hoc routing protocol that will be used for routing traffic between the infrastructure and the ONs. Furthermore the performance metrics End-to-end delay (ms) and packet loss (%) are depicted for each acceptable solution, giving some degree of freedom for the final decision, depending on the level of emphasis given to specific target QoS levels.

Considering the knowledge management process and in order to fulfil the requirement for more proactive and faster response to changes, the process can be enhanced with context matching functionality. First the currently captured context is identified and then it is matched against a set of pre-existing reference context-action pairs so as to identify the best way to handle it i.e., select the power to be transmitted by the AP and/or terminals, the routing protocol to be used. Context matching can be based on well-known techniques with the k-Nearest Neighbour(s) (k-NN) algorithm being a firm candidate. A pertinent solution, which is based on k-NN and also exhibits non-prohibitive complexity, has been provided in [1], [2].

6.2.2. Exploitation of Simulations and Policy Derivation

As previously stated, an important step in this dissertation is to properly exploit the extracted simulation results and recommendations in order to extract policies that can be used by the operator of the wireless infrastructure to control the decision upon creating the ONs ("operator-governed").

In particular the Knowledge-based Suitability Determination Algorithm will generate these policies, giving the opportunity to the CSCI to decide on the feasibility of creating the ON when required, while in operation or even in a proactive manner. In this sub-section, it is presented an example of how proper policies can derive from the algorithm, based on the steps described in 6.2.1, with the use of the results of the offline-simulations, conducted in Chapter 4 and 5.

Table 6-I provides the best routing protocol with respect to the application that is requested and also the transmission power range of the AP of the infrastructure for the two Phases (Uniform/Random), derived from the simulations conducted in Chapter 4.

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Cells that cannot provide an acceptable solution according to the simulation results are denoted as n/a (not available).

Table 6-I: Best routing protocol, with respect to the application requested and the transmission power range for the AP of the Infrastructure

Applications	Without Mobility									
	Phases in Uniform					Phases in Random				
	1	2	3	4	5	1	2	3	4	5
Browsing	-	AODV	OLSR	AODV	AODV	-	AODV	OLSR	AODV	AODV
VoIP	-	OLSR	AODV	OLSR	n/a	-	AODV	AODV	AODV	AODV
Video Conf.	-	AODV	GRP	n/a	n/a	-	OLSR	OLSR	AODV	AODV

Moreover Table 6-II, comprises data derived from the off-line simulations of Chapter 5, which the Knowledge-based Suitability Determination process will use in order to develop proper policies for the creation of ONs in a mobile environment. In particular, what are being provided is the best routing protocol with respect to the application that is requested and also the transmission power range of the AP and/or terminal of the wireless infrastructure in various mobility levels in indoor and outdoor environment.

Furthermore the performance metrics End-to-end delay (ms) and packet loss (%) are depicted for each acceptable solution. Also cells that are denoted as n/a correspond to cases where an acceptable solution cannot be provided according to the simulation results.

The simulations results in Table 6-I and Table 6-II arbitrarily consider the end-to-end delay and the packet Loss (%) as the metrics for judging the quality of solutions (pairs of power, routing). They must be both satisfied for a solution to be acceptable.

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Table 6-II: Best routing protocol with details of End-to-end delay (ms) and packet loss (%) metrics, with respect to the application requested and the transmission power range for the AP of the Wireless Network Infrastructure and the MTs

(a) Outdoor environment

	Applications	Mobility Levels						
		0m/sec	*1m/sec*	*1,5m/sec*	*3m/sec*	*5m/sec*	*10m/sec*	*15m/sec*
Phase 2 (80%/100%)	*VoIP*	OLSR *(150ms-0.0%)*	DSR *(150ms-0.0%)*	AODV *(151ms-0.002%)*	AODV *(152ms-0.016%)*	OLSR *(152ms-0.016%)*	AODV *(152ms-0.016%)*	AODV *(152ms-0.017%)*
	Video Conf	OLSR *(103ms-0.16%)*	OLSR *(126ms-0.16%)*	GRP *(140ms-0.23%)*	AODV *(106ms-0.42%)*	AODV *(111ms-0.36%)*	OLSR *(124ms-0.56%)*	OLSR *(133ms-0.64%)*
Phase 3 (60%/100%)	*VoIP*	OLSR *(150ms-0.0%)*	OLSR *(150ms-0.0%)*	OLSR *(151ms-0.0%)*	AODV *(155ms-0.015%)*	AODV *(158ms-0.015%)*	AODV *(153ms-0.014%)*	AODV *(159ms-0.019%)*
	Video Conf	OLSR *(107ms-0.08%)*	OLSR *(117ms-0.11%)*	OLSR *(123ms-0.28%)*	OLSR *(138ms-0.55%)*	OLSR *(149ms-0.76%)*	n/a	n/a
Phase 4 (60%/60%)	*VoIP*	OLSR *(150ms-0.0%)*	AODV *(198ms-0.026%)*	AODV *(195ms-0.021%)*	n/a	n/a	n/a	n/a
	Video Conf	OLSR *(122ms-0.27%)*	n/a	n/a	n/a	n/a	n/a	n/a

(b) Indoor environment

	Applications	Mobility Levels					
		0m/sec	*0,25m/sec*	*0,5m/sec*	*1m/sec*	*1,5m/sec*	*3m/sec*
Phase 2 (80%/100%)	*VoIP*	OLSR *(150ms-0.0%)*	AODV *(152ms-0.0%)*	GRP *(155ms-0.12%)*	AODV *(163ms-0.05%)*	AODV *(193ms-0.06%)*	n/a
	Video Conf	OLSR *(99ms-0.22%)*	GRP *(112ms-0.64%)*	GRP *(112ms-0.56%)*	GRP *(118ms-0.83%)*	OLSR *(116ms-0.77%)*	OLSR *(124ms-0.77%)*
Phase 3 (60%/100%)	*VoIP*	DSR *(150ms-0.0%)*	AODV *(153ms-0.023%)*	AODV *(161ms-0.024%)*	AODV *(161ms-0.04%)*	AODV *(188ms-0.05%)*	n/a
	Video Conf	GRP *(75ms-0.43%)*	GRP *(113ms-0.8%)*	OLSR *(109ms-0.91%)*	AODV *(148ms-0.74%)*	n/a	n/a
Phase 4 (60%/60%)	*VoIP*	DSR *(150ms-0.0%)*	AODV *(177ms-0.05%)*	AODV *(178ms-0.04%)*	AODV *(179ms-0.05%)*	n/a	n/a
	Video Conf	OLSR *(94ms-0.61%)*	OLSR *(108ms-0.71%)*	GRP *(111ms-0.88%)*	n/a	n/a	n/a

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In this respect, as also presented in details in sub-Section 6.2.1, the process of the Knowledge-based Suitability Determination Algorithm for the derivation of policies can be outlined as follows. There is the perception of the situation encountered and based on this and the results from the off-line simulations, there is concrete indication of the best acceptable decision pairs, of AP and terminals ranges and corresponding routing protocols.

Table 6-III: Definition of policies using the Event Condition Action format

```
on event (Criteria_of_Network_Monitoring)
 CREATE ON
   if (Service 1 AND Mobility < M_threshold) THEN
      { SOLUTION 1: Trx_AP, Trx_MT, Best Routing Protocol, QoS_achieved ,
          ……….. ,
       SOLUTION n: Trx_AP, Trx_MT, Best Routing Protocol, QoS_achieved }

     if (Service n AND Mobility < M_threshold) THEN
      { SOLUTION 1: Trx_AP, Trx_MT, Best Routing Protocol, QoS_achieved ,
           ……….. ,
        SOLUTION n: Trx_AP, Trx_MT, Best Routing Protocol, QoS_achieved }
  END
```

Furthermore, Table 6-III, illustrates the approach followed in the algorithm for defining the policies responsible for the suitability of ON creation. The definition is given in a pseudo-code language. These policies are actually rules formatted using the Event Condition Action (ECA) type. According to this approach, a policy (or rule) is actually a statement of the type:

ON <Event> IF <Condition> THEN <Action>

where traditionally, the event part specifies the signal that triggers the invocation of the rule, the condition part is a logical test that, if satisfied or evaluates to true, causes the

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action to be carried out, the action part consists of the actual execution of the modification/update.

