UNIVERSITY OF PIRAEUS **ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ**

ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ

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UNIVERSITY OF PIRAEUS **ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΕΙΡΑΙΩΣ**

PHD THESIS

TECHNOECONOMIC ANALYSIS AND USER PROFILE MANAGEMENT IN THE CONTEXT OF WIRELESS B3G NETWORKS AND SERVICES

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ABSTRACT

During the last two decades extremely rapid evolution is observed in Technology and Communications. This evolution benchmarks a new era and calls everyone to be a part of this, by using the new infrastructures developing. At the same time, this evolution is reflected in the enormous investments made on the development of pioneer systems and infrastructures. These infrastructures aim at coping with the continuous needs of the users, as well as adapting to their unique preferences. This may be realised through constantly updated, adaptive and innovative services. These services will have to be viable and dependable systems, able to fulfil users' needs, any time requested. The viability of such systems is guaranteed through the appropriate technoeconomic analysis and the adaptation to users' preferences, through cognitive networks. In this context, this PhD thesis deals with issues of technoeconomic analysis and user profile management, for services and wireless Beyond the Third Generation networks.

The First Chapter of this thesis is introductory. It presents the axes on which the thesis is set and the field of knowledge is covered within these axes. More specifically, the structure of the PhD thesis is presented, outlining the field of knowledge it discusses. The technoeconomic analysis that takes place, in order to certify Reconfigurable Networks' viability, serves as the cost efficiency assessment procedure. Quality of Service estimation and functionality improvement comprise the target of the User Profile Management in the context of services and wireless Beyond the Third Generation Networks. Moreover, within the First Chapter the support by the State of the Art is presented, in order to showcase the relevance of this analysis with the current trends in technology. Finally, the Chapter concludes with an overview of Beyond the Third Generation systems and introduction each of the chapters of this thesis.

The Second Chapter is a technoeconomic analysis and evaluation of the Beyond the Third Generation infrastructures. It is essential to have evidence that the transition to the Beyond the Third Generation infrastructures is a technological achievement, progress and increase of the options for user's satisfaction, and a financially viable and profitable solution. In this way, the functionality and efficiency of these networks is

verified, resulting to the improvement of Quality of Service and consequently, to user satisfaction.

The Third Chapter discusses on the User Profile in a Mobile Service environment. It is mandatory for the purpose it is set up for; the fulfilment of user requirements. Thus, this chapter defines the way, by which User Profile has to be structured, as well as the parameters that comprise it, in order to reflect user preferences. Furthermore, it presents two different methodologies for encoding and recording such preferences, namely the Bayesian Average methodology and the Bayesian Networks methodology. The results of the application of the two methodologies and a comparison between these results is also taken down and presented.

The Fourth Chapter is a technical, specific instance, and acts as a sequence of the Third Chapter. Precisely, it presents the structure and the parameters of the User Profile, within an E-learning Service environment. Recording and predicting users' future preferences are also studied within this chapter, through Bayesian Networks methodology. Based on this methodology, the results of different case scenarios are also discussed.

The Fifth Chapter considers User Profile in a Transportation Management – Car Pooling Service environment. This chapter also presents the structure and the parameters of User Profile, focusing on its management. Moreover, in the context of this service, the way of selecting a specific transportation service, through correlating a driver and a passenger sharing the itinerary, is also discussed. The methodology used is the Objective Function. The results of the different case scenarios created to test the methodology are also presented.

The Sixth Chapter describes the conclusions of the PhD thesis and potential future extensions of the work are also given.

As the wide scientific field of this PhD thesis is "Quality of Service Management in Future Multimedia Applications", the main objective of this thesis focuses on the technoeconomic analysis for the verification of the financial viability in the investment on Beyond the Third Generation networks and User Profile management for service and wireless Beyond the Third Generation networks. In this sense, simulations have taken place, the results of which are used to certify the legitimacy of the allegations, with respect to the effectiveness of the presented methodologies for resolving the presented problems.

Keywords: Beyond the Third Generation (B3G) systems, cognitive networks, technoeconomic analysis, user profile management

ΠΕΡΙΛΗΨΗ

Τις τελευταίες δύο δεκαετίες παρατηρείται ραγδαία εξέλιξη στην Τεχνολογία και τις Επικοινωνίες. Η εξέλιξη αυτή αντανακλάται στις τεράστιες επενδύσεις που λαμβάνουν χώρα για την ανάπτυξη περαιτέρω καινοτόμων συστημάτων και υποδομών. Ταυτόχρονα, η εξέλιξη αυτή σηματοδοτεί μια νέα εποχή και καλεί όλους τους πολίτες να αποτελέσουν μέρος της εξέλιξης αυτής, μέσω της χρήσης των νέων υποδομών που αναπτύσσονται. Οι υποδομές αυτές έχουν ως στόχο τόσο να αντεπεξέλθουν στις διαρκώς αυξανόμενες ανάγκες των χρηστών, όσο και να προσαρμοστούν στις ιδιαίτερες προτιμήσεις τους. Αυτό είναι δυνατό να πραγματοποιηθεί μέσω της παροχής διαρκώς αναβαθμιζόμενων, προσαρμοστικών και καινοτόμων υπηρεσιών. Οι υπηρεσίες αυτές θα πρέπει να αποτελούν συστήματα βιώσιμα, ικανά να καλύπτουν τις ανάγκες των χρηστών, όποτε και αν ζητηθεί. Η βιωσιμότητα (viability) αυτή πιστοποιείται τόσο μέσω της τεχνοοικονομικής ανάλυσης (technoeconomic analysis), αλλά και μέσω της προσαρμογής στις προτιμήσεις των χρηστών (adaptation in user preferences) μέσω των γνωσιακών δικτύων (cognitive networks). Στο πλαίσιο αυτό κινείται η παρούσα διδακτορική διατριβή, η οποία πραγματεύεται ζητήματα τεχνοοικονομικής ανάλυσης και διαχείρισης προφίλ χρήστη, για υπηρεσίες και ασύρματα δίκτυα πέραν της τρίτης γενιάς (Beyond the Third Generation - B3G).

Το Πρώτο Κεφάλαιο αποτελεί εισαγωγή της διδακτορικής διατριβής. Παρουσιάζει τους άξονες στους οποίους κινείται η διατριβή και το γνωστικό πεδίο το οποίο καλύπτει. Πιο συγκεκριμένα, παρουσιάζεται η δομή της διδακτορικής διατριβής, υπογραμμίζοντας τα επιμέρους επιστημονικά πεδία, με τα οποία καταπιάνεται. Η διαδικασία αποτίμησης της οικονομικής αποδοτικότητας λαμβάνει χώρα μέσω της τεχνοοικονομικής ανάλυσης, ώστε να πιστοποιηθεί η βιωσιμότητα των Επαναδιαρθρώσιμων Δικτύων (Reconfigurable Networks). Η εκτίμηση της Ποιότητας Υπηρεσίας (Quality of Service) και η βελτίωση της λειτουργικότητας του συστήματος (functionality) αποτελούν το στόχο του πεδίου της διαχείρισης Προφίλ Χρήστη (User Profile Management) στο πλαίσιο των υπηρεσιών και των ασυρμάτων, Πέραν της Τρίτης Γενιάς Δικτύων. Επιπλέον, στο πλαίσιο του Πρώτου Κεφαλαίου, γίνεται συσχέτιση των αξόνων της διδακτορικής διατριβής με τις τελευταίες εξελίξεις. Τέλος, το Κεφάλαιο ολοκληρώνεται με την επισκόπηση των Δικτύων Πέραν της Τρίτης Γενιάς και την εισαγωγή σε κάθε ένα από τα κεφάλαια της διατριβής.

Το Δεύτερο Κεφάλαιο αποτελεί την τεχνοοικονομική ανάλυση και αξιολόγηση των υποδομών Πέραν της Τρίτης Γενιάς. Είναι αναγκαίο να γνωρίζουμε ότι το πέρασμα στις υποδομές Πέραν της Τρίτης Γενιάς αποτελεί τόσο τεχνολογική πρόοδο και ανάπτυξη των επιλογών για την ικανοποίηση του χρήστη, αλλά και οικονομικά βιώσιμη λύση. Με τον τρόπο αυτό πιστοποιείται η λειτουργικότητα και η αποδοτικότητα των δικτύων αυτών, έχοντας ως αποτέλεσμα τη βελτίωση της Ποιότητας Υπηρεσίας και κατ' επέκταση την ικανοποίηση των προτιμήσεων του χρήστη.

Το Τρίτο Κεφάλαιο περιλαμβάνει τη μελέτη του Προφίλ του Χρήστη σε ένα Περιβάλλον Κινητών Επικοινωνιών (mobile service). Το σύστημα αυτό είναι απαραίτητο να ικανοποιεί το σκοπό για τον οποίο δημιουργήθηκε: την πλήρωση των αναγκών και προτιμήσεων του χρήστη. Το Κεφάλαιο λοιπόν αυτό ορίζει τον τρόπο με τον οποίο θα πρέπει να δομείται το Προφίλ Χρήστη και τις παραμέτρους που το επηρεάζουν, ώστε να αντικατοπτρίζει τις προτιμήσεις του χρήστη. Επιπλέον, παρουσιάζει δύο μεθόδους για την κωδικοποίηση και καταγραφή των προτιμήσεων αυτών, τη μέθοδο Bayesian Average και τη μέθοδο Bayesian Networks. Τέλος, παρουσιάζονται τα αποτελέσματα των μεθόδων και η μεταξύ τους σύγκριση.

Το Τέταρτο Κεφάλαιο αποτελεί εξειδικευμένο παράδειγμα και συνέχεια του Τρίτου Κεφαλαίου. Συγκεκριμένα, παρουσιάζει τη δομή και τις παραμέτρους του Προφίλ του Χρήστη σε ένα Μαθησιακό Περιβάλλον (e-learning service). Η καταγραφή και η πρόβλεψη των μελλοντικών προτιμήσεων του χρήστη μελετώνται μέσω της μεθόδου των Bayesian Networks, ενώ αναλύονται πιθανά σενάρια με βάση τη μέθοδο αυτή.

Το Πέμπτο Κεφάλαιο μελετά το Προφίλ του Χρήστη σε ένα Περιβάλλον Εξυπηρέτησης Μεταφοράς (Transportation Management – Car Pooling service). Το Κεφάλαιο πραγματεύεται τη δομή ενός τέτοιου συστήματος και εστιάζει στη διαχείριση του Προφίλ Χρήστη. Ορίζει τις παραμέτρους που επηρεάζουν το Προφίλ του Χρήστη στο πλαίσιο της υπηρεσίας αυτής και παρουσιάζει τον τρόπο επιλογής μιας συγκεκριμένης υπηρεσίας μεταφοράς, μέσω του διαμοιρασμού της με έναν άλλο χρήστη. Η μέθοδος που χρησιμοποιείται είναι εκείνη της Αντικειμενικής Συνάρτησης (Objective Function). Επίσης, μελετώνται διαφορετικές περιπτώσεις εφαρμογής της μεθόδου αυτής και παρουσιάζονται τα αποτελέσματα.

Τέλος, στο Έκτο Κεφάλαιο περιγράφονται τα συμπεράσματα της διδακτορικής διατριβής και προτείνονται κάποιες πιθανές μελλοντικές επεκτάσεις για τη συνέχιση της εργασίας σε θέματα που προέκυψαν εξ' αυτής.

Καθώς το ευρύτερο επιστημονικό πεδίο της διδακτορικής διατριβής είναι "Διαχείριση Ποιότητας Υπηρεσίας σε Μελλοντικές Εφαρμογές Πολυμέσων", η διατριβή επικεντρώνεται στην τεχνοοικονομική ανάλυση για την πιστοποίηση της βιωσιμότητας και η διαχείριση του προφίλ του χρήστη για υπηρεσίες και ασύρματα Δίκτυα Πέραν της Τρίτης Γενιάς. Παράλληλα, πραγματοποιούνται προσομοιώσεις, τα αποτελέσματα των οποίων χρησιμοποιούνται για την πιστοποίηση της ορθότητας των ισχυρισμών σχετικά με την καταλληλότητα των παρουσιαζομένων μεθόδων επίλυσης των προβλημάτων.

Λέξεις – Κλειδιά: Γνωσιακά δίκτυα, Διαχείριση Προφίλ Χρήστη, Συστήματα Beyond the Third Generation (B3G), Τεχνοοικονομική Ανάλυση

Στους γονείς μου, Νίκο και Κατερίνα
στον αδερφό μου, Κώστα
στη μικρή μου Άντια
και στον Ηλία μου…

Dedicated to
my parents, Nikos and Katerina,
my brother, Kostas
my little Antia
and my Ilias…

FOREWORD

It is the journey that matters, not the destination… These are the words used by Konstantinos Kavafis, a talented Greek poet, to express the beauty of every journey that takes place during peoples' lives. As every journey, this PhD thesis' progress encountered difficulties and adversities, but also enjoyed many successful moments.

Heading towards the completeness of my PhD thesis, which was started and concluded in the context of the *Telecommunication Networks and Integrated Services Laboratory*, of the *Department of Technology Education and Digital Systems*, within *University of Piraeus, Greece*, I would like to express my deep thanks to certain people that stood by me and each one of them contributed in her/ his own way to its completion.

The corner – stone of this effort was my family. I owe so much to my parents, Nikos and Katerina. My parents, since the day I was born, took care of me, providing me with all their love and care, bequeathing their principles and moral equipage that would join me for the rest of my life. The stood and stand by my side, real helpmates during the route of my studies, encouraging and inspiriting every effort towards the completeness of my PhD thesis. They were and are a paradigm to me and I express my deepest thankfulness and gratitude from the bottom of my heart for everything.

My brother, Kostas, has been the paradigm to me and set the path to continue with him towards knowledge and education. We lived together as students and as fresh professionals. We shared our anxiety and engrossements for our lives, but we also shared successes. I thank him very very much for the love, the support and his faith to my abilities.

A very big part in the completeness of my PhD thesis has my supervisor, Associate Professor in University of Piraeus, Dr. Panagiotis Demestichas. I would like to deeply thank him for trusting my potential and capability and with both scientific and moral support he contributed to the completeness of my PhD thesis. Our cooperation has been catalytic for me, inspiring me and helping me continuously. Thanks to this cooperation my scientific horizons were broadened, I sharpened my critical view and through this procedure my willingness to pass on this knowledge was established.

Furthermore, very important was the contribution of Vice-Rector of University of Piraeus and President of the Technology Education and Digital Systems Department, Dr. Georgios Vassilacopoulos and the Associate Professor in University of Piraeus, Dr. Demetrios Sampson. Our cooperation started during my undergraduate years, within which they offered their help whenever I needed, providing me important scientific advice and guidance, motivating me to become better.

Moreover, I would like to thank Associate Professor in University of Piraeus, Dr. Athanassios Kanatas. His scientific contribution and moral support was very important for the completion of my PhD thesis.