As previously presented, the creation of an ON, relies on specific criteria continuously monitored by the respective network monitoring mechanism (sub-Section 6.2.1). The satisfaction of these criteria comprises the event (Table 6-III– line 1) that will trigger the creation of the ON and, depending on the requested service and the mobility level of the nodes (Table 6-III – line 3) multiple solutions are provided, having as a reference for example Table 6-II. The solution consists of the AP and MTs transmission powers and corresponding routing protocols with the acceptable QoS (Table 6-III – lines 4-6).

Table 6-IV: Policy example instantiated with respect to Table 6-II

on event (*bad coverage of nodes inside the cell*)

CREATE ON

if (*Service: VoIP* **AND** *Mobility* <*3m/sec*) **THEN**

{ ***SOLUTION 1*:** R1, T0, AODV, *152ms - 0,016%* **,**

***SOLUTION 2*:** R2, T0, AODV, *155ms - 0,015%* }

if (*Service: Video Conferencing* **AND** *Mobility* < *3m/sec*) **THEN**

{ ***SOLUTION 1*:** R1, T0, AODV, *106ms - 0,42%* **,**

***SOLUTION 2*:** R2, T0, OLSR, *138ms - 0,55%* }

END

Table 6-IV, illustrates an example on how a policy can be instantiated with respect to Table 6-II (simulations results). For example in case that a user requests for VoIP application in an Outdoor environment with average mobility < 3m/sec, there are two acceptable solutions. *SOLUTION 1* with AP/MTs ranges R1 and T0 respectively and best routing protocol AODV giving a 152ms delay and with 0,016% packet loss.

In the same direction the second one is *SOLUTION 2*, with R2, T0 and AODV with 155ms delay and with 0,015% packet loss. In case where the operator will decide the first solution, the gain would come from the reduction of the transmission power of the AP at the 80% of the initial one, whereas in case of *SOLUTION 2*, the reduction would

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be at the 60%, giving nevertheless worst but acceptable level of QoS. Consequently, there is also some degree of freedom for the final decision on the creation of ONs, which can vary depending on the level of emphasis given to specific target QoS levels and aimed savings in power consumption.

Consequently, a policy in the case of the VoIP and Outdoor environment with no mobility may explicitly enforce the AP and the terminals to reduce transmission powers (range) at the 60% (phase 4) of the initial one and command the creation of an ON that will utilise OLSR for routing traffic (grey shaded cell in Table 6-II). Furthermore, giving another example from the mobility perspective, when regarding the VoIP and Outdoor Environment in phase 3 (Table 6-II *(a)*) the policy may explicitly provide the change of the routing protocol from OLSR to AODV when the average mobility exceeds the 1,5m/sec (grey shaded line in Table 6-II *(a)*).

Finally, these policies will be passed to the CMON functional block, as presented in detail in sub-Section 3.2.2. The CMON, as already described, is responsible for the creation, maintenance and termination of the ONs, according to the results of the suitability determination process and particularly the policies obtained from the CSCI functional block.

Figure 6-3 depicts a graphical example from the execution of the algorithm for the creation of an ON, with the use of policies, as previously described. Suppose that the MT4 node suffers from high delay inside the initial coverage of the BS. In order to offer adequate QoS and at the same time to achieve a reduction of the power consumption, an ON is created between the BS and the MT4, with three intermediate nodes, namely MT1, MT2 and MT3. One of the policies that the CSCI will provide to CMON is the following:

If (*Service of MT4:* ***VoIP*** AND *Mobility (MT1, MT2, MT3, MT4) <* ***3m/sec***)

> **THEN CREATE *ON1*** with **Ranges**: R2 and T1, **Routing Protocol**: AODV
> with **Delay**: *152ms and* ***Packet Loss*** *: 0,016%*

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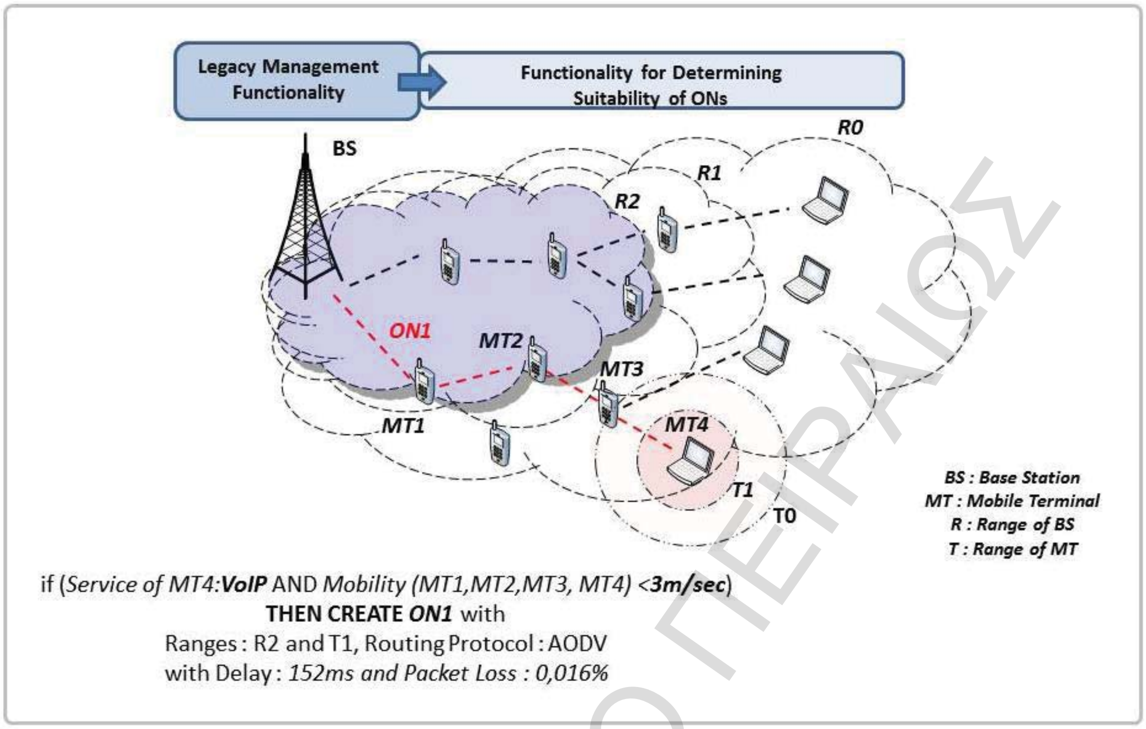

Figure 6-3: Graphical example of the creation of an ON, with a policy rule

6.2.3. Green footprint of ONs

In this sub-section the green footprint perspective is highlighted, for the scenarios that have been already presented in previous chapter (sub-Section 2.3.2). Moreover, there will be a discussion for two of the aforementioned scenarios in order to investigate the green benefits from the creation of the ONs with the proper use of the extracted policies derived from the suitability determination process. The results depict the greener footprint that is achieved in the context of FI by the proposed approaches.

In the coverage extension scenario lower transmission power levels are achieved in the infrastructure and the terminals, which lead to lower electrical energy consumption. This occurs because the terminal needs less power to communicate with an intermediate node, than the infrastructure. Therefore, a higher green footprint is achieved that is also reflected to lower OPEX and particularly to the reduction of the expenses made by the operator for the operation of the infrastructure. Moreover, capacity extension and resource aggregation scenarios lead to less investment in infrastructure and

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consequently less hardware deployed. This also means that lower OPEX, as well as CAPEX are achieved. In addition, the green footprint of opportunistic ad-hoc scenario is also proved by the energy consumption diminishment that is achieved through the localization of application provisioning. This is achieved because of the fact that the terminals do not longer communicate with the infrastructure, but with each other in a near location. Finally, in opportunistic traffic aggregation the green footprint is achieved by succeeding to support limited ON terminals, fact that leads to lower electrical energy consumption.

Two of the above-mentioned scenarios are presented below, in order to investigate the green benefits from the creation of the ONs with the use of policies derived from the suitability determination process. Particularly, the coverage extension and the traffic aggregation in the radio access network scenarios are presented.