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I would also like to thank my colleague and friend, Apostolos Katidiotis. We started together this journey, sharing our doubts and dreams, reaching again together the completeness of our PhD theses. I thank him for the support during all these years and for the very nice moments we shared.

Moreover, I would like to thank Dr. George Dimitrakopoulos, for helping me during my PhD thesis, providing me with apposite comments and his scientific experience in the problems I faced.

I would also like to thank Dr. Kostas Tsagkaris, who contributed to the completion of my PhD thesis, providing my with his help and knowledge in the problems I encountered.

Furthermore, the rest members of the Telecommunication Networks and Integrated Services Laboratory have contributed to the completion of my PhD thesis, namely Dionysis Petromanolakis, Aggelos Saatsakis, Marios Logothetis and Andreas Georgakopoulos. I would like to thank them and wish them to complete their own journey towards knowledge very soon.

I would also like to thank some people that had a very important part in the completion of my PhD thesis, providing me their love and support. I would like to thank my cousin, teacher and mother of my beloved godchild Antia, Katerina Kontovraki, who, since my adolescence, was there for me, to tolerate my anxiety, support my dreams and encourage me, in every goal I set.

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Finally, many many thanks I would like to express to Ilias Katsogiannis, my significant other. His smile and optimism encouraged me to complete my PhD thesis with very much love and excitement. He supported and impelled me even in moments I lost my temper and confidence, and gave his personal rhythm and tempo in my PhD thesis. Thank you for everything…

With honour,

Panagioula N. Kritikou

ΠΡΟΛΟΓΟΣ

Σημασία δεν έχει ο προορισμός, αλλά το ταξίδι... Με αυτά τα λόγια εξέφρασε ο Κωνσταντίνος Καβάφης την ομορφιά κάθε ταξιδιού που γίνεται κατά τη διάρκεια της ζωής ενός ανθρώπου. Και όπως όλα τα ταξίδια, έτσι και η πορεία αυτής της διατριβής, είχε τις δυσκολίες, τις αντιξοότητες, αλλά και τις χαρές της.

Οδεύοντας προς την ολοκλήρωση της διδακτορικής μου διατριβής, η οποία ξεκίνησε και ολοκληρώθηκε στο *εργαστήριο Δικτύων Τηλεπικοινωνιών και Ολοκληρωμένων Υπηρεσιών* του τμήματος *Διδακτικής της Τεχνολογίας και Ψηφιακών Συστημάτων του Πανεπιστημίου Πειραιώς*, θα ήθελα να εκφράσω τις ευχαριστίες μου στους ανθρώπους που στάθηκαν δίπλα μου και συνέβαλαν ο καθένας με το δικό του τρόπο στην ολοκλήρωση αυτής.

Ακρογωνιαίος λίθος σε αυτήν την προσπάθεια υπήρξε η οικογένεια μου. Οφείλω ένα μεγάλο ευχαριστώ στους γονείς μου, Νίκο και Κατερίνα. Οι γονείς μου είναι εκείνοι που φρόντισαν από παιδί να με διδάξουν την αγάπη και τη φροντίδα, να μου δώσουν αρχές και πνευματικά εφόδια για τη ζωή μου. Στάθηκαν στο πλευρό μου πραγματικοί συμπαραστάτες καθ’ όλη τη διάρκεια των σπουδών μου, ενθαρρύνοντας και εμψυχώνοντας κάθε μου προσπάθεια που συνέβαλε στην ολοκλήρωση της διδακτορικής μου διατριβής, και όχι μόνο. Ήταν και είναι πρότυπα για τη ζωή μου και τους ευχαριστώ μέσα από την καρδιά μου για όλα.

Ο αδερφός μου, Κώστας, μου έδωσε το παράδειγμα και μου πρότεινε το χέρι να συνεχίσουμε παρέα την πορεία προς τη γνώση και τη μόρφωση. Ζήσαμε μαζί τα φοιτητικά μας χρόνια και κάναμε τα πρώτα μας επαγγελματικά βήματα. Μοιραστήκαμε ανησυχίες, προβληματισμούς, αλλά και επιτυχίες. Τον ευχαριστώ θερμά για την αγάπη, την υποστήριξη και την πίστη του στις δυνάμεις μου.

Σημαντικότατο μερίδιο στην ολοκλήρωση της διδακτορικής μου διατριβής έχει ο επιβλέπων καθηγητής μου, Αναπληρωτής Καθηγητής Πανεπιστημίου Πειραιώς, Δρ. Παναγιώτης Δεμέστιχας. Θέλω να τον ευχαριστήσω θερμά που έδειξε εμπιστοσύνη στις δυνατότητες και τις ικανότητές μου και τόσο με επιστημονική, όσο και ηθική υποστήριξη συνέβαλλε στην ολοκλήρωση της διδακτορικής μου διατριβής. Η συνεργασία μας υπήρξε καταλυτική για εμένα, αποτελώντας πηγή έμπνευσης για την επαγγελματική μου πορεία.

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Ιδιαίτερα σημαντική υπήρξε η συμβολή του Αντιπρύτανη του Πανεπιστημίου Πειραιώς και Προέδρου του Τμήματος Ψηφιακών Συστημάτων Δρ. Γεωργίου Βασιλακόπουλου, καθώς και του Αναπληρωτή Καθηγητή Δρ. Δημητρίου Σάμψων. Η συνεργασία μας ξεκίνησε από το προπτυχιακό ακόμα επίπεδο, κατά το οποίο με βοήθησαν ιδιαίτερα οποτεδήποτε χρειάστηκα, παρέχοντάς μου ιδιαίτερα σημαντική επιστημονική καθοδήγηση και συμβουλές, δημιουργώντας μου με τον τρόπο αυτό τα κίνητρα για να γίνω καλύτερη.

Επίσης, θα ήθελα να ευχαριστήσω τον Αναπληρωτή Καθηγητή Δρ. Αθανάσιο Κανάτα, οποίος με την επιστημονική του συμβολή και την ηθική υποστήριξη συνέβαλε σημαντικά στην ολοκλήρωση της διδακτορικής μου διατριβής.

Θα ήθελα ακόμα να πω ένα πολύ μεγάλο ευχαριστώ στη Λέκτορα Δρ. Βέρα-Αλεξάνδρα Σταυρουλάκη, η οποία στάθηκε κοντά μου όλα αυτά τα χρόνια, παρέχοντάς μου τόσο την επιστημονική της γνώση, όσο και την αμέριστη συμπαράσταση σε ηθικό και ψυχολογικό επίπεδο. Η βοήθειά της ήταν καταλυτική για την ολοκλήρωση της διατριβής αυτής και της χρωστώ πάρα πολλά.

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Επίσης, θα ήθελα να ευχαριστήσω τον Δρ. Κώστα Τσαγκάρη, ο οποίος συνέβαλλε σημαντικά στην ολοκλήρωση της διδακτορικής μου διατριβής, παρέχοντας τη βοήθειά του και τις γνώσεις του, για την επίλυση των προβλημάτων ή προβληματισμών που αντιμετώπιζα.

Ακόμα, σημαντικό μερίδιο στην ολοκλήρωση αυτής της εργασίας κατέχουν τα υπόλοιπα μέλη του εργαστηρίου Δικτύων Τηλεπικοινωνιών και Δικτυακών Υπηρεσιών και πιο συγκεκριμένα οι Διονύσης Πετρομανωλάκη, Άγγελος Σαατσάκης, Μάριος Λογοθέτης και Ανδρέας Γεωργακόπουλος. Τους ευχαριστώ πολύ και τους εύχομαι σύντομα να ολοκληρώσουν το δικό τους ταξίδι προς τη γνώση.

Επίσης, θα ήθελα να ευχαριστήσω ιδιαίτερα κάποιους ανθρώπους που έπαιξαν πολύ σημαντικό ρόλο στην ολοκλήρωση της διδακτορικής μου διατριβής, παρέχοντάς μου γενναιόδωρα την αγάπη τους και τη στήριξή τους. Πολύ μεγάλο ευχαριστώ στην ξαδέρφη μου, καθηγήτριά μου και μαμά της αγαπημένης μου Άντιας, Κατερίνα Κοντοβράκη, η οποία από τα μαθητικά μου χρόνια ως καθηγήτριά μου, άκουγε τις ανησυχίες μου, στήριζε τα όνειρά μου και με ενθάρρυνε σε όποιο στόχο και αν έθετα.

Πολύ μεγάλο ευχαριστώ οφείλω και στις αγαπημένες μου φίλες Δήμητρα Ανδριτσάκου, Μαρία Παππά, Ροδάνθη Βιδάλη, Λουΐζα-Μαγδαληνή Παπαδοπούλου, Βέρα-Αλεξάνδρα Σταυρουλάκη και Δάφνη Μπράβου και τους αγαπημένους μου φίλους Γιώργο Τσουκαλά, Στέλιο Τζηρά και Robert Schmidt. Στάθηκαν όλα αυτά τα χρόνια σύμμαχοι και συμπαραστάτες στον αγώνα μου για τη διδακτορική μου διατριβή, αλλά και σε οποιαδήποτε βοήθεια χρειάστηκα, ήταν πάντα κοντά μου. Σας ευχαριστώ όλους μαζί και καθέναν ξεχωριστά για όλα όσα μου έχετε προσφέρει...

Τέλος, ένα ιδιαίτερα μεγάλο ευχαριστώ θέλω να πω στον Ηλία Κατσόγιαννη, το σύντροφό μου. Με το χαμόγελό του και με την αισιοδοξία του με ώθησε να ολοκληρώσω αυτή τη διδακτορική διατριβή με πολλή αγάπη και μεράκι. Με στήριξε και μου έδινε κουράγιο ακόμα και σε στιγμές που έχανα την ψυχραιμία και την αυτοπεποίθησή μου και έδωσε το δικό του ρυθμό και το δικό του τέμπο στη διδακτορική μου διατριβή. Ευχαριστώ Ηλία μου...

Με τιμή,

Παναγιούλα Ν. Κρητικού

TABLE OF CONTENTS

1. INTRODUCTION TO TECHNOECONOMIC ANALYSIS AND USER PROFILE MANAGEMENT IN THE CONTEXT OF WIRELESS B3G NETWORKS AND SERVICES

Abstract

The following section composes the introduction of this PhD thesis. It outlines the basic concepts it is based on, presenting the structure of the thesis. The State of the Art is also presented, in order the connection with the current trends to be showcased. Moreover, an overview of the Beyond the Third Generation Networks is made. Finally, a brief introduction of each chapter of this PhD thesis is made, underlining each chapter's focus, the problem it solves, the methodology used and the results produced by the application of the methodology.

Keywords

Chapter overview, state of the art, thesis structure

1.1. Introduction

During the last two decades there has been exponential development in the field of technology. Data, applications and services are now available at any time and place, through the use of Mobile Communications Systems. Thus, regardless the context, the user has the potential to access the information desired.

More specifically, this ability is realised through the use of wired and wireless access technologies, in other words, through the fixed and wireless devices. As expected, there has been an emphasis on the continuously evolving Beyond the Third Generation (B3G) infrastructures, which are made available through the wireless access technologies and are capable to fulfil users' specific needs and preferences for services, regardless the place, the time and the equipment.

In order to fulfil these special and personalised user preferences, these systems will have to conform to and integrate certain system features that include both technical requirements and human interaction. Moreover, the system will also have to take into consideration both the particular results of the system, i.e. the output of the system, and the overall characteristics of the system.

The subsequent section analyses the requirements of a system, the way these requirements have been taken into consideration in this thesis and therefore the structure of this thesis for supporting system's requirements and features.

1.2. Thesis' Structure

Undoubtedly new services, available through innovative infrastructures, are very successful, as they have received wide acceptance by users and gradually have gained ground in the market. This has happened as these services facilitate peoples' routine, saving effort, time and money and are easier than before to access, using the new, inventive infrastructures.

B3G networks' utmost goal is to support customers with a wide range of applications and offer cheap and flexible application access. As mentioned previously, this is achieved with the combination of different access technologies, which are beneficial and resource efficient. The customer connects to an access network based on a combination of personal preferences as grade of Quality of Service, level of security, price of usage, operator and service access.

In order to achieve this goal, a B3G system should be able to fulfill different end-user demands. Such demands include:

- Ubiquitous access; with easy access to applications and services, regardless the place, the time and the equipment of the system,
- Network characteristics; appropriate Quality of Service and security at reasonable cost,
- Terminal characteristics; vast choice of terminals with easily understandable user interface and user friendly billing capabilities, including advice of charge,
- Multi-profile usage; regarding Quality of Service (QoS) profile for same service, context information, choice of service/content provider.

Furthermore, it is considered that the B3G users take on different *roles* during a working day and for each new role the user may apply a different usage package with predefined characteristics. This may be relevant to the kind of services available in the package, the price this service is offered at, the quality of this service and security [1]. The requirements formed by users and have to be gratified in the B3G context are:

- Always best connected; a user always connects to the best possible network (based on personal criteria) available to support the service required,
- Personalization; including personal service selection, different personal profiles pointing out users interests,
- Simplicity; meaning that services must be easy to configure and easy in use.

As described above, B3G systems put new demands on the network to suit user expectations of the future communication society. Satisfying these expectations, results to the establishment of the usage of the specific service. It is therefore important to make sure that users' requirements are obeyed.

Thus, in order to comply with users' expectations, exploiting the advantages offered by B3G networks and taking into consideration user preferences, the system will have to make *cost efficient provision* and *user profile management*, in the context of the service.

Cost efficient provision is realized through technoeconomic analysis, contributing to overall system's quality, and the augmentation of user satisfaction. Furthermore, it has to be mentioned that technoeconomic analysis takes into account the Quality of Service provided in each service. In this PhD thesis Reconfigurable infrastructure is investigated, being able to dynamically adapt to the environment requirements and conditions, in principle, by means of self-management. This means that Reconfigurable Networks may operate with diverse alternate configurations, in order to achieve the best configuration for the characteristics of the service required. The tool used for the technoeconomic analysis is the Net Present Value technique (NPV). The Net Present Value technique is one of the most popular tools for financial evaluation and is considered to be one of the most robust techniques for analyzing a variety of investment activities [2].

On the other hand, standalone is the provision of user preferences, through *user profile management*, and consequently the definition of the appropriate *Quality of Service* as well as the formulation of the apposite *functionality* of different applications of such systems. Put another way, user profile management takes place for discovering the best suitable Quality of Service for each user, along with the way a service will have to be set and improve its functionality. Both these research areas lead to increasing user satisfaction, by making the system more effective and *user centric*. In the context of this thesis, Bayesian Networks, Bayesian Average and Objective Function are the methodologies used within the chapters for recording and learning user preferences and consequently achieve better Quality of Service and increased functionality for satisfying users.

Bayesian Networks is a method for evaluating, in a qualitative and quantitative manner, elements of the user behavior and accordingly updating the User Profile [3]. Bayesian Rating methodology uses the Bayesian Average method, which is a method of calculating the mean of a data set where there is a known prior probability of the value being estimated. It is of particular value when calculating means of multiple differently sized data sets from a larger population [4]. Objective Function (OF) is defined as the simplest case of optimization, or mathematical programming and refers to the study of problems in which one seeks to minimize or maximize a real function (or objective function) by systematically choosing the values of real or integer variables, within an allowed set [5].

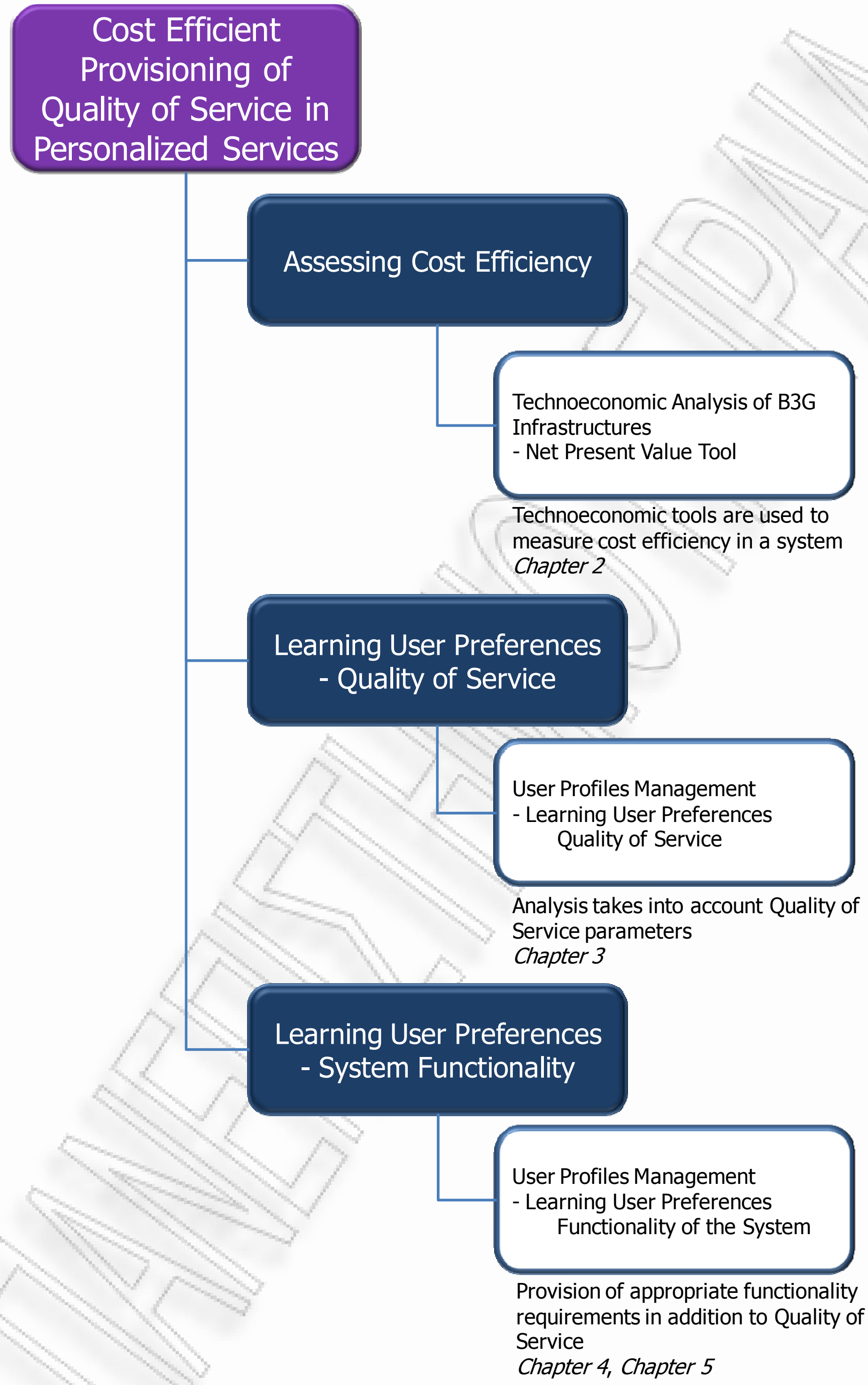

Figure 1-1: Analysis of the scientific field of the thesis

These techniques are applied to a mobile service, in order to investigate the way Quality of Service may be measured and set properly for each user and to a transportation management – car-pooling service and e-learning service in order to define the suitable functionality for each service.

Figure 1-1 presents the structure of the PhD thesis, showcasing each chapter's content.

The following sections make a reference to the State of the Art, which supports this PhD thesis' structure and subsequently introduce each of the axes of this PhD thesis.

1.3. Support by the State of the Art

The rationale that was developed in the previous section is empowered by a recent research presented in [6]. Within this research it is supported that users look for (web) services that not only can meet their requirements, but are also capable of performing the required functionalities with an acceptable degree of Quality of (web) Service. Quality of Service is a significant differentiator among the competing implementations. To this end, Quality of Service must transcend system-centric quality measures to encapsulate not only implementation details that may influence performance metrics, but also deployment and user-experience issues. As Al-Masri and Mahmoud (2009) have illustrated, Quality of (web) Service parameters are distinguished in two basic types of parameters; objective and subjective parameters. Objective parameters correspond to measurements that are concrete or quantitative. Subjective parameters correspond to qualitative measures, either based on the client's perception or regulated by the service provider.

In other words, this work [6], being a specialized instance, supports the two-fold idea developed in this thesis, which serves as a more generalized view of the Quality of Service investigation. Figure 1-2 illustrates a part of the identified Quality of Service parameters in [6].

On the one hand, the technoenomic analysis defines whether an investment on a new, more powerful technology that aims at improving Quality of Service for users, is not only technologically pioneer but also financially profitable. In this way, the objective parameters of Performance and Dependability are reinforced, as the system has better performance and is dependable, thanks to the better technology used. On the other hand, the Reputation of the system, counted by the ratings that the user has attributed the service with, represents user satisfaction when using this service. In this sense, being able to know user's opinion on the service, it may adapt in order to offer the service enhanced with the features requested. Ergo, the overall functionality of the system is improved.

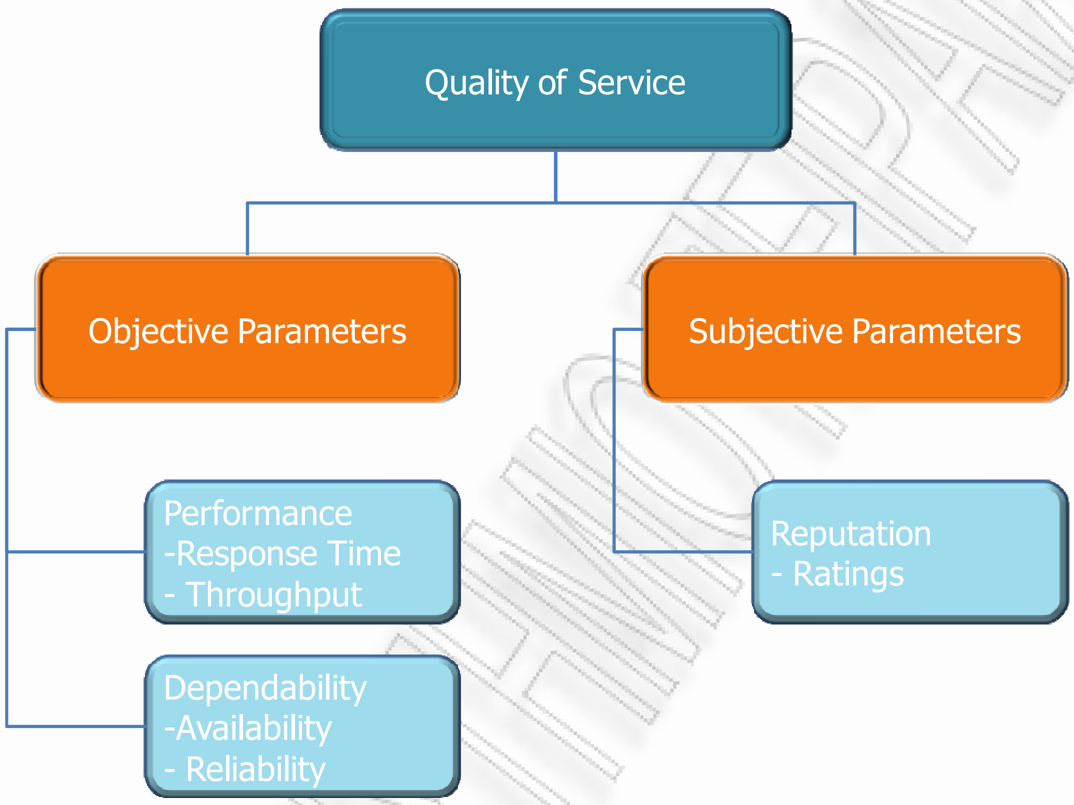

Figure 1-2: Part of basic Quality of Service parameters; objective and subjective parameters

Conclusively, this PhD thesis takes into consideration objective as well as subjective parameters, in order to make a globed analysis of the factors that influence Quality of Service in services and B3G networks and contribute to the enhancement of the system's functionality. These factors are namely the technoeconomic analysis and the user profile management of services and wireless B3G networks.

1.4. B3G Networks Overview

In today's telecommunications market a variety of new wireless access technologies with great potentials are available, as a result of numerous research and development activities as well as standardization bodies in the area of wireless networking solutions, like the 3GPP/3GPP2 (3rd Generation Partnership Project) [7], IEEE (Institute of

Electrical and Electronic Engineers) [8], WWRF (Wireless World Research Forum) [9], DVB [10], and IETF (Internet Engineering Task Force) [11]. The wireless access world as it is formed nowadays includes mobile communications (2G/2.5G/3G/3.5G), wireless local/metropolitan area networks (WLANs/ WMANs), wireless personal area networks (WPANs) and short range communications, as well as digital video/audio broadcasting (DVB/DAB).

One of the most recent trends in the area of wireless access communications is the migration towards the so called Beyond the Third (3^{rd}) Generation (B3G) era. The motivation is to exploit the available technologies in the most effective manner. The main concept behind B3G systems is that a Network Operator (NO) can operate and rely on networks with multiple, different radio access technologies (RATs), for achieving the required capacity and QoS levels, in a cost efficient manner. A NO can select the set of networks, potentially belonging to affiliated NOs, which are best suited for delivering agreed-upon business objectives, given the current service area conditions. Regarding this issue from the users' perspective, the supporting network technologies are irrelevant, as long as cost and appropriate business criteria (e.g., QoS, reliability, etc.) are fulfilled.

In order to accomplish this functionality, two complementary technologies have been developed; Composite Radio Networks [12] and Reconfigurable Networks [13], [14]. As illustrated in Figure 1-3, these two technologies may offer these services to users, based on both the requirements of each service and user's preferences.

Composite Radio networks, sometimes also referred to as cooperative networks, jointly handle a difficult condition. The main assumption is the collaboration between the RATs/ networks, so as to direct the traffic to the most appropriate RAT/ network of the Composite Radio infrastructure, according to service area regions, time zones, profile requirements and network performance criteria.

Reconfigurable Networks have the ability to dynamically adapt to the environment requirements and conditions, in principle, by means of self-management. Reconfiguration may affect all layers of the protocol stack, namely; the physical, MAC (Medium Access Control) and LLC (Logical Link Control), IP, transport, presentation, session and application layers.

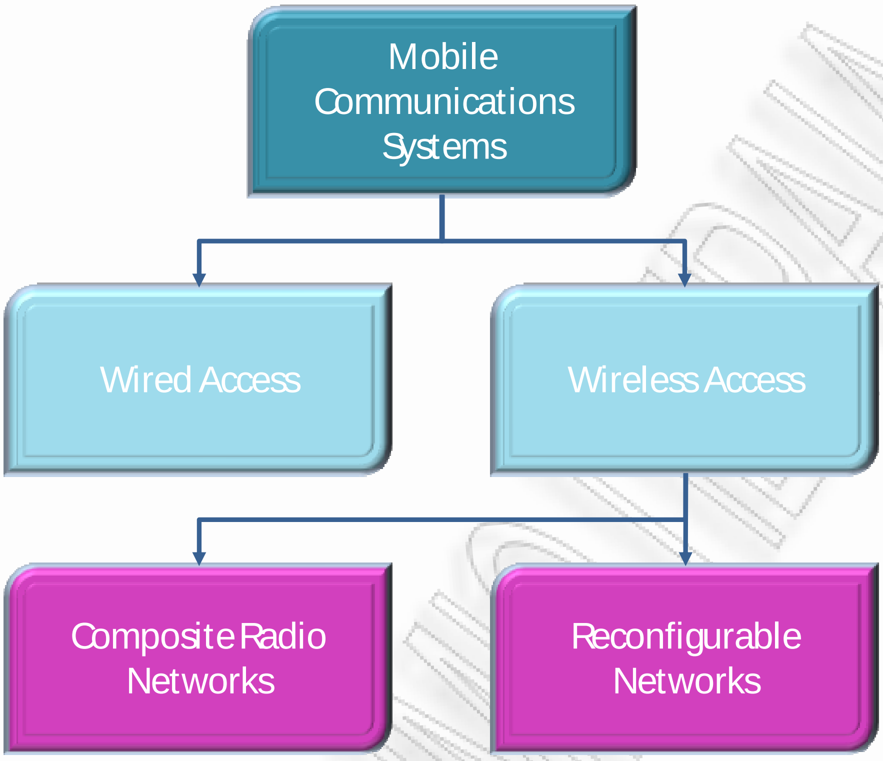

Figure 1-3: Mobile Communication Systems Analysis

One of the key features of Reconfigurable Networks are reconfigurable elements (terminals or network elements) that can operate with diverse alternate configurations, especially, RAT and spectrum at the PHY/MAC layers [13], [15]-[19] as depicted in Figure 1-4.

In other words, it is envisaged that reconfigurable elements will comprise reconfigurable transceivers capable of switching between a certain number of potential modes and operating at various frequencies in a dynamic, autonomous fashion.

In this sense it is essential to exploit the abilities provided by B3G Networks for creating applications and services that comply with users' requirements and preferences and are available ubiquitously, in the best terms regarding Quality of Service and system functionality improvement.

Thus, this thesis has elaborated, as mentioned in the previous, on technoeconomic analysis of B3G systems and user profile management in different contexts. The forthcoming sections provide information on each of the chapters that compose this thesis.