Coverage Extension Scenario

Focusing on the coverage extension scenario, the initial transmission power of the AP is gradually decreased and some of the terminals cannot communicate any more with the infrastructure. It is obvious that the only way for those terminals to reach the AP is to proceed with the creation of ONs and receive data through the intermediate nodes. After the creation of the ON, applications can be satisfactorily supported and provided at adequate QoS levels, with less AP and terminals power resources.

Figure 6-4 refers to the scenario depicted in Figure 5-1 and presented in sub-Section 5.2.2. In particular, depicts the total power consumption that is required for supporting the data traffic in the test case prior to (phase 1) and after the formation of the ON (phase 2 to 4). All the nodes in the network and the infrastructure element (AP) are considered in the computation of the total energy consumption. As depicted, the formation of the ON can result in a reduction of 40% of the initial transmission power. This result supports our initial claims of better use of resources in terms of energy consumption.

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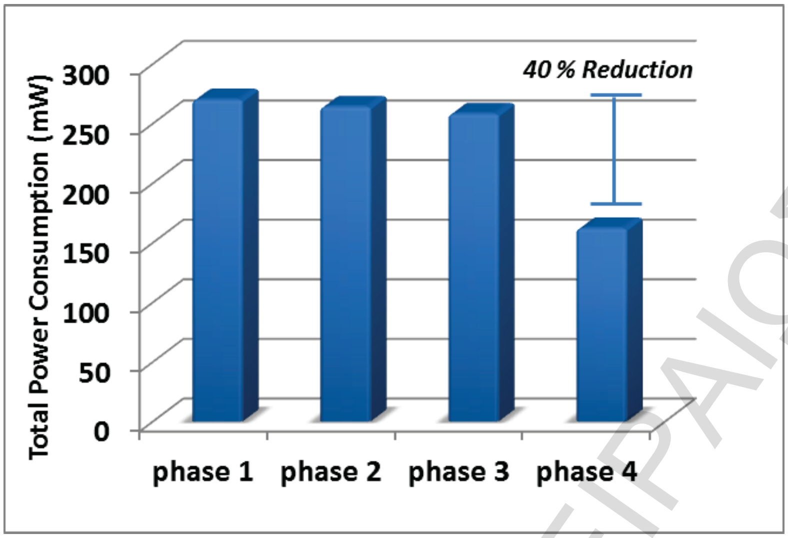

Figure 6-4: Total Power Consumption in mW

Opportunistic traffic aggregation Scenario

Focusing on the traffic aggregation scenario, there may be users that face poor channel quality towards the infrastructure, because they may residing at the edge of the AP and at the same time very good channel quality towards some of their neighbours. It is obvious that users with poor channel quality, compared to those with better quality, need more resources (e.g. power, time) to transmit the same amount of data. After the creation of the ON, users with good channel conditions towards the infrastructure will be responsible for forwarding traffic to those that have poor channel conditions, through their direct interfaces. Therefore, the ON will increase the overall system capacity and resource utilization, and offer a service in an energy efficient manner.

In this respect, a set of four nodes set-up direct connections (via cellular interfaces) with a network in order to transmit data packets of the size of 1MB each. It is assumed that users' devices are equipped with 3G interfaces (for the connection with the AP) and with IEEE 802.11g interfaces for the peer-to-peer connections among them. At some point in time the quality of the nodes' connections significantly drops, thus the connection throughput is limited for three of them to 0.5Mbps. At the same time, these nodes maintain very good channel quality towards some of their neighbours, offering a rate of 54Mbps by using IEEE 802.11g interface. The AP in collaboration with the nodes, detects that situation, and initiates the process for the creation of an ON. They jointly determine one or several nodes, with high channel conditions to aggregate and/or relay traffic of other users, which have poor channel conditions towards the infrastructure.

Figure 6-5, depicts the anticipated average delivery latency prior to and after the formation of ON. It corresponds to the one-way time (in seconds) from the source sending a packet to the destination receiving it. With direct links, it is observed that the average delivery latency is around 13sec, while the deployment of the ON yields a significant drop of this metric to 2.3sec.

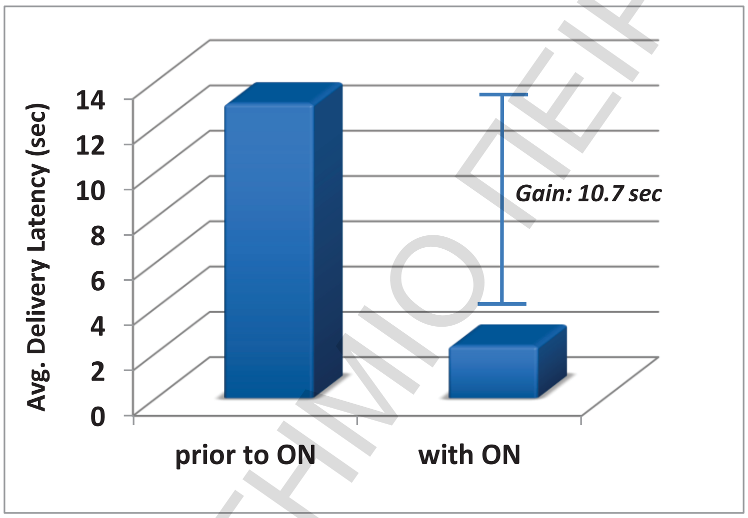

Figure 6-5: Average Delivery Latency Estimation in sec

Moreover, Figure 6-6 depicts the total power consumption that is required for the traffic of the test case prior and after the creation of the ON. It considers again all nodes in the range of the AP and the infrastructure element. As Figure 6-6 depicts, the creation of the ON can result in a reduction of 22% of the required transmission power, which can be justified by the shorter direct links that are used for forwarding traffic within the ON. Considering the above facts, the results revealed that the creation of the ONs offers improved efficiency in resource provisioning and at the same time achieves green targets. Finally, as already presented in previous chapter (Chapter 3) the CMSs can ensure fast and reliable establishment of ONs and perform well when facing same situations, thus resulting in faster reductions of the energy consumption, achieving efficiently green targets.

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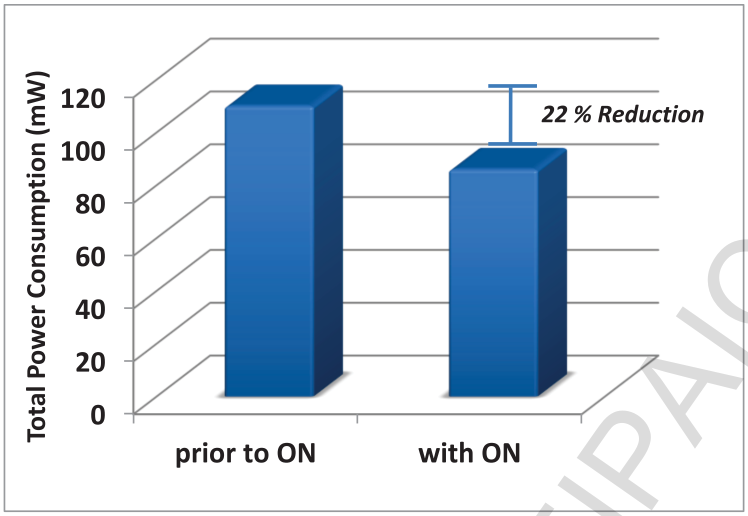

Figure 6-6: Total Power Consumption in mW

6.3. Validation Platform

This section provides the platform environment, which has been used in order to validate the creation scheme. The platform encompasses several hardware (test-beds/equipment) as well as software entities (algorithms/protocols). Moreover is provided the functionality of the software entities, for several scenarios of the ONs already presented in Chapter 2. Finally a proof a concept is presented of the CSCI and CMON functionalities for ON management and especially of the CSCI, incorporating the Knowledge-based Suitability Determination Algorithm, which is one of the main goals of this dissertation.

Therefore, the platform environment provides the means for the conduction of validation activities in terms of scenarios and use cases, enabling the incorporation and refinement of management functionality for the proposed ON-based solution. The validation reveals that the ON-based solution has benefits in terms of adequate QoS level provisioning.