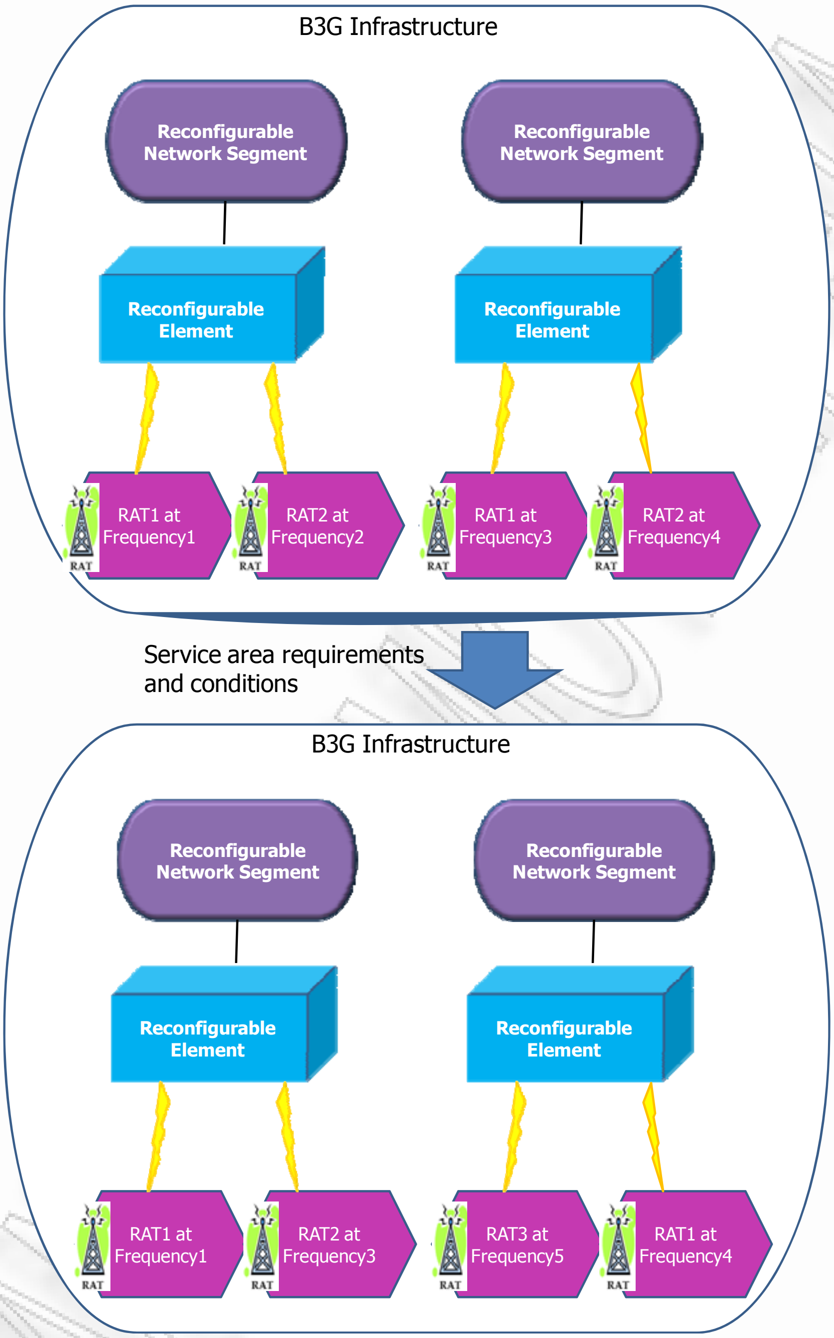

Figure 1-4: Reconfigurable elements concept

1.5. Technoeconomic analysis of B3G Infrastructures

As mentioned before, B3G infrastructures are in the centre of all technological achievements and researchers, organisations, networks managers and equipment manufacturer are working on them. For the successful adoption and establishment of these infrastructures it is very important to emphasise on the Quality of Service and the technoeconomic viability of the infrastructures, as an investment.

More particularly, high and stable Quality of Service delivery is a very important feature of the services that are made available through B3G infrastructures, contributing catalytically to *user's satisfaction*. It is more than obvious that when a user is satisfied regarding the kind and the quality of a certain service, then it is more likely that he is going to use this service again, establishing its use.

Moreover, the investment refund and amortization of a B3G network is essential as well. Such an infrastructure has to be robust, reliable and stable in covering users' needs. This means that the user is aware that the network he is using is reliable and able to satisfy users' needs and requirements whenever needed and thus, he keeps on using the service, making the service viable and profitable.

As already mentioned, Composite Radio networks have served as an excellent first step towards the realization of B3G systems. However, the implementation of a B3G infrastructure by means only of network co-operation may not be effective, especially on a long-term basis. In order for a NO to operate a multi-RAT network it may be necessary to massively deploy alternate radio networks.

The motivation for Reconfigurable Networks is to overcome some of the drawbacks associated with Composite Radio networks. More specifically, one of the most prominent aspects of Reconfigurable Networks is the fact that RAT management can be achieved through the deployment of software. For example, software can be invoked to activate the appropriate RAT, in the service area regions and time zones that face specific environmental conditions, which can be optimally handled by that specific RAT. When the environment conditions change, this RAT may be replaced with another that is better suited for supplying services under the changed environmental conditions. In this way, the service specifications will comply with user preferences, in terms of service personalization and adaptation to the specific requirements set by the user, enhancing the overall system functionality.

Therefore, it is essential to assess whether these technologies are not only capable of providing the user with the requested service in an efficient manner, but also there is the need to certify that a new technology is profitable and able to refund the investment amount of money.

In chapter 2, the main target is to assess both technologies' technoeconomic parameters, in order to be able to come to a scientific conclusion on whether Reconfigurable Networks make up an investment able to reimburse the money spent. Thus, the Net Present Value technique (NPV), which is one of the most popular tools for financial evaluation and is considered to be one of the most robust techniques for analyzing a variety of investment activities [24], is used in this case.

NPV consists of Capital Expenditure (CAPEX), Operational Expenditure (OPEX), Amortization (Depreciation), Taxation, Revenues and Discount Rate. These parameters are investigated for both cases. Results are presented for different cases and comparison is made, in order to have an orbicular view of the results produced.

1.6. Mobile Services

In the recent years a number of new and powerful wireless networking standards have emerged, as already introduced. More specifically, a key topic in the research area of B3G/4G networks is related to mechanisms and strategies to efficiently realize the collaboration between the different technologies and consequently their join use. The aim is to exploit the variety of the various available access standards to the benefit of manufacturers, operators and end-users.

The B3G concept introduces the idea of diverse, heterogeneous Radio Access Technologies (RATs) able to converge into one composite radio environment, where the user is "always best connected", while the most appropriate technology is selected and applied by the system seamlessly. Cognitive and reconfigurable wireless networks have appeared as a complementary concept to B3G networks, as already discussed. Cognitive systems determine their behavior, goals, principles, experience and knowledge, reactively or proactively and acting in response to external triggers [25]-[30].

Along with these technologies and in order to exploit the potentials they offer, new services have also been deployed. These services are made available through the internet [25]-[32] and aim at facilitating users' lives, replacing the user from being at a certain place and making a specific activity faster and easier. Therefore, mobile services are heralded to create a tremendous spectrum of business opportunities [33]. Mobile services have initiated as plain audio or text service delivery and have evolved to more complicated services, taking into consideration both context and fulfilling needs. Such services include e-banking, e-learning, e-business, e-market, e-government. Day by day users get to discover these services and use them as a tool to complete as many tasks as possible, facilitated by new technologies. Thus, user acceptance of these services is of paramount importance [33].

This means that the already developed web based systems make users' lives easier, saving them time and effort. *Personalization* applies to many aspects of peoples' lives and is a feature that enhances user's experience by adapting to his certain preferences, increasing his satisfaction.

In this way, a system may and, as inferred by the above, need to be properly modelled, in order to map user's preferences and needs. The information extracted is collected and may be used, in order to satisfy user's future requests for the same type of service. In other words, the system may use the historical data gathered from users past activity and exploit this knowledge so as to provide the user a more personalised service experience. This is achieved by storing the collected data appropriately coded in *User Profile* component. Therefore, the utilisation of the information collected for user's satisfaction is now feasible, ensuring Quality of Service, every time the user requests the specific service.

This is the main subject of chapter 3. It addresses user preferences modelling through the User Model component, aiming at recording user's activity. After specifying parameters which effect directly user's preferences and therefore user's satisfaction, the system makes use of two methodologies for evaluating the results and consequently user's satisfaction regarding with the Quality of Service provided; Bayesian Rating and Bayesian Networks. The results of these two methods are presented and discussed accordingly.

1.7. E-learning systems

As a consequence of the advent of new communication technologies, modern mass communication is no longer constrained by the traditional one-way, asymmetric communication medium, as presented previously. Today it is possible to present communication materials, which automate convoluted interaction with individuals. In this way, the ability to achieve symmetric communication is extended and the development of advanced e-learning systems (or platforms) [34]-[37] is accomplished. Moreover, evolved systems have the ability to adapt themselves in order to conform to each reader's unique characteristics, capacities, and preferences [38]-[40], while contemporary computer software technologies can project interactively-tailored content and formats according to the designer's intended purpose(s) [40]. This can be accomplished by means of electronic message presentation formats such as software engineering in combination with learning techniques [41].

In other words, it is important to combine knowledge elaborated on new technologies along with theories [41] that may distinguish user types and therefore have a criterion of the way a user learns best.

Yet, there is still a missing piece in this puzzle; personalization. It is important for a system to be able to identify user's separate, different, individual needs and be able to adapt to them. This is in direct relation to user's motivation for lifelong learning and, of course, satisfaction increase.

Personalization may be approached as a methodology to categorize user's unique needs, explore the ways to interact with the user in order to have feedback on his preferences on these unique needs and, in the end, configure the material and the system as a whole accordingly. Yet, it is important to be noted, that the interactivity and functionality necessary to be attributed to the system in order to learn users' preferences, must be carefully studied, structured and provided to the user. This happens as such systems are used not only by users with high acquaintance with technology and computers, but also novices that need specific guidance in order to concentrate on the material to be learnt and not the way an e-learning system works.

The benefits of this procedure are clear; users perceive better the material presented, their satisfaction is increased, they are motivated to continue using the system and therefore they are enhancing their knowledge and the use of the service is established. Therefore, e-learning systems [34]-[37] seem to gain ground constantly, as they allow users to access them at any time and place, at their own convenience.

The main concept dealt with in chapter 4 is the personalization and functionality structure within an e-learning system. The components of such a system's architecture are presented and discussed. Focus is on User Profile component, the parameters that compose it and how these parameters may enhance user's experience when using this system. Concepts from Bayesian Networks are used in order to present the results of the simulation of such a system.

1.8. Car-pooling (sharing) systems

Most of large cities of the world are today overcrowded with personal vehicles. This phenomenon has resulted in a never ending congestion state, which inevitably leads to high pollution, loss of time and money, degradation of quality of life, and a huge waste of non renewable fossil energy [45], [46]. Governments have understood that transportation inefficiency, as most vehicles only carry the driver, is a hurdle to sustainable development. This inefficiency is a good that could be addressed to us. In fact, such cities have a poor social fabric, as most people live alone or in a small family cell and consequently they face difficulties to extend their social circle and trust each other. Indeed, the idea of offering a passenger a place in his own car or willing to be transported by an unknown driver is something difficult to envisage, especially when both involved parties do not know enough about each other.

It sounds obvious that increasing the level of trust between people and allowing them to know more about each other, can be a key factor to the improvement of transportation efficiency [45], [47]. This community driven cooperative transportation is part of the vision of this chapter. It can only be enabled if an appropriate information technology (IT) system is offered to all citizens to use. This IT system would be utilized as a mean to create communities, to improve trust between people and to organize and supervise the transportation itself. Icing on the cake, such information available for the users also helps potential passengers to know more about the driver attitude and behavior, and vice versa. Therefore, while safety in car transportation is increased, some important information about the driver can be used for improving the level of mutual knowledge between the car driver and potential passengers.

Some countries have already taken action and, in order to address transportation inefficiency, they have introduced car-pooling systems [46], [48]. Such countries are the United States, Germany, Great Britain and of course Greece [49]-[56]. Yet these solutions are independent and have not received wide acceptance, yet.

Chapter 5 presents an integrated, community driven, mobility solution combining the concepts of communities, mobility and car pooling. More specifically, the idea of a car-pooling system that takes into consideration user characteristics and preferences regarding their transportation is presented. Furthermore, the architecture of such a system is presented, while emphasis is given on user personalization and system functionality. This is achieved by using objective function, a method to measure user's preferences on certain parameters. The methodology is analyzed and different scenarios and their according results are discussed.

1.9. Summary

As a result of all the previously mentioned, it is now clear that the scientific field of "Quality of Service Management in Future Multimedia Communication Systems" focuses on defining, analysing and evaluating the Quality of Service Parameters in New Services, using the B3G infrastructures. Quality of Service Parameters are the *Technoeconomic Analysis* for ensuring the economic viability and the investment amortization in B3G Networks and the *User Profile Management* for adapting each Service in each user's personal preferences and needs, so as to set this Service and make these Networks financially stable and profitable.

Recapitulating, this PhD thesis is moving on two axes; the *Evaluation and Technoeconomic Analysis for B3G Networks* and the *User Profile Management*, as stems from the previous analysis. Both axes aim at forming the best circumstances for users in order to increase their satisfaction. This is achieved by ensuring that Reconfigurable Networks comprise a remunerative investment, as this technology has the ability to adapt to users preferences according to the service and the context. Moreover, User Profile is gone through, analysing its parameters in three different cases; mobile services (as a generalised service), e-learning and transportation. This User Profile components analysis targets to achieve the maximum possible user's satisfaction, improving system's functionality.

The structure of each chapter presented hereinafter is as follows; initially, the problem and its definition are presented, the solution of the problem ensues and the respective results produced from the solution application compose the structure followed for each of the axes of this thesis.

1.10. Chapter References

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2. TECHNOECONOMIC ANALYSIS AND EVALUATION OF B3G INFRASTRUCTURES

Abstract

The B3G concept can be realized in two complementary ways. The first solution is the integration of the diverse radio access technologies into one Composite Radio environment. The alternative solution is provided by the concept of Reconfigurable (adaptive) Networks. Composite Radio networks, sometimes also referred to as cooperative networks, jointly handle a difficult condition. Reconfigurable Networks on the other hand, support B3G Systems by providing technologies that enable network elements and terminals to dynamically adapt to the environment requirements and conditions, in principle, by means of self-management. This chapter provides proof on the business advantages of Reconfigurable Networks. In this context, the chapter performs an evaluation of the investment in both Composite Radio and Reconfigurable Networks, presenting a methodology that can be used for the financial assessment of such networks by applying investment appraisal techniques. Concrete results, produced by different scenarios, for both cases are presented and analyzed. The analysis clearly proves that Reconfigurable Networks can provide significant business benefits for Network Operators, as well as users, enhancing their experience within a service provided through them and increasing their satisfaction.