In general, the architecture of the platform environment follows the Service Oriented paradigm. Hence, each entity in the environment can offer several services related to its role and functionality, while, on the other hand and in order to accomplish its objective, it is taking benefit of the services offered by other entities. Thus the entities in the system can act as service providers and service consumers at the same time.

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6.3.1. Platform Description

The platform for the management of ONs comprises CMSs (CSCI/CMON functional blocks) and control channels and aims at the efficient application provision through the management of ONs in coordination with the infrastructure.

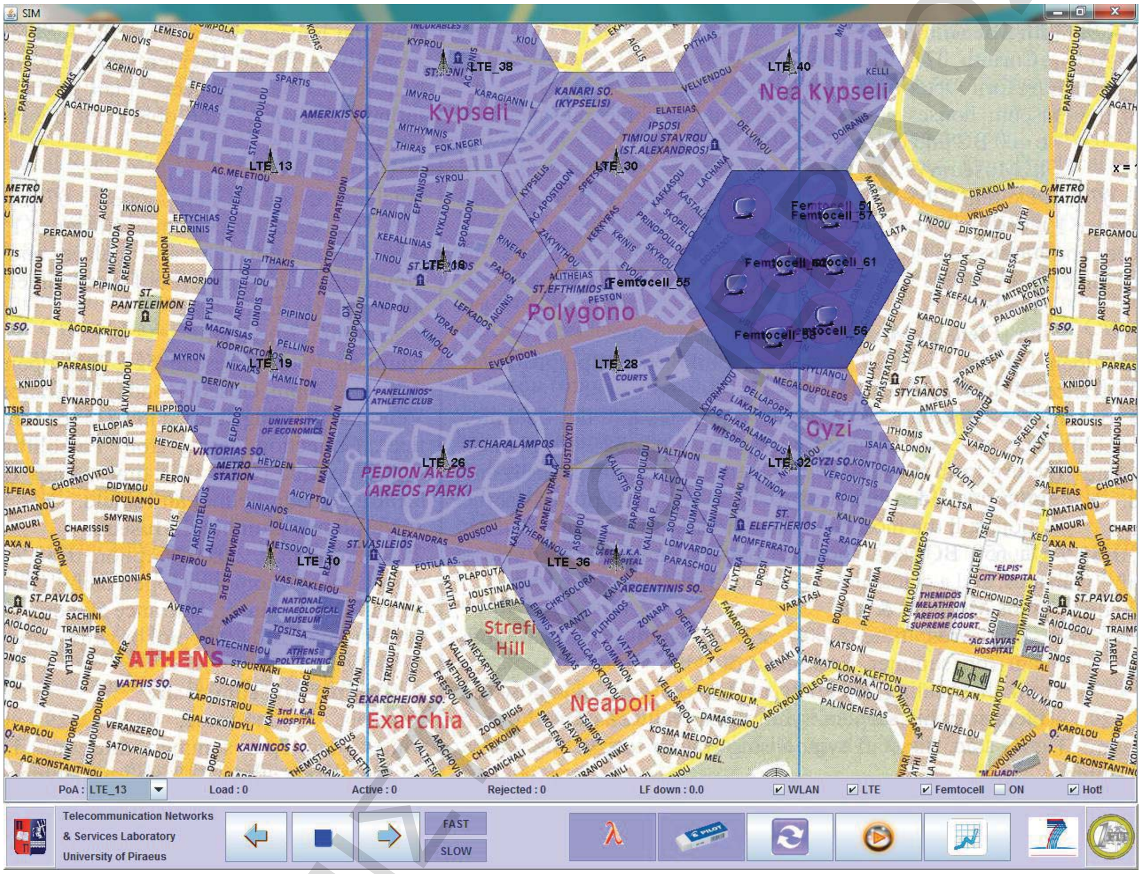

Figure 6-7: Indicative screenshot of the platform's GUI

It has been developed as a Multi Agent System (MAS) based on Java and JADE [3] and it consists of several software and hardware components that can support the execution of a great variety of scenarios and use cases and moreover they are facilitating the integration of new hardware or software functionalities.

The platform is intrinsically flexible and extendable, since it is based on JADE middleware that enables the integration, interaction and cooperation of all the entities that reside in it. The platform offers high-level interfaces with various interconnection ways, enabling experimentation with different problem handling practices, varied hardware and software configurations or even diverse architecture designs. In general, JADE components exchange messages which are serialized and transmitted over TCP, according to the FIPA Agent Communication Language (ACL) message structure specification [4]. In particular, the platform due to the utilization of the JADE middleware which provides distributed functionality can be executed in a distributed way, e.g. the BS CSCI/CMON agents can run on different machines and exchange messages according to the C4MS structure.

Software includes agents that run on terminals and are able to communicate and manage devices like 3G modem, agents that are used to generate traffic and simulate network conditions for validation purposes, agents that are responsible for interfacing with software or hardware components like the Femtocells. An indicative screenshot of the platform's main Graphical User Interface (GUI) is shown in Figure 6-7.

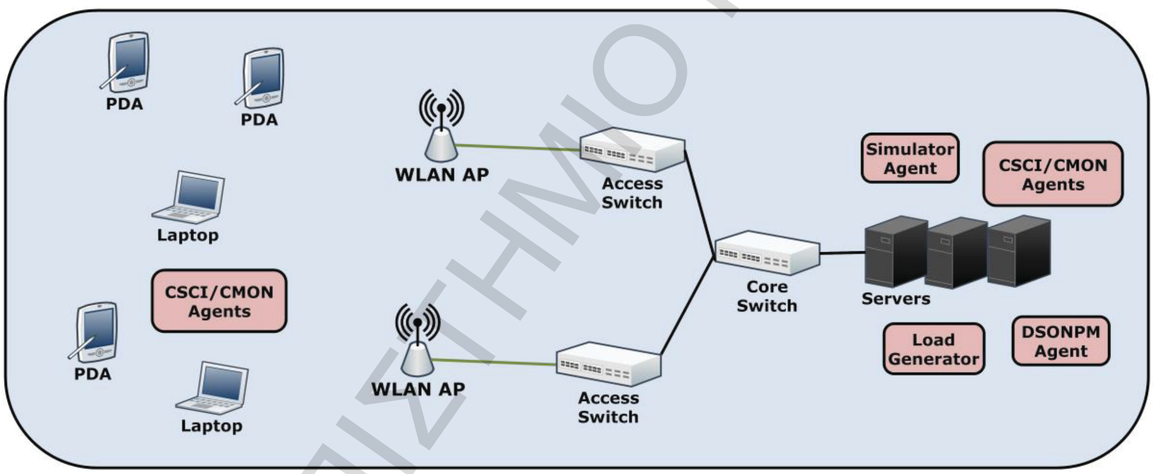

Figure 6-8: Indicative topology of the platform's hardware

Furthermore, in order to conduct the validation activities, network elements and devices were used in the platform, such as core and access switches, Wlan APs, laptops and finally PDAs with 3G, EDGE, GPRS and wifi support. Figure 6-8 depicts an indicative topology of the platform, with the agents that are typically present in the environment.

6.3.2. Functionality of CSCI/CMON

In this sub-section is provided the functionality of the software entities that have been implemented in the platform, for the coverage extension and the capacity scenario as already presented in Chapter 2.

Coverage extension Scenario

ON based opportunistic coverage extension is demonstrated on the platform environment as illustrated in Figure 6-9. In this scenario the following tasks are performed. Initially, all Macro BSs are functioning properly and all mobile devices are properly served. ON is not needed yet. A Macro BS experiences failure. As a result, mobile devices are left without coverage. ON is started forming up in order to serve the out of infrastructure terminals. Mobile devices are connected to each other in order to gain access to the infrastructure. When the previously failed Macro BS goes back online, ON is not needed anymore and it is terminated.

The functionalities of CSCI and CMON for the coverage extension are the following:

- The context awareness entity of the CSCI is responsible for monitoring the status of the infrastructure network. In addition, it involves information about node capabilities (e.g. location, mobility level, supported application etc.).
- The CSCI is responsible for the identification of the terminals that are out of the coverage. The Knowledge-based Suitability Determination Algorithm of the CSCI identifies the terminals that are suitable to be redirected to the new BS.
- The decision making mechanism of the CMON is responsible for the formation of ON paths for each terminal to new BS
- The control functional entity of the CMON is responsible for the solution enforcement.

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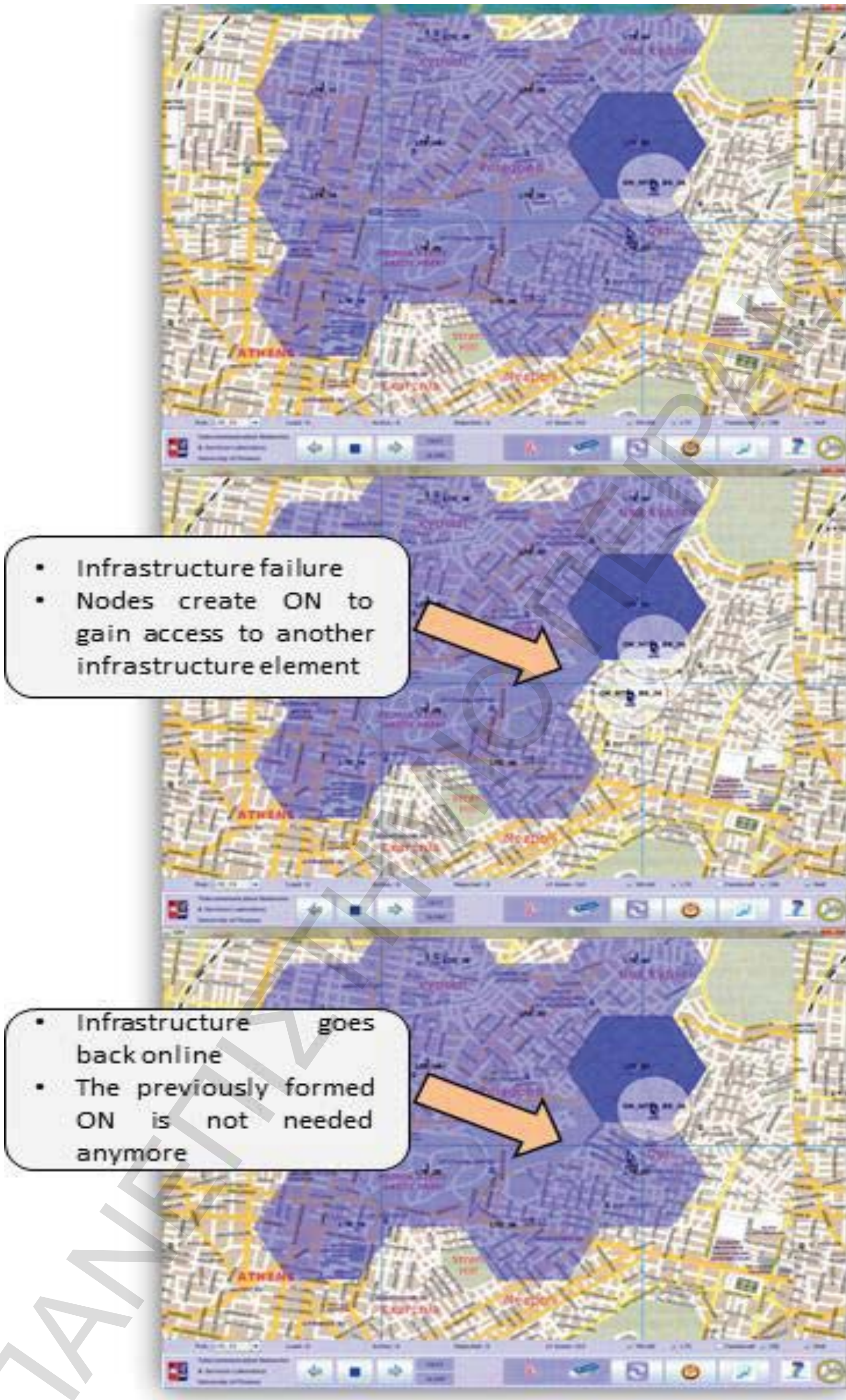

Figure 6-9: Coverage-Extension on the platform environment

Capacity extension Scenario

Capacity extension mechanisms in an outdoor environment are showcase in the platform as illustrated in Figure 6-10. In this scenario the following tasks are performed. First the Infrastructure elements experience congestion problems and traffic hotspots are identified, by the CSCI functional entity. The DSONPM, CSCI and CMON collaborate in order to solve congestion by redirecting terminals with ON capabilities to alternate BSs. Finally, terminals of the congested area with ON capabilities find paths to alternate BSs through other terminals with ON capabilities in non-congested and congested area.

The functionalities of the two entities CSCI/CMON for the capacity extension through neighboring terminals are the following:

- The context awareness functional block of the CSCI is responsible for acquiring the status of infrastructure elements and the status of terminals (e.g. their status, location, mobility level, etc.)
- The decision making mechanism of the CSCI is responsible for the identification of terminals that are located in a congested area and need access to alternate infrastructure elements through neighboring terminals.
- The decision making mechanism of the CSCI (Knowledge-based Suitability Determination Algorithm) is responsible for the identification of suitable terminals that will potentially participate in the to-be-created ON, e.g. terminals with low mobility level.
- The decision making mechanism of the CMON is responsible for the formation of ON paths for each terminal in the congested area that needs to be redirected to alternate BSs and allocates the terminals to alternate BSs.
- The control functional entity of the CMON is responsible for the solution enforcement.

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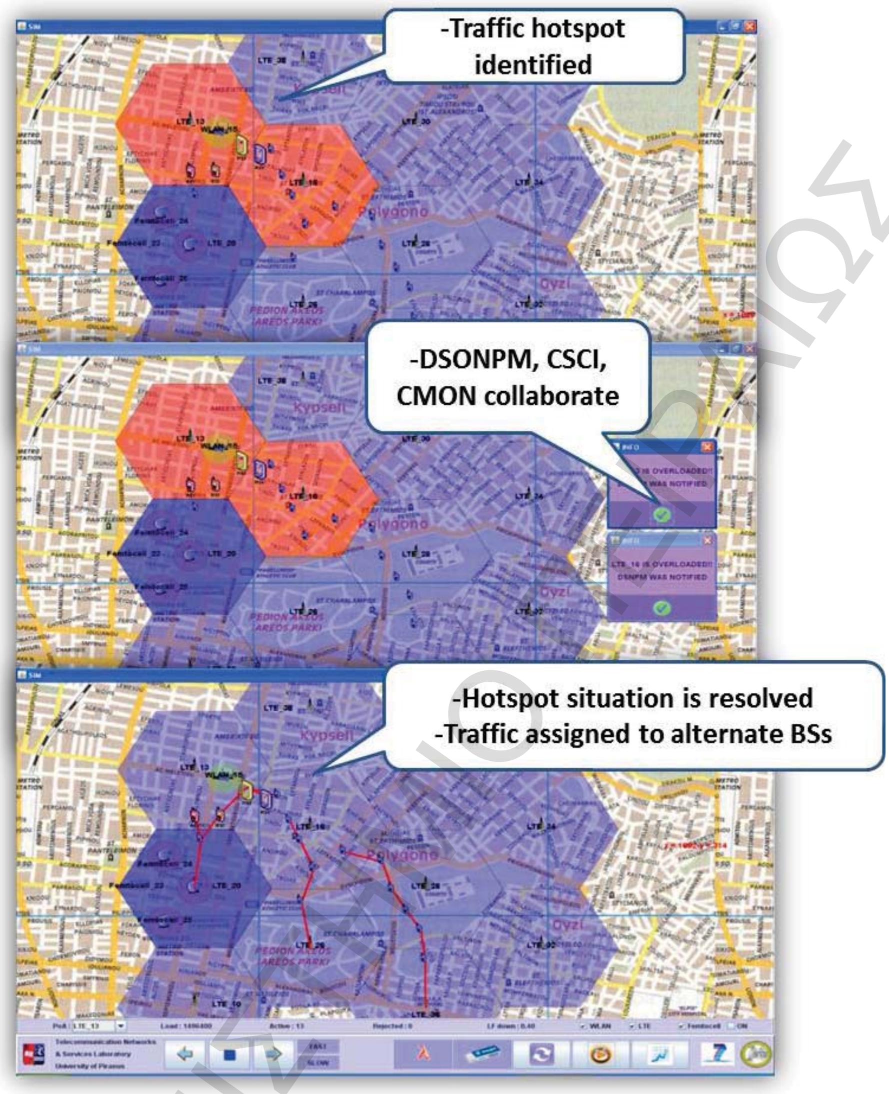