Keywords

CAPEX, Composite Radio Networks, Net Present Value, OPEX, Reconfigurable Networks

2.1. Introduction

As presented previously, one of the most recent trends in the area of wireless access communications is the migration towards the so called Beyond the 3rd Generation (B3G) era. The motivation is to exploit the available technologies in the most effective manner. The main concept behind B3G systems is that a Network Operator (NO) can operate and rely on networks with multiple, different radio access technologies (RATs), for achieving the required capacity and Quality of Service (QoS) levels, in a cost efficient manner.

The B3G concept can be realized in two complementary ways. The first solution proposed was the integration of the diverse radio access technologies into one Composite Radio environment [1]. More recently, the concept of Reconfigurable (adaptive) Networks has been proposed [2], [3].

Composite Radio networks have served as an excellent first step towards the realization of B3G systems. However, the implementation of a B3G infrastructure by means only of network co-operation may not be effective, especially on a long-term basis. In order for a NO to operate a multi-RAT network it may be necessary to massively deploy alternate radio networks. This leads to great increases in capital expenditures (CAPEX), whenever new technologies are introduced. It should also be considered that not all technologies are suitable for all conditions. Therefore, in some time-zones or areas, part of the infrastructure for new technologies may not be required to be "active", as they exhibit low utilization, even though these technologies may have been acquired at a high cost.

The motivation for Reconfigurable Networks is to overcome some of the drawbacks associated with Composite Radio networks. More specifically, one of the most prominent aspects of Reconfigurable Networks is the fact that RAT management can be achieved through the deployment of software. For example, software can be invoked to activate the appropriate RAT, in the service area regions and time zones that face specific environmental conditions, which can be optimally handled by that specific RAT. When the environment conditions change, this RAT may be replaced with another that is better suited for supplying services under the changed environmental conditions. Therefore, massive deployment of network elements and hardware components is not required, and thus the associated CAPEX is reduced.

From the short analysis in the previous, it can be deduced that the deployment of Reconfigurable Networks can bring important business benefits for a Network Operator. An initial analysis of the business perspectives of end-to-end Reconfigurable Networks has been performed in [4], where a Business Systems Architecture Process (BSAP) methodology was introduced in addition to a unified business model (UBM) for Reconfigurability.

The aim of this work (which can be seen as complementary to the work in [4]) is to provide concrete proof on the business advantages of Reconfigurable Networks. In this context, within this chapter an evaluation of the investment in both Composite Radio and Reconfigurable Networks is performed. First, some fundamentals on investment evaluation are presented. This is followed by the business case analysis and the respective parameters taken into account in this work. Furthermore, the application of the investment evaluation tool in specific case studies for Composite Radio and Reconfigurable Networks and the analysis of the corresponding results are presented.

2.2. Investment Evaluation Aspects

Investment evaluation or investment appraisal refers to the analysis process used to determine whether a firm should undertake an investment activity, considering the expenses required and the estimated future benefits deriving from the investment.

Several formal methods exist for investment appraisal such as Net Present Value, Internal Rate of Return, Payback Period, Profitability Index, etc [5], [6]. This analysis focuses on the Net Present Value technique, which is one of the most popular tools for financial evaluation and is considered to be one of the most robust techniques for analyzing a variety of investment activities [7]. In the following section some general aspects on the Net Present Value will be presented.

2.2.1. Net Present Value Definition

The Net Present Value (NPV) of an investment is defined as the sum of the present value of the annual cash flows produced by the investment minus the initial expenses for the investment. The annual cash flow is in essence the sum of incoming and outgoing money in the specific year, or in other words the annual net benefit.

In order to calculate the present value of these cash flows, the revenues and expenses are discounted by the same factor, which represents the capital cost of the firm. This transformation of revenues (incoming cash flows) and all expenses (outgoing cash flows) of the investment into their present values deduces that the Net Present Value technique expresses the net profit or cost in the specific time the decision is made.

The process of calculating the NPV for a specific investment comprises three main steps [7]. The first step is to estimate the annual cash flows for the investment, i.e. the revenues and expenses for each year of the investment period. The second step is to determine the discount rate that will be used to calculate the present value of the cash flows. Finally, in the third step, the NPV is calculated using the cash flows and discount rate specified in the previous two steps.

The generic formula used for the calculation of net present value is ([8], [9]):

$$NPV = \sum_{i=0}^{n} \frac{CF^i}{(1+r)^i} - Initial\,Investment \qquad (1)$$

Where:

- n is the investment period, i.e. the number of years for the investment analysis,
- CF^i is the net cash flow (revenues minus expenses) of year ι,
- r is the discount rate,
- $Initial\ Investment$ corresponds to the initial expenses at the start of the investment.

2.2.2. Cash Flows

The first step for the computation of the NPV is to define the annual cash flows, as was introduced in the previous. The annual cash flows are computed as the expenses subtracted from the benefits (i.e. revenues) for each year of the investment project [8][9].

2.2.2.1 Expenses

Two main categories of expenses should be taken into account for the calculation of cash flows and the NPV; the expenses for acquiring and upgrading any physical assets required for the investment and the expenses necessary for maintaining this investment.

These are Capital and Operational Expenditure, respectively. This sub-section analyzes this type of expenses and examines the way they influence the investment.

Capital Expenditure (CAPEX) refers to the initial investment for installing technology and the necessary infrastructure, the operational software, as well as the additional investments during the years for upgrading the system or supporting increased capacity [8].

In the current analysis CAPEX is mainly considered as the cost of setting up radio sites, which can be further analyzed as the product of the number of radio sites required and the expenses for hardware, software and installation required for each radio site.

Operational Expenditure (OPEX) concerns the expenses to preserve and operate the system, to maintain/ acquire potential software licenses, as well as costs for system reconfiguration [8], [9]. Following the classification of operational expenditures in [10], in the subsequent analysis it is considered that the annual OPEX primarily comprises the network operation and maintenance costs, continuous cost of infrastructure and provisioning and service management costs.

It should also be noted that expenses and thus cash flows are implicitly influenced by taxation. Therefore taxes that will be charged to the investment are a form of indirect expense.

2.2.2.2 Revenues

The main source of benefits, used for the calculation of the Net Present Value, in the case of telecommunication networks are the revenues from users/subscribers. Revenues from users or subscribers for a specific year of the investment are calculated as the product of the annual Average Revenue Per User (ARPU) and the predicted number of users for that year.

2.2.2.3 Amortization/ Depreciation

If a company purchases a capital asset of a certain value at year t, this expenditure is not considered to influence the expenses of year t, but is allocated over the following years in a way that is usually specified by tax legislation. Usually, each category of capital asset legislation defines a number of years over which the asset is deduced, considering an annual expense that equals the value of the asset divided by the number of years. This deduction of the capital expenses over a period of time (in this case the time horizon of the investment) is called amortization or depreciation [8], [9].

The annual amortization is deducted from operation benefits of the specific year, when accounting profits and considering that payable tax is a function of accounted profits, amortization reduces annual taxes. Therefore, by reducing the annual tax, amortization implicitly influences the cash flow for a specific year.

The most straightforward and frequently used method to calculate amortization or depreciation is the straight line method [11], where the distribution of the capital expense for the asset over the amortization years is done by dividing the initial expense in equal annual amounts.

2.2.3. Discount Rate

The discount rate used in the calculation of the NPV, also referred to as rate of return or company cost of capital, is usually defined by calculating the rate that the capital required for the investment could return if it were invested in an alternative project with similar risks [7].

One way to calculate the expected return of an investment is the Capital Asset Pricing Model (CAPM), which defines a relationship between the risk of an investment for a company and the expected return of the investment [12].

More specifically according to the CAPM formula the expected rate of return for an asset $\overline{r_a}$ is defined as:

$$\overline{r_a} = r_f + \beta \cdot \left(\overline{r_m} - r_f \right) \tag{2}$$

where:

- r_f is the risk-free premium, in other words the rate for a zero-risk investment,
- β is the beta of the security, which is a measure of the volatility of a portfolio (a collection of investments) compared to the rest of the market. Beta is calculated for individual companies using regression analysis [9],
- $\overline{r_m}$ is the expected market return,

- $\left(\overline{r_m} - r_f\right)$ is the equity risk premium, that is, the difference between the average premium for the market and the risk free premium.

2.2.4. Net Present Value Formula Used in the Analysis

In the previous, the various factors that influence the value of the NPV for telecommunication networks were presented, namely Capital Expenditures (CAPEX), Operational Expenditures (OPEX), revenues, amortization and taxation.

Taking these factors into account in the generic formula for the NPV (1), the formula for the calculation of the NPV can be formulated as follows [12]:

$$NPV = -I_X - \sum_{i=1}^{n} \frac{(CPX_X^i - \tau \cdot A_X^i)}{(1+r)^i} + \sum_{i=1}^{i=n} \frac{(R_X^I - \tau \cdot R_X^I)}{(1+r)^i} - \sum_{i=1}^{n+1} \frac{O_X^i}{(1+r)^i} + \sum_{i=2}^{n+1} \frac{\tau \cdot O_X^i}{(1+r)^i} \quad (3)$$

Where:

- X refers to the investment analysed each time; in the current analysis the investments considered are in Composite Radio or Reconfigurable Network systems,
- I_X is the initial investment for investment X ,
- CPX_X^i is the CAPEX at year i for investment X ,
- A_X^i is the amortization for the CAPEX at year i for investment X ,
- τ is taxation rate,
- R_X^i is the amount of revenues derived from users at year i for investment X ,
- O_X^i is the operational cost (OPEX) for investment X , at year i ,
- n is the timeline for the investment,
- r is the discount rate.

The aforementioned formula will be used in the following for the evaluation of the Composite Radio and Reconfigurable Networks investment projects.

2.3. Business Case

In order to be able to properly compare the investment in Composite Radio and Reconfigurable Networks it is preferable to use the same values for some parameters /

inputs to the respective NPV calculations. This section presents some general assumptions that apply to both investment ventures and sets the framework that will be used for the analysis.

The analysis focuses on a Network Operator of a typical Western European country that is in the possession of licenses for the simultaneous operation of various wireless access technologies. More specifically, in this analysis two wireless standards are considered, namely UMTS and WiMAX. The Network Operator has two main options for the deployment of his infrastructure. The first option is the set-up of a Composite Radio network comprising various distinct hardware elements corresponding to the different technologies. The second option is to set up a Reconfigurable Network consisting of reconfigurable elements, i.e., elements with reconfigurable transceivers capable of operating more than one wireless access standard at the same time. In the current analysis, *three* transceivers per radio site are assumed.

The investment horizon considered is 10 years and spans over the years 2008-2017.

2.3.1. Service Area and Network Dimensioning

A service area is considered that comprises a certain number of cells/ radio sites. An initial surface of roughly 950 Square Kilometres is assumed. The number of radio sites is derived by dividing the surface of the considered service area by the cell area. The cell area corresponds to a regular hexagon surface with a radius of approximately 1,3 Kilometres. It is considered that each year there is an extension to the surface of the service area covered and thus a corresponding upgrade in the network, in order to increase capacity and support higher demand.

The number of required radio sites per year is summarized in Table 2-1.

Table 2-1: Radio sites required per year

Number of radio sites required	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Cumulative	220	234	247	261	275	288	302	316	330	343
Incremental	220	14	13	14	14	13	14	14	14	13

Over the years of the investment, different demand patterns are assumed for each radio site. Nine demand cases are considered where users request two types of services according to different corresponding patterns. Users are uniformly distributed in the service area. A certain percentage of video and voice sessions are associated with each demand pattern, as depicted in Table 2-2. Application profiles show that the voice service should be provided at *16 kbps*, and video service at *32*, *64*, *128* or *256 kbps*.

Table 2-2: Demand patterns

Demand patterns	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9
Voice	95%	85%	75%	65%	55%	45%	35%	25%	15%
Video	5%	15%	25%	35%	45%	55%	65%	75%	85%

In order to effectively serve the user demand, it is required to decide for each radio site what the most appropriate configuration pattern is, i.e. which combination of wireless technologies should be used to offer the required services. The most appropriate reconfiguration for a specific radio site is selected and enforced by appropriate management functionality for Reconfigurable Networks [13], [14].

In general, for a radio site the following possibilities exist: to provide services only over UMTS or to provide services through the combination of UMTS and WiMAX. It should be noted that the operator prefers to serve the main volume of voice sessions over UMTS, while only a small percentage of such sessions will be served by WiMAX. Therefore, the use of only WiMAX for a specific radio site is not considered.

The possible configurations for a radio site and the corresponding options in terms of hardware elements for the case of Composite and Reconfigurable Networks is summarized in Table 2-3.

Table 2-4 presents the most appropriate configuration for each demand pattern derived from management functionality for Reconfigurable Networks [13], [14].

Table 2-3: Possible configurations and corresponding hardware requirements for Composite and Reconfigurable Networks

Possible configurations for a radio site	Composite Radio network options	Reconfigurable Networks options
3 UMTS transceivers (UUU)	1 UMTS element with 3 transceivers (***U3 Base Station***)	1 reconfigurable element (Base Station) with 3 transceivers, where all 3 transceivers are configured to operate in UMTS
2 UMTS transceivers and 1 WiMAX transceiver (UUW)	1 UMTS element with 2 transceivers (***U2 Base Station***) and 1 WiMAX Base Station	1 reconfigurable element (Base Station) with 3 transceivers, where 2 transceivers are configured to operate in UMTS and 1 transceiver is configured to operate in WiMAX
1 UMTS transceiver and 2 WiMAX transceivers (UWW)	1 UMTS element with 1 transceiver (***U1Base Station***) and 2 WiMAX Base Stations	1 reconfigurable element (Base Station) with 3 transceivers, where 1 transceiver is configured to operate in UMTS and 2 transceivers are configured to operate in WiMAX

Table 2-4: Configuration selected per demand pattern

Demand pattern	Configuration
Case 1	UUU
Case 2	UUU
Case 3	UUW
Case 4	UUW
Case 5	UUW
Case 6	UUW
Case 7	UUW
Case 8	UWW
Case 9	UWW

For the first 2 cases of demand patterns where voice sessions dominate, configuration UUU is the only feasible one. As video sessions increase, and voice traffic decreases, a note-worthy superiority of the configuration combining UMTS and WiMAX (UUW) can be observed. Two UMTS transceivers are adequate for serving voice, as well as video sessions outside the range of the WiMAX transceiver for case 3 to 7. The WiMAX transceiver can be dedicated to offering higher QoS, with respect to cases 1 and 2, to video sessions in its coverage range. Finally, at certain traffic mixtures with a low percentage of voice and a high percentage of video sessions, configuration UWW exhibits the best performance, which applies for cases 8 and 9.

It is considered that over the years a percentage of radio sites faces different cases of demand patterns (Table 2-2) and is thus configured accordingly (Table 2-4).