Figure 6-10: Opportunistic Capacity Extension in Platform

In particular, the approach followed here for the creation of an ON is based on the Ford-Fulkerson flow control algorithm [5]. An overview of the overall process and the corresponding interactions between the various functional entities is depicted in Figure 6-11, with 3 main phases. Particularly, the procedure starts when a BS identifies a congestion situation, through its CSCI entity. This is depicted in the "Problem identification" phase of Figure 6-11. As soon as an infrastructure element starts experiencing congestion issues it reaches a warning level where reconfiguration is imminent. The congested BSs send a notification to the DSONPM entity in order to inform it about the problematic situation. DSONPM indicates the BS that will solve the problem (selected BS), which will also populate the set of terminals that will be moved from the congested area to alternate BSs. Furthermore the CSCI is responsible for the identification of candidate terminals that will participate to the creation of ONs ("Suitability determination" phase of Figure 6-11). All non-congested BSs in the vicinity are identified.

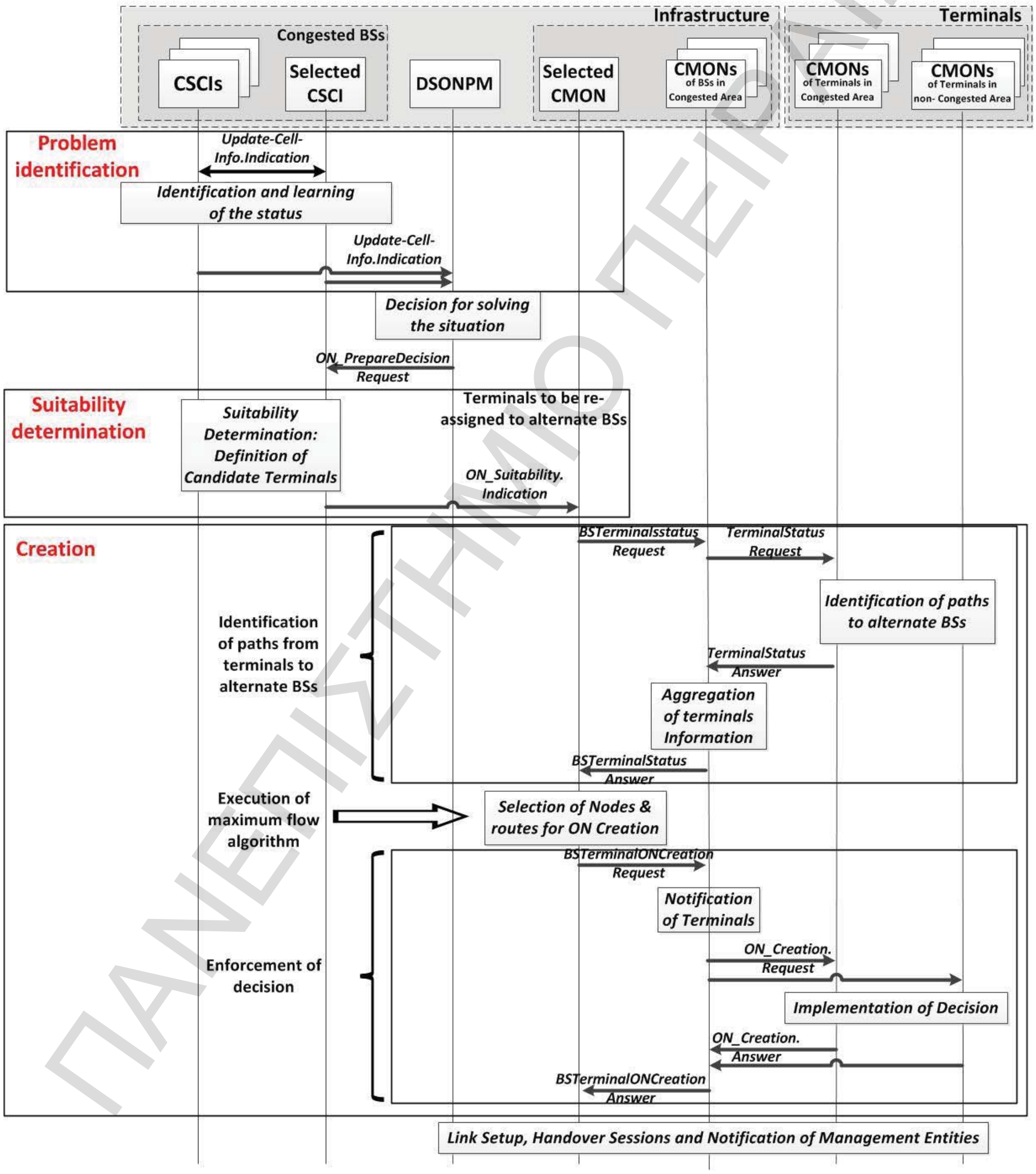

Figure 6-11: Message Sequence Chart for Capacity extension

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For both the congested as well as the uncongested BSs information on the respective terminals is acquired through the CMON entities (“Creation” of Figure 6-11). Such information includes the BS to which each terminal is currently connected, the capacity of each terminal, and its neighboring terminals. The information from all terminals is collected by the selected BS CMON entity in order to obtain information on all potential paths from terminals in the congested area to alternate BSs, through other terminals in the non-congested or congested area. Each path comprises a set of nodes (BS or terminal), the capacity of these nodes, and the cost of the links between the nodes. The aim is to find the most appropriate paths (a subset of all available paths) to re-route the terminals in the congested area to alternate BSs. As an outcome, each terminal should be provided with a path to a BS, allowing it to obtain the required QoS.

6.3.3. Proof of Concept

In order to obtain a proof of concept of the CSCI and CMON functionalities for ON management and especially of the CSCI which is one of the main goals of this dissertation, corresponding prototypes have been implemented, based on Java and the JADE agent platform as already presented. These have been integrated into a wider platform which comprises a network traffic simulator used to simulate various traffic load conditions (e.g. congestion) in a certain service area or network, diverse (actual and emulated) network elements, several user devices, self-management functionalities and corresponding GUIs [6].

An indicative network topology which consists of 8 LTE Macro BSs and 25 terminal devices (which are capable of creating an ON, thus they can be re-directed to alternative, available BSs) is being investigated. Each terminal is assigned to a BS. Terminals may use two types of services namely, Voice and Video conference. Voice service requires a data rate of 12.2 Kbps. Video conference service can be offered at 4 quality levels i.e., 512, 256, 128 and 64 Kbps.

Moreover, each BS, apart from the assigned terminals serves an extra number of simulated users i.e., each service and each quality level as indicated previously is being provided to 15 initial simulated users. Each terminal of an ON is connected to each other with an IEEE 802.11b/g interface.

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As already introduced, in the capacity extension scenario ONs are exploited so as to address problems of infrastructure elements. All Macro (BSs) operating in the area are initially depicted as blue hexagons in the corresponding GUI (Figure 6-10). Two hotspots are created (through the traffic simulator) depicted as red hexagons in Figure 6-10. The occurrence of congestion has as a result that a proportion of users will have to move to neighboring BSs in order to relieve the congested ones, through the process described in Chapter 2.

Red lines in Figure 6-10 denote the paths that are created in order to re-route traffic from the congested BSs (red hexagons in Figure 6-10) to alternate BSs via intermediate terminals (ON nodes). As soon as the congestion situation is resolved, traffic allocation statistics are available through the demonstration platform in order to prove that traffic was successfully re-assigned to neighboring infrastructure elements. In order to evaluate our approach the following metrics are considered: i) normalized load and ii) active users.