Table 2-5: Percentage of radio sites facing a specific demand pattern and thus a corresponding configuration

Configuration pattern	**UUU**	**UUU**	**UUW**	**UUW**	**UUW**	**UUW**	**UUW**	**UWW**	**UWW**
Demand patterns	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**	**Case 9**
2008	50%	50%							
2009	40%	40%	20%						
2010		70%	20%	10%					
2011			60%	20%	20%				
2012				60%	20%	20%			
2013					55%	25%	20%		
2014						55%	25%	20%	
2015							60%	20%	20%
2016							55%	25%	20%
2017							50%	25%	25%

This percentage of radio sites with a specific configuration for a certain year corresponding to the demand pattern that has to be supported is presented in Table 2-5. For example, the first row of Table 2-5 shows that in 2008, 50% of the radio sites face a demand pattern corresponding to case 1 of Table 2-2 and the other 50% face a demand pattern corresponding to case 2 of Table 2-2. Based on the most appropriate configuration for each demand pattern, as selected by the appropriate network management functionality (Table 2-4), the configuration for all radio sites in year 2008 is the UUU configuration.

Finally, combining the number of required radio sites per year (Table 2-1) and the percentage of radio sites with a specific configuration (Table 2-5) the number or radio sites with a specific configuration can be derived. More specifically, the number of radio sites with a specific configuration can be found by multiplying the number of sites required and the percentage of sites per year facing a certain demand. The following formula represents this relation:

$$\#ofSitesWithSpecificConfig = \#ofSites_{Req} \cdot \%ofSites_{PerYear,CertainDemand} \qquad (4)$$

In this way Table 2-6 is formed as follows:

Table 2-6: Number of radio sites with a specific configuration

Configuration pattern	UUU	UUU	UUW	UUW	UUW	UUW	UUW	UWW	UWW
2008	110	110							
2009	94	94	47						
2010		173	49	25					
2011			157	52	52				
2012				165	55	55			
2013					158	72	58		
2014						166	76	60	
2015							190	63	63
2016							182	83	66
2017							172	86	86

By combining the data in Table 2-3 and Table 2-6, the hardware requirements for Composite Radio and Reconfigurable Networks can be derived. These directly affect the expenses for each year of the respective investment, as will be presented in the following.

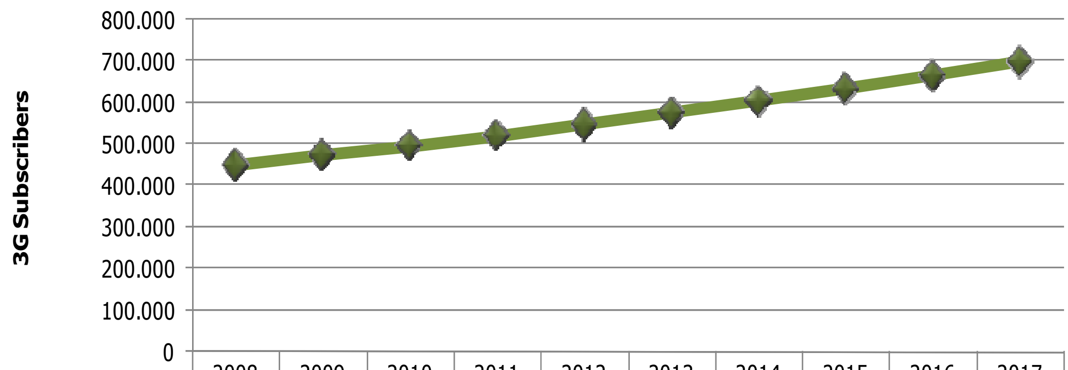
2.3.2. Subscriber and Revenue Information

Based on wireless market analysis reports such as [14] it can be observed that in typical Western European countries such as UK, Italy, France, Germany and Spain, for an average subscriber population of 57,76 million there is an average of 2,28 million of 3G subscribers. Considering a regular operator with a 20% market share, it can be realistically assumed that the number of 3G subscribers for such an operator is approximately 450.000.

In other words, the number of the operator 3G subscribers is calculated as the product of the number of 3G subscribers and the market share:

$$\#Operator3GSubscribers = \#3GSubscribers \cdot MarketShare \qquad (5)$$

(This number of 3G subscribers can be assumed to be served by a 3G mobile network such as UMTS).



2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
450.000	472.500	496.125	520.931	546.978	574.327	603.043	633.195	664.855	698.098

Figure 2-1: Subscriber information of the Network Operator

Considering an annual growth rate of 5% for the 3G subscriber population the estimated number of corresponding users for the operator for the period 2008-2017 is presented in Figure 2-1. It can further be considered that initially a percentage of the 3G subscribers of the operator will subscribe for services offered over the B3G infrastructure, i.e. either the Composite Radio or the Reconfigurable Network. This percentage is the *"B3G penetration rate"* which is used to denote the number of operator B3G subscribers within the operators' 3G subscriber population. More specifically, based on this penetration rate, an annual number of B3G subscribers can be derived so as to calculate the estimated revenues per year. Here, it is assumed that *the penetration rate* for B3G services for the specific operator is 5% per year. In other words, the annual number of B3G subscribers in the service area addressed, equals 5% of the 3G subscribers. In summary, the number of B3G subscribers of the operator is calculated as follows:

$$\#OperatorB3GSubscribers = \#Operator3GSubscribers \cdot B3GPenetrationRate \qquad (6)$$

The estimation on the number of *B3G* subscribers is summarized in Table 2-7. Table 2-7 also presents the assumed monthly Average Revenue per User (ARPU), based on data in [15].

The data in Table 2-7 is used for the computation of the revenues per year.

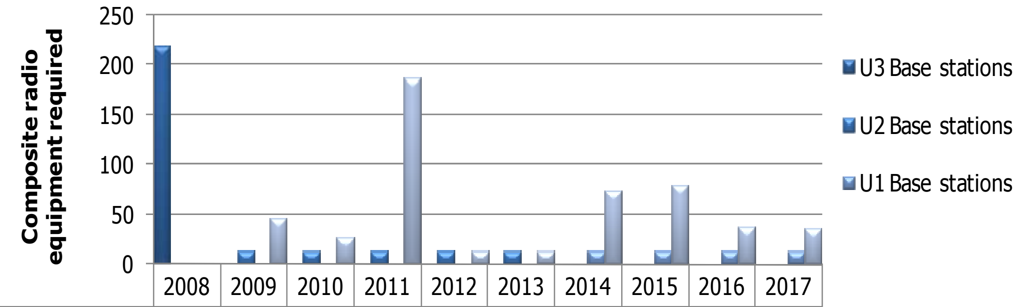
Table 2-7: B3G Subscribers and ARPU

Year	Number of B3G subscribers	ARPU per month
2008	22.500	26,00 €
2009	23.625	26,00 €
2010	24.806	27,00 €
2011	26.046	27,00 €
2012	27.348	28,00 €
2013	28.716	28,00 €
2014	30.152	28,00 €
2015	31.659	29,00 €
2016	33.242	29,00 €
2017	34.904	29,00 €

More specifically, the annual ARPU is obviously calculated by multiplying the ARPU per month by 12. This, additionally multiplied with the number of the operator B3G subscribers, gives the Revenues per year:

$$Revenues_{PerYear} = OperatorB3GSubscribers \cdot (ARPU_{PerMonth} \cdot 12) \qquad (7)$$

The calculated annual revenues are depicted in Figure 2-2.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
U3 Base stations	220	0	0	0	0	0	0	0	0	0
U2 Base stations	0	14	13	14	14	13	0	0	0	0
U1 Base stations	0	0	0	0	0	0	14	14	14	13
WiMAX Base stations	0	47	27	187	14	13	74	80	37	36

Figure 2-2: Annual Revenues

2.3.3. Discount Rate

For the calculation of the discount rates the following values have been used for the parameters of the CAPM formula (2) [12].

- $r_f = 4.04\%$, which is the combination of a real risk free premium of 2% and an inflation rate of 2%,
- $\left(\overline{r_m} - r_f\right) = 2.3\%$,
- $\beta = 1.35$.

With the above parameters, which are typical of a mobile operator in a large Western European country, the resulting discount rate is ***7.145%.***

2.4. NPV Elements Calculation Analysis

2.4.1. CAPEX

CAPEX for both Composite Radio and Reconfigurable Networks is calculated as the sum of Base Stations (BS) per year, and Customer Premises Equipment (CPE) costs per year, as depicted in formula (8).

$$CAPEX = BSCost_{PerYear} + CPECost_{PerYear} \tag{8}$$

The BS cost per year for Composite Radio networks depends on the number of different elements required for each radio site. As was introduced in section 2.3.1, for each radio site a certain configuration is specified through appropriate network management functionality (Table 2-6). In the case of Composite Radio networks this configuration influences the number of elements required per technology for each radio site (Table 2-3). More specifically, the number of different types of equipment required for Composite Radio networks (U3, U2, U1, and WiMAX) is derived as a function of the number of sites with a specific configuration per year and the number of elements per type required for the specific configuration.

The BS cost per year for Composite Radio networks is calculated as the sum of total cost for each type of equipment required. This in turn is calculated as the number of the required equipment multiplied with the corresponding total cost for the specific equipment type. The calculation of the BS cost per year for Composite Radio networks is represented by the following formula:

$$\begin{aligned} CompositeRadioBSCost_{PerYear} = {} & \#ofU3BS_{Req} \cdot U3BSTotalCost \\ & + \#ofU2BS_{Req} \cdot U2BSTotalCost \\ & + \#ofU1BS_{Req} \cdot U1BTotalCost \\ & + \#ofWiMAXBS_{Req} \cdot WiMAXBSTotalCost \end{aligned} \tag{9}$$

Similarly to Composite Radio, the BS cost per year for Reconfigurable Networks is calculated as the product of the number of Reconfigurable Base Station required and the Reconfigurable Base Station Total Cost.

$$ReconfNetBSCost_{PerYear} = \#ofReconfBS_{Req} \cdot ReconfBSTotalCost \tag{10}$$

As was mentioned in section 2.3.1 (Table 2-3) one reconfigurable element is sufficient to support any configuration. This means that there is a one-to-one correspondence between the number of radio sites per year and the number of reconfigurable base stations required. Customer Premises Equipment Costs (second factor of formula (8)) are calculated in the same manner for both Composite Radio and Reconfigurable Networks. The number of CPE required per year corresponds to the number of the operator B3G subscribers for that year. The annual CPE cost, is the product of the number of CPE required and the cost per CPE.

$$CPECost_{PerYear} = \#ofCPE_{Req} \cdot CostPerCPE \qquad (11)$$

2.4.2. OPEX

OPEX is calculated in the same way for both Composite Radio and Reconfigurable Networks and it is defined as the sum of the Network Operation and Maintenance, Continuous Cost of Infrastructure and Service Provisioning and Management [10], as presented in formula (12):

$$\begin{aligned} OPEX = & \ Network\ Operation\ \&\ Maintenance + \\ & Continuous\ Cost\ Of\ \ Infrastructure + \\ & Service\ Provisioning\ \&\ Mngnt \end{aligned} \qquad (12)$$

Analyzing the above mentioned factors, Network Operation and Maintenance (NOM) is defined as the product of the number of radio sites required and the Network Operation and Maintenance cost per site.

$$NetworkOperation\ \&\ Maintenance_{PerYear} = \#ofRadioSites \cdot NOM\ CostPerSite \qquad (13)$$

The second factor of the formula (12) is the product of the number of radio sites and Continuous Cost per Site.

$$Continuous\ \ Cost\ \ of\ \ Infrastructure_{PerYear} = \#ofRadioSites \cdot ContinuousCostPerSite \ (14)$$

The third factor of formula (12) is given by the product of the number of Operator B3G Subscribers and the Cost per B3G Subscriber, which is the (average) service and provisioning cost per subscriber.

$$ServiceProvisioning\ \&\ Mngnt_{PerYear} = \#OperatorB3GSubscrs \cdot CostPerB3GSubscr \ (15)$$

2.4.3. Revenues

Revenues are calculated as was presented in section 2.3.2. The procedure for calculating Revenues applies for both Composite Radio as well as Reconfigurable Networks.

2.4.4. Amortization

Amortization for Composite Radio and Reconfigurable Networks is calculated following the procedure described hereinafter.

For the first year of the investment the amortization is calculated by dividing the CAPEX of the same year with the number of the years of the investment, as presented in the following formula.

$$Amortization_{FirstYear} = \frac{CAPEX_{SameYear}}{\#ofYears_{oftheInvestment}} \tag{16}$$

For the remaining years amortization is equal to the sum of the amortization of the previous year plus the quotient of the CAPEX of the same year and the number of remaining years of the investment, as the following formula depicts.

$$Amortization = Amortization_{PreviousYear} + \frac{CAPEX_{SameYear}}{\#ofYears_{oftheInvestment} - \#ofPreviousYears} \tag{17}$$

2.5. Results of Evaluation of Investment in Composite Radio and Reconfigurable Networks

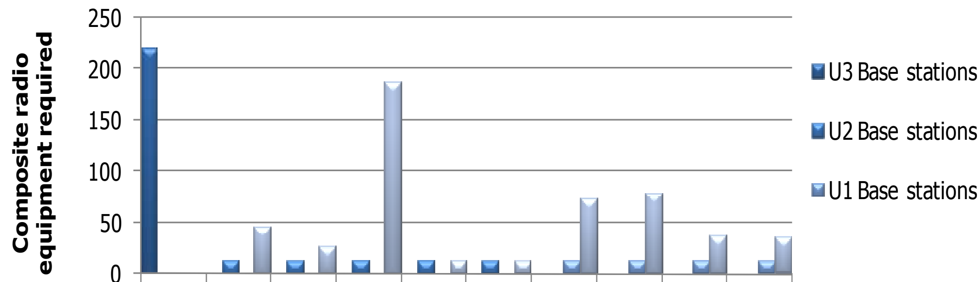
This section presents results derived from the calculation of the NPV for Composite Radio and Reconfigurable Networks for various cases. The impact of the various factors that influence the calculation of the NPV is investigated. The presentation of the results starts with a simple scenario, where slightly lower OPEX is assumed for Reconfigurable Networks (Section 2.5.1). Section 2.5.2 presents the NPV results where it is assumed that both solutions have the same OPEX. Section 2.5.3 addresses the case where increased (compared to the initial scenario) CAPEX values are assumed for Reconfigurable Networks. Section 2.5.4 presents results for the case where increased values for both CAPEX and OPEX are considered for Reconfigurable Networks. In Section 2.5.5 results for the case of upgrading an existing network infrastructure are provided. It can be argued that tax and amortization effects differ between countries and therefore may influence the final NPV assessment in a diverse way. Therefore, for all cases, results are also presented, where tax and amortization effects are excluded from the NPV formula.

2.5.1. Case 1: Lower OPEX for Reconfigurable Network

2.5.1.1 Composite Radio Network

CAPEX

As mentioned in Section 2.4, CAPEX depends on the number of radio sites used in the system. Furthermore, the configuration of each radio site can be mapped to specific requirements in infrastructure elements. These requirements for Composite Radio networks are presented in Figure 2-3.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
U3 Base stations	220	0	0	0	0	0	0	0	0	0
U2 Base stations	0	14	13	14	14	13	0	0	0	0
U1 Base stations	0	0	0	0	0	0	14	14	14	13
WiMAX Base stations	0	47	27	187	14	13	74	80	37	36

Figure 2-3: Equipment required for the Composite Radio infrastructure per year

The cost per type of equipment is presented in detail in Table 2-8.

Table 2-8: Cost of equipment for Composite Radio infrastructure

Type of equipment	Hardware cost	Software cost	Installation cost	Total cost
UMTS Base Station with 3 Transceivers	16.000 €	8.000 €	6.000 €	30.000 €
UMTS Base Station with 2 Transceivers	15.000 €	7.000 €	6.000 €	28.000 €
UMTS Base Station with 1 Transceiver	14.000 €	6.000 €	6.000 €	26.000 €
WiMAX Base Station	20.000 €	10.000 €	6.000 €	36.000 €

Furthermore, the cost per CPE for this case is considered to be equal to 100 €. Consequently, also taking into account the CPE costs ((11)), the CAPEX for the Composite Radio solution is formed as presented in Figure 2-4.

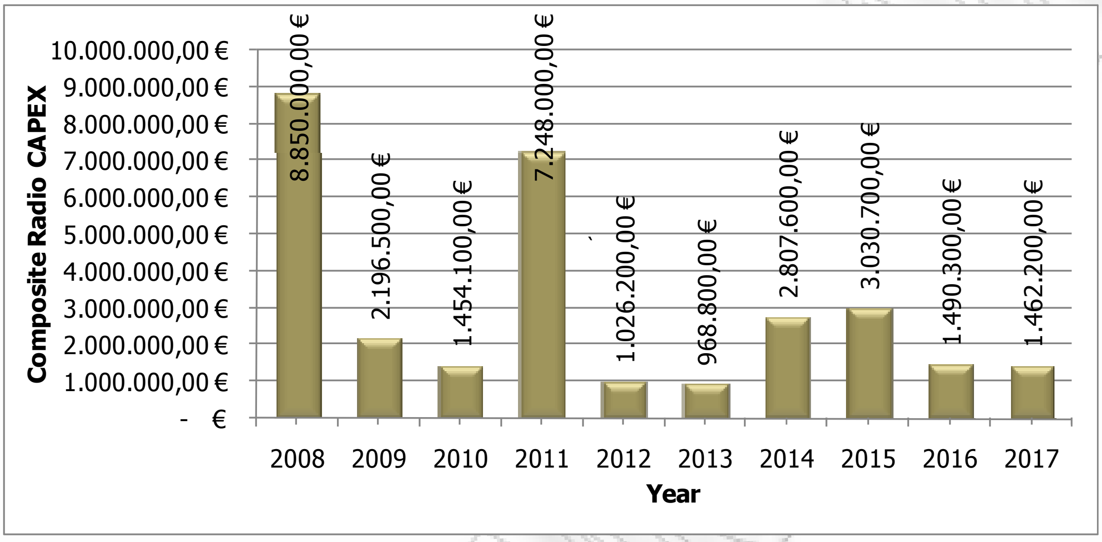


Figure 2-4: Composite Radio CAPEX

OPEX

The OPEX for the Composite Radio network over the years 2008-2017 is presented in Figure 2-5.

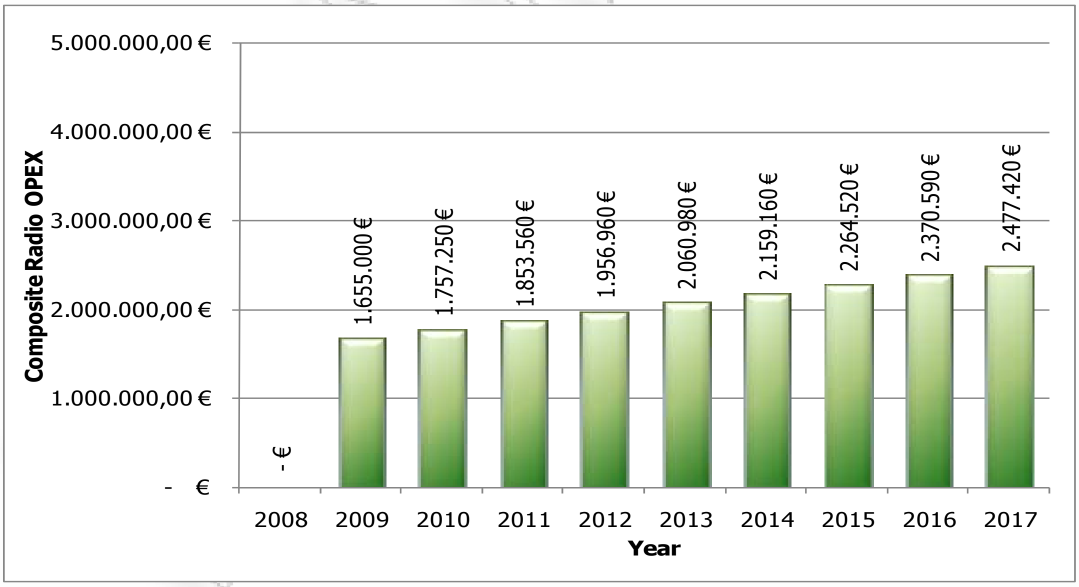


Figure 2-5: Composite Radio OPEX

More specifically, the considered Network Operation and Maintenance is 3.500 € per site, the Continuous Cost of Infrastructure is 3.000 € per site and the Service Provisioning and Management Cost is 10 € per subscriber. It should be noted that for the first year of the investment horizon the OPEX is considered to be 0 as no operational expenses have occurred yet.

Amortization

Using straight depreciation for capital expenses for each year, following the process presented in section 2.4.4, amortization for a Composite Radio network is as illustrated in Figure 2-6.

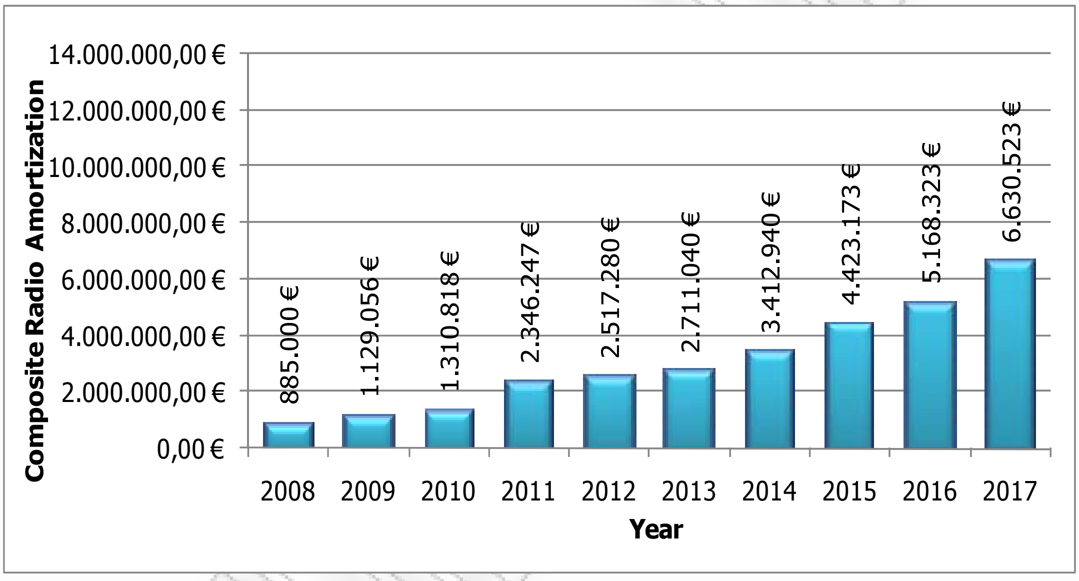


Figure 2-6: Composite Radio Amortization

In order to compute the NPV for the Composite Radio solution, the data presented in the previous, is used as input for the NPV formula (3) introduced in section 2.4. More specifically, the Revenues, CAPEX, OPEX and Amortization data presented in Figure 2-2, Figure 2-4, Figure 2-5 and Figure 2-6 respectively are used. Furthermore, the discount rate (as calculated in section 2.3.3) has a value of 7.145, while the tax rate τ is considered to be 30%. The outcome of the calculations is that **the Net Present Value for the Composite Radio solution is 17.443.584 €**.

In order to have a clearer picture of the NPV tax and amortization effects are excluded from the NPV formula. **The Net Present Value for the Composite Radio solution**

without taking into account the effects of **taxation and amortization is 27.695.138 €**.

2.5.1.2 Reconfigurable Networks

CAPEX

The requirements for infrastructure elements for the case of an investment in Reconfigurable Networks are presented in Figure 2-7.

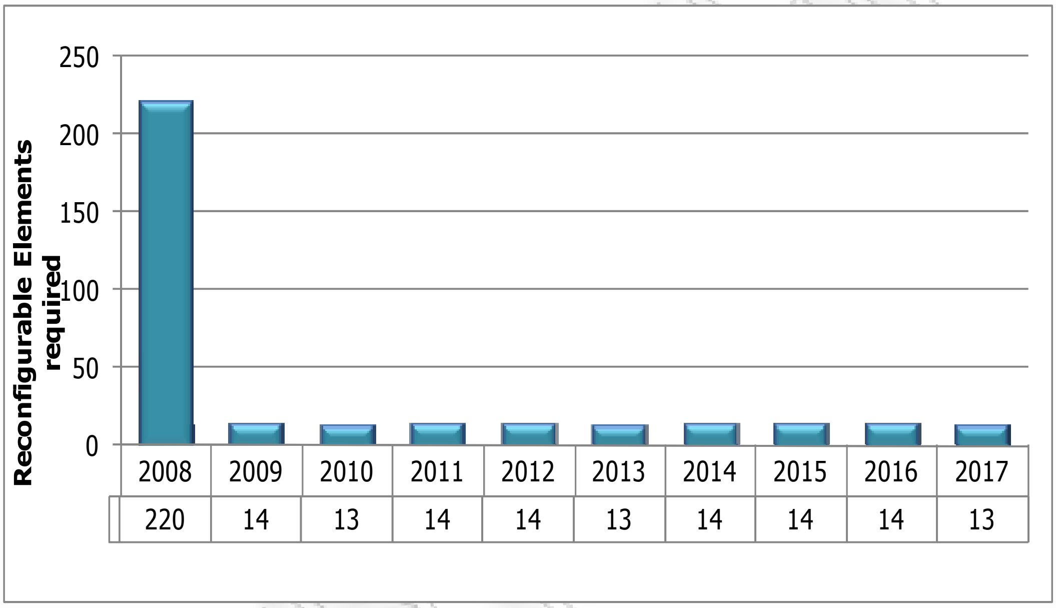


Figure 2-7: Equipment required for the Reconfigurable Network infrastructure per year

As was already mentioned, reconfigurable elements are elements with reconfigurable transceivers capable of operating more than one wireless access standard at the same time, as was introduced in the previous. Therefore, the change of configuration in a specific radio site does not lead to the requirement for an additional element. It can thus be observed in Figure 2-7 that the hardware necessary for an upgrade of the infrastructure in the case of Reconfigurable Networks is significantly less compared to the case of Composite Radio networks.

It is assumed that the total cost for a reconfigurable element is 36.000 €, more specifically the cost for hardware is considered to be 20.000 €, for software 10.000 €, while installation costs equal 6.000 €. Furthermore, the cost per CPE for this case is considered to be equal to 150 €, slightly higher than for the Composite Radio solution.

Consequently, also taking into account the CPE costs (formula (11)), the CAPEX for the Reconfigurable Network solution is formed as presented in Figure 2-8.

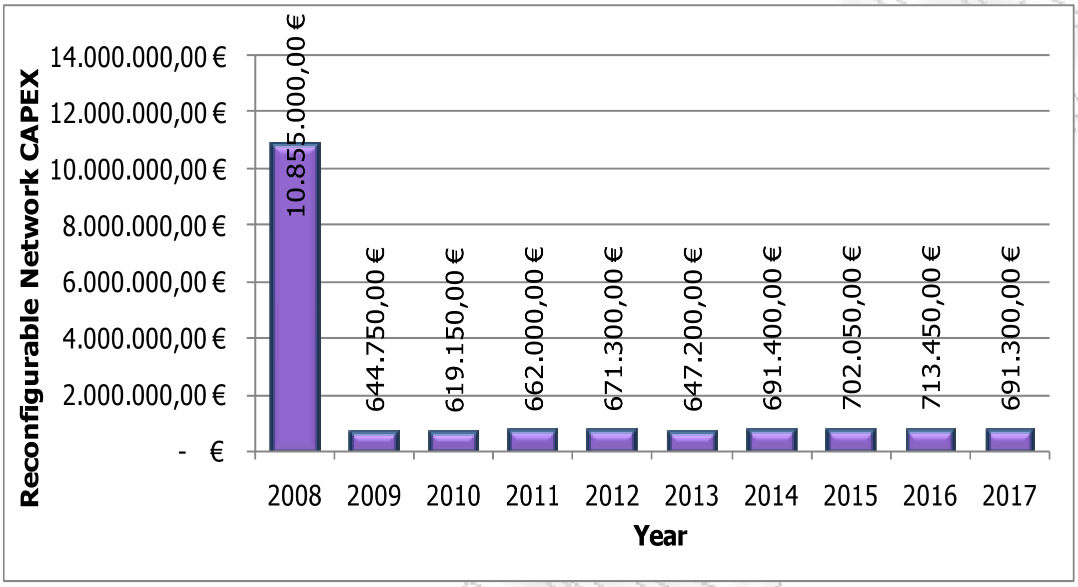


Figure 2-8: Reconfigurable Networks CAPEX

It should be noted that even though the cost for a reconfigurable element is higher than (or equal to) that of a (plain) UMTS or WiMAX element, the annual CAPEX for the Reconfigurable Network solution is much less over the years than the relative CAPEX for the Composite Radio. This is due to the fact that less reconfigurable elements are required for the same service area.

OPEX

The OPEX for the Reconfigurable Network over the years 2008-2017 is presented in Figure 2-9.

In the case presented here, it is assumed that operational and maintenance cost for Reconfigurable Networks is slightly lower than that of the cost for Composite Radio networks. This is assumed as reconfigurable elements adapt their operation according to the current needs and state of the network in an autonomous manner.

Consequently, it is envisaged that reconfigurable elements ease the operation and maintenance process of the network. This in turn leads to a decrease in the corresponding operation and maintenance cost and thus OPEX. More specifically, the considered Network Operation and Maintenance is 2.500 € per site, the Continuous Cost of Infrastructure is 3.000 € per site and the Service Provisioning and Management Cost is 10 € per subscriber.