Figure 6-12 *(a)* depicts the normalized load which refers to the current load of the BS divided by the maximum supported capacity. As this figure illustrates, the normalized load in the congested BS gradually increases until it reaches an alarming level (threshold 0.7) and the aforementioned ON set-up procedure is triggered.

Eventually, the normalized load decreases as a proportion of users have moved to neighboring BSs. Figure 6-12 *(b)* depicts the active users which reflect to the number of active sessions that are currently in use. This metric increases until the solution mechanism is triggered. After the solution enforcement a gradual decrease is observed.

On the other hand, the normalized load of a neighboring non-congested BS tends to increase as it receives a proportion of the users from the previous congested area as Figure 6-13 *(a)* illustrates. Also, the number of active users of the same BS tends to increase as well (Figure 6-13 *(b)*).

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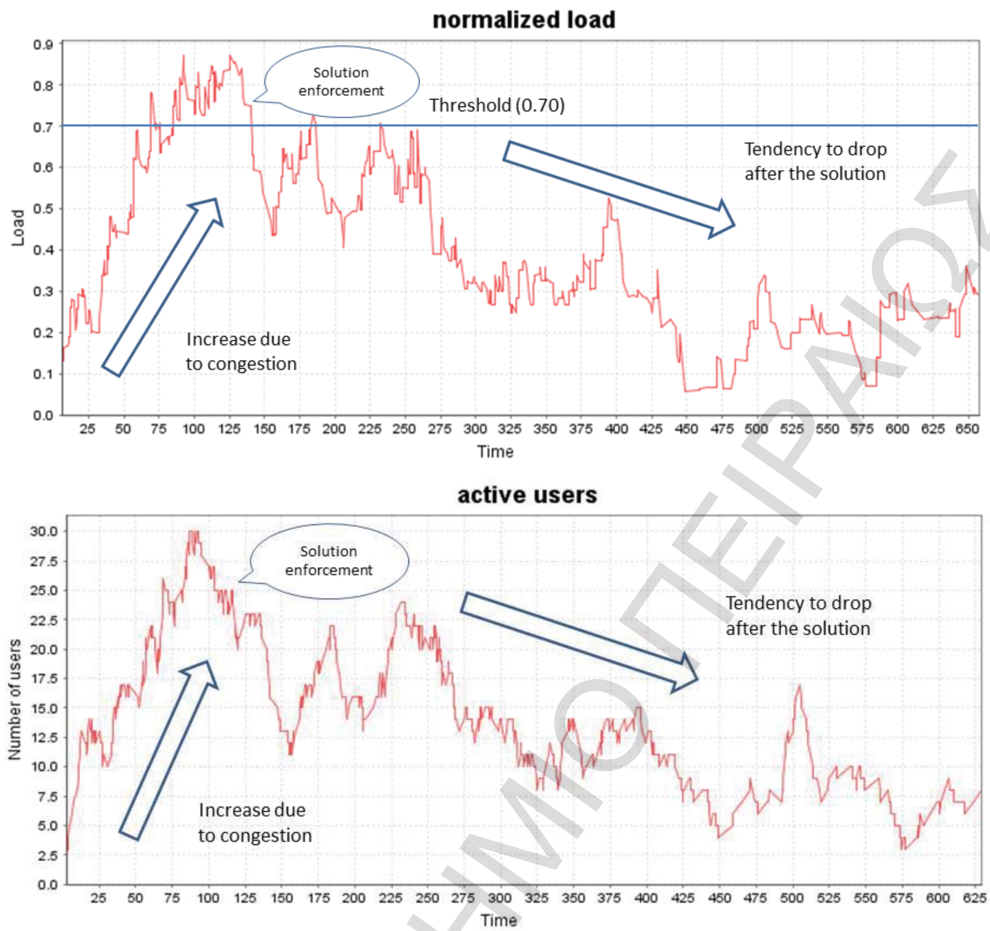

(a)

(b)

Figure 6-12: Normalized Load and Number of Active users in a congested BS

Through the capacity extension scenario apparently the congested BSs are relieved as traffic is re-routed into neighboring infrastructure elements. Moreover, the non-congested BSs that acquired traffic did not reach the threshold so as to become congested. Therefore, the users experience better QoS as the problematic BSs are not congested anymore.

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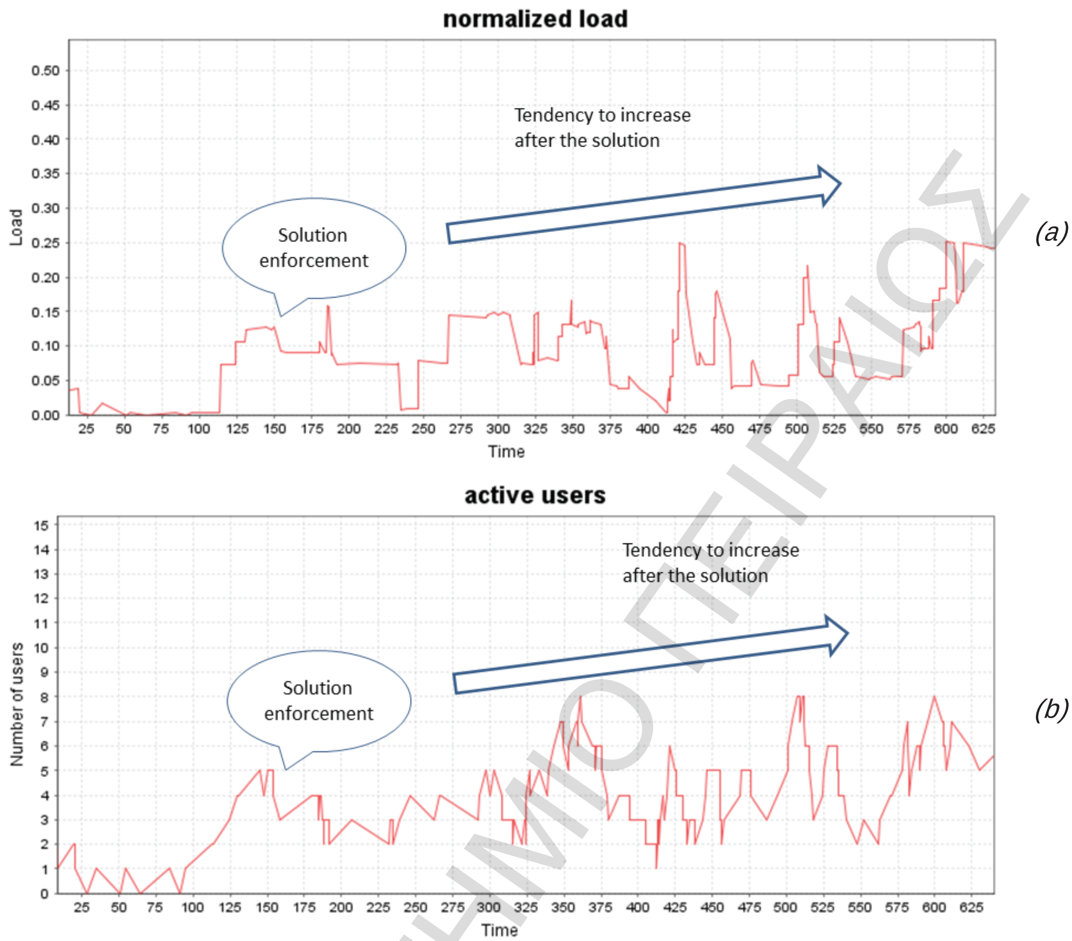

Figure 6-13: Normalized Load and Number of Active users in a non-congested BS

6.4. Conclusions

This chapter presented the policy derivation process and particular the Knowledge-based Suitability Determination Algorithm, considering specific simulation parameters used in Chapters 4 and 5. The exploitation of the results and the process of how proper policies can be derived from the algorithm with the use of the offline-simulations have also been presented. The algorithm collects context/profile information and knowledge in order to provide a proper policy, for the actual creation of the ON. These policies will be then used by the CMON functional block for the actual creation of the ONs, achieving benefits in terms of adequate QoS level provisioning and energy (power) consumption. Moreover, in this chapter has been presented the implementation of a platform environment in

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which is provided the functionality of the software entities CSCI/CMON, for several scenarios of the ONs. In particular indicative scenarios were studied, in order to obtain a proof of concept for the management functionalities.

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7. SUMMARY – ONGOING CHALLENGES

The enormous increase in wireless access demand requires efficient solutions for problems, which are associated with increased efficiency in resource utilization and application QoS provisioning, as well as lower energy/power consumption. In this respect, this dissertation covers a solution that considers the possibility of extending the wireless network infrastructure, which is owned by a wireless operator by the so called ONs, which comprise network elements and devices that are organized in an infrastructure-less manner to serve specific local and temporary application provision needs. Moreover, CMSs can be used for managing the ONs by making decisions based on context, policies and profiles and empowered by knowledge and experience deriving from learning functionality. The decision of the wireless network infrastructure to create or not an ON needs to be fast and dynamic, it should respect several aspects, including particularly traffic/applications variations, mobility levels and/or energy/power consumption levels and it should result in benefits with respect to provisioned QoS for the whole network.

In the context of this dissertation, a FA for the management and control of the ONs was proposed for improved efficiency in resource provisioning and providing users with high quality services anytime and anywhere. This infrastructure governed ONs Management is divided into two building blocks, namely CSCI and CMON. A fundamental idea behind the introduction of these two types of functional blocks was to provide the means to facilitate close cooperation between the infrastructure and the ON(s). Such cooperation is essential for ensuring viability of the solution and value creation for the stakeholders, i.e., operators, service providers and users.

Accordingly, the aim of this dissertation was the performance evaluation of the operator governed ONs as an extension to the infrastructure in various scenarios. In particular, one of the main target was to study the feasibility of extending the infrastructure with an ON (why, where and when) i.e. to find the conditions under which it will be beneficiary for the overall network. This is actually done by recognizing that the first step prior to proceeding with the establishment of such an ON is to be able to judge the suitability of doing so. Normally, the responsibility for such functionality burdens the CMSs, in particular the CSCI entity and the Suitability Determination procedure, which as a decision making process should be able to reply positively or negatively upon taking such an action.

The study was mainly based on extensive network simulations, which revealed that the ON-based solution seems to work and has great potentials to bring about benefits under certain circumstances. These simulations will mainly support the CSCI functionality to judge the suitability of ONs. Especially, the appropriate exploitation of the cut-off values identified from the comprehensive simulation analysis, can be used to extract policies in order to facilitate online, dynamic decisions on whether to boost the creation of the ONs or not. In this respect the Knowledge-Based Suitability Determination Algorithm was presented, which is considered responsible for making decision upon the feasibility of the creation of ONs when judged as appropriate. Under the same spirit, the ultimate goal was to use the obtained policies for endowing the management plane which is responsible for the communication and coordination among wireless network infrastructure and infrastructure-less segments, with proper, advanced functionality that will make timely decisions under preset suitability criteria.

However, there are still plenty of challenges ahead regarding the topics described. In this respect, the results of this dissertation pave the way for further and intensive future research.

Next Generation Cellular RATs

A first next step that seems rather straightforward to follow is to include a multi – AP environment in order to study the interference aspects, including also the case of more than one heterogeneous access networks. Second, it is important to extend our validation studies towards cellular RATs such as 3GPP-LTE and LTE-advanced that is expected to dominate the mobile communications landscape pretty soon. This will comprise part of our future study provided that there will be concrete steps towards the standardization of machine to machine communications (being a prerequisite and enabling technology in our scheme) and also towards the respective supporting LTE simulation platforms.

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Newly coming Applications

It seems also that is of paramount importance to give emphasis in specific newly coming FI applications, bandwidth-hungry and high-quality user-centric applications, such as High Definition (HD) and 3D video content. Additionally, a mixing of application traffic and the inclusion of service type related priorities is also of high importance from QoS perspective and it will comprise subject of our future study.

Energy Consumption

Moreover, the study of the power implications on the terminal nodes that need to carry more load e.g. due to BS's coverage shrinking, is of high importance, and it will be also part of our future work. In particular regarding the power consumption, there must be an extension in our study adding in our simulations realistic energy consumption models, in order to discover the consequences on the terminals side.

Technoeconomic perspective

Last but not least, another interesting and also very important challenge is to devote time in studying the issue from a technoeconomic perspective in order to derive economic incentives for the user to get involved e.g. incentives that might needed to increase the willingness of the user to "let" its terminal offer resources for ensuring satisfactory QoS provision.

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8. APPENDIX A – ACRONYMS

Acronym	**Explanation**
3GPP	3rd Generation Partnership Project
A	
AP	Access Point
ACL	Agent Communication Language
AODV	Ad hoc On-Demand Distance Vector
API	Application Programmable Interface
B	
B3G	Beyond-3G
BS	Base Station
BE	Best Effort
C	
CAPEX	CApital EXPenditures
CMS	Cognitive Management System
CSCI	Cognitive management System for the Coordination of the Infrastructure
CMON	Cognitive Management system for the Opportunistic Network

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CPC	Cognitive Pilot Channel
CCR	Cognitive Control Radio
CN	Core Network
CCM	Configuration Control Module
CCC	Cognitive Control Channels
C4MS	Control Channels for the Cooperation of the Cognitive Management System
CWN	Composite Wireless Network
D	
DSONPM	Dynamic, self-Organizing Network Planning and Management
DSR	Dynamic Source Routing
DTN	Delay Tolerant Networking
DSM	Dynamic Spectrum Management
E	
ETSI	European Telecommunications Standards Institute
EPC	Evolved Packet Core
ECA	Event Condition Action
F	
FA	Functional Architecture
FIPA	Foundation for Intelligent Physical Agents

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G	
GeSI	Global e-Sustainability Initiative
GRP	Geographic Routing Protocol
GUI	Graphical User Interface
GSM	Global System for Mobile Communications
H	
HNB	Home Node B
HSDPA	High-Speed Downlink Packet Access
HD	High Definition
I	
IPDV	Instantaneous Packet Delay Variation
ICPIF	Impairment Calculated Planning Impairment Factor
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform
J	
JRRM	Joint Radio Resources Management
JADE	Java Agent DEvelopment Framework
K	
k-NN	k-Nearest Neighbour

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L	
LTE	Long Term Evolution
M	
MAS	Multi Agent System
MANET	Mobile Ad-hoc NETworks
MS	Mobile Station
MT	Mobile Terminal
MPRs	Multipoint Relays
MOS	Mean Opinion Score
MAC	Medium Access Control
N	
O	
OPEX	Operational Expenditures
OLSR	Optimized Link State Routing protocol
P	
Q	
R	
RAT	Radio Access Technology
RRS	Reconfigurable Radio Systems

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RAN	Radio Access Network
RREQ	Route REQuest
RREP	Route REPlies
S	
SO	Service Oriented
T	
TC	Topology Control
TRx	Transmission and Reception Unit
U	
UMTS	Universal Mobile Telecommunications System
V	
VoIP	Voice over IP
W	
WLAN	Wireless Local Area Network
X	
Y	
Z	

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9. APPENDIX B – LIST OF PUBLICATIONS (OCTOBER 2012)

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Short CV

Marios Logothetis was born in Athens, Greece, in 1981. He has received his Diploma and Master Degree, from the Department of Digital Systems in the University of Piraeus, in 2003 and 2006, respectively. Since January 2007 he is research engineer at the University of Piraeus, in the Laboratory of Telecommunication Networks and Integrated Services. He has been involved in "Phase II of End-to-End Reconfigurability" (E2RII) and "End-to-End Efficiency" (E3) projects which were funded by the European Commission under 6th and 7th Framework Programmes (FP6 and FP7), respectively.

Moreover he has been involved in several European projects such as "Wireless Intelligent – Hospital Premises Network'" (WinHPN) and to the EU-funded FP7/ICT "Opportunistic Networks and Cognitive Management Systems for Efficient Application Provision in the Future Internet" (OneFIT). His main interests include management and performance evaluation of mobile ad hoc networks and wireless sensors in the Future Internet era.

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