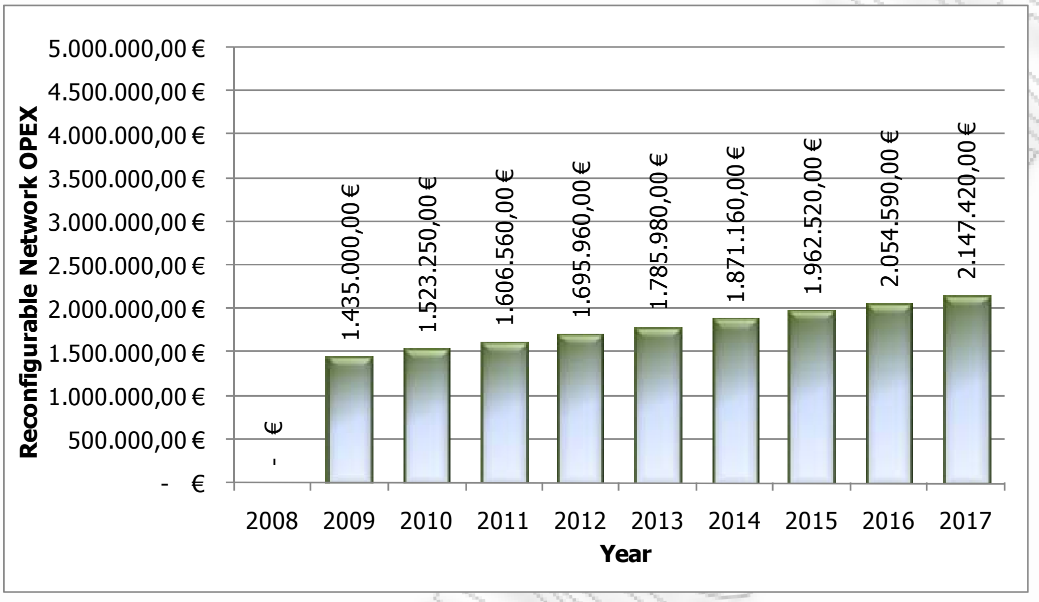


Figure 2-9: Reconfigurable Networks OPEX

Amortization

Using the process described in section 2.4.4 amortization for the Reconfigurable Network option is as illustrated in Figure 2-10.

In order to compute the NPV for the Reconfigurable Network solution, the data presented in the previous, is used as input for the NPV formula. More specifically the Revenues, CAPEX, OPEX, and Amortization data presented in Figure 2-2, Figure 2-8, Figure 2-9 and Figure 2-10 are used.

Additionally, as for the Composite Radio case, the discount rate is 7.145 and the tax rate τ is considered to be 30%. The result of the calculations is that **the Net Present Value for the Reconfigurable Network solution is 25.120.408 €**.

The Net Present Value for the Reconfigurable Network solution without taking into account the effects of **taxation and amortization is 38.601.400 €**. This value is higher than the respective value for Composite Radio case (27.695.138 €) and therefore Reconfigurable Networks are viewed as a preferable solution to the Composite Radio.

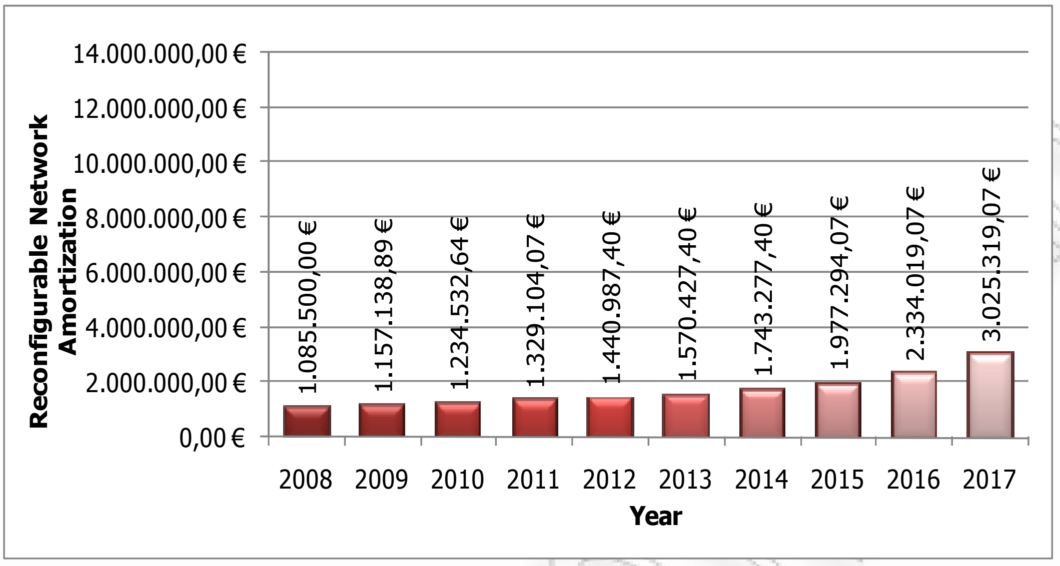


Figure 2-10: Reconfigurable Networks Amortization

2.5.2. Case 2: Same OPEX for Both Solutions

In the previous analysis different OPEX values were assumed for Reconfigurable Networks and Composite Radio networks. This sub-section provides results on the NPV value when the same OPEX is assumed for both solutions, i.e. Composite and Reconfigurable Networks. More specifically, for the computation of the NPV for the Reconfigurable Network solution, Composite Radio OPEX presented in Figure 2-5 is used while the Revenues, CAPEX, and Amortization data remain the same as in section 2.5.1.2. The result is that **the Net Present Value for the Reconfigurable Network solution is 23.952.041 €**, in other words it remains higher than that of the Composite Radio case (17.443.584 €).

The **Net Present Value for the Reconfigurable Network solution without** taking into account the effects of **taxation and amortization is 36.631.985 €**, which is still higher than the NPV of the Composite Radio case, when calculated without taking into account tax and amortization effects (27.695.138 €).

2.5.3. Case 3: Same OPEX for both solutions and increased CAPEX for Reconfigurable Networks

In the initial test case, presented in sub-section 2.5.1.2 it was assumed that the total cost for a reconfigurable element is 36.000 €. In this case the total cost for a reconfigurable element is considered to be 40.000 €, including a hardware cost of 20.000 €, a software cost of 12.000 €, and installation costs that equal 8.000 €. Consequently, the CAPEX for the Reconfigurable Network solution is formed as presented (by the second column per year) in Figure 2-11.

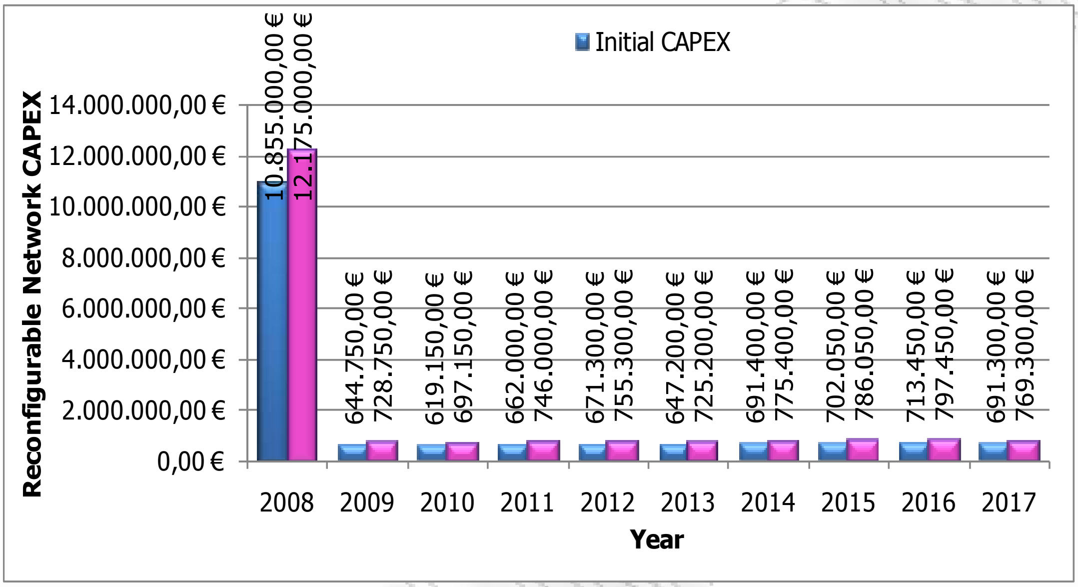


Figure 2-11: Increased Reconfigurable Network CAPEX compared to initial CAPEX (Figure 2-8)

The derived value for the NPV of the Reconfigurable Network solution is 23.657.201 €. Even though the increase in CAPEX has resulted in a decrease in the NPV, the NPV continues to be much higher than that of the respective Composite Radio NPV.

The **Net Present Value for the Reconfigurable Network solution without** taking into account the effects of **taxation and amortization is 34.816.189 €**. The respective NPV value for Composite Radio is 27.695.138 €, which is still lower than NPV value for Reconfigurable Networks. Therefore, Reconfigurable Networks are preferred in this case as well.

2.5.4. Case 4: Increased CAPEX and OPEX for Reconfigurable Networks

In this case, apart from considering an increased CAPEX, as in the previous (Figure 2-11), an additional increase in the OPEX is assumed. More specifically, the considered

Network Operation and Maintenance is 4.500 € per site, the Continuous Cost of Infrastructure is 3.000 € per site and the Service Provisioning and Management Cost is 10 € per subscriber. The OPEX for the Reconfigurable Network in this case is formed as presented (by the second column per year) in Figure 2-12.

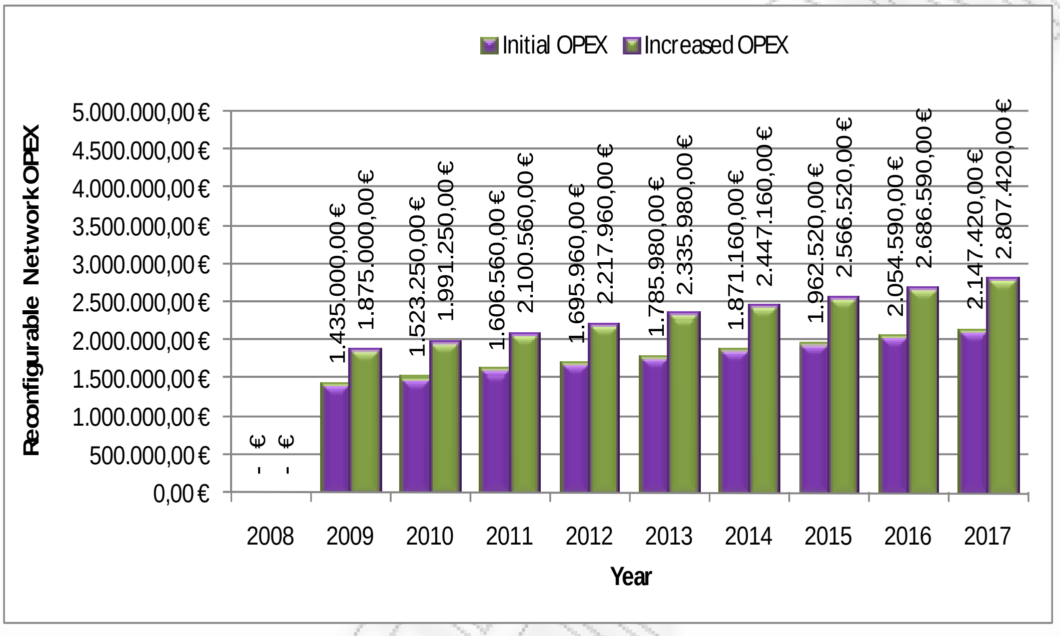


Figure 2-12: Increased Reconfigurable Network OPEX compared to initial OPEX (Figure 2-9)

This results in a further decrease in the Net Present Value for the Reconfigurable Network solution. However, **the derived value for the NPV of the Reconfigurable Network solution is 21.336.046 €** and thus it remains a preferable solution to the Composite Radio solution.

The **Net Present Value for the Reconfigurable Network solution without** taking into account the effects of **taxation and amortization is 33.193.469 €**. This value is still higher than the respective in Composite Radio case (27.695.138 €), therefore Reconfigurable Networks are considered to be a preferable solution, even when the CAPEX and OPEX is increased in such Networks.

2.5.5. Case 5: Upgrading an existing network

This section presents additional results under the assumption that the UMTS technology has already been set up by the network provider, while WiMAX technology has not been rolled out yet. More specifically, the case of upgrading an existing network refers to the case where a basic UMTS network infrastructure is already in place. Over the years the number of radio sites is increased in order to cover a larger geographical region (i.e. to increase the surface of the service area). Thus, the "upgrading process" in the case of Composite Radio network does not require any initial investment costs (null CAPEX for year 1), while for the rest of the years of investment the CAPEX of case 1 is considered (Figure 2-4). However, the upgrade of a Composite Radio network over the years, entails the need of introducing additional UMTS Base Stations and WiMAX Base Stations in both existing sites as well as new sites, to increase capacity and support the requirement for higher data rates. In the case of upgrading the existing infrastructure to a Reconfigurable Network, reconfigurable elements (Base Stations) are initially introduced in existing sites, replacing the UMTS infrastructure, thus entailing a significant initial investment. Over the years though additional reconfigurable elements are only required for new sites. Thus, the CAPEX for Reconfigurable Networks is the same as for case 1 (Figure 2-8).

The results in this case show that the NPV for Composite Radio networks is **24.689.053 €** when taking into account taxation and amortization. For the Reconfigurable Network solution the NPV is **25.120.408 €** when taking into account taxation and amortization.

For **Composite Radio networks when taxation and amortization are not taken into account** in the NPV formula, the calculated value of NPV **is 36.545.138 €**. For Reconfigurable Networks, when taxation and amortization are not taken into account in the NPV formula, the calculated value is **38.601.400 €**.

It can thus be observed that although the difference between the NPV of the two solutions appears decreased, compared to the previous cases, Reconfigurable Networks still provide a better investment opportunity.

2.5.6. Analysis of Results

This section provides a summary of the results from the NPV calculations for Composite Radio and Reconfigurable Networks presented in the previous and highlights the main conclusions that can be drawn from this investment evaluation.

Table 2-9: Summary of results for NPV including tax and amortization effects

<table>
<tr><th rowspan="2">Cases</th><th colspan="2">Types of Networks</th></tr>
<tr><th>Composite Radio</th><th>Reconfigurable</th></tr>
<tr><td>Case 1: Lower OPEX for Reconfigurable Networks</td><td rowspan="4">17.443.584 €</td><td>25.120.408 €</td></tr>
<tr><td>Case 2: Same OPEX for both solutions</td><td>23.952.041 €</td></tr>
<tr><td>Case 3: Same OPEX, increased CAPEX for Reconfigurable Networks</td><td>23.657.201 €</td></tr>
<tr><td>Case 4: Increased CAPEX and OPEX for Reconfigurable Networks</td><td>21.336.046 €</td></tr>
<tr><td>Case 5: Upgrading an existing network</td><td>24.689.053 €</td><td>25.120.408 €</td></tr>
</table>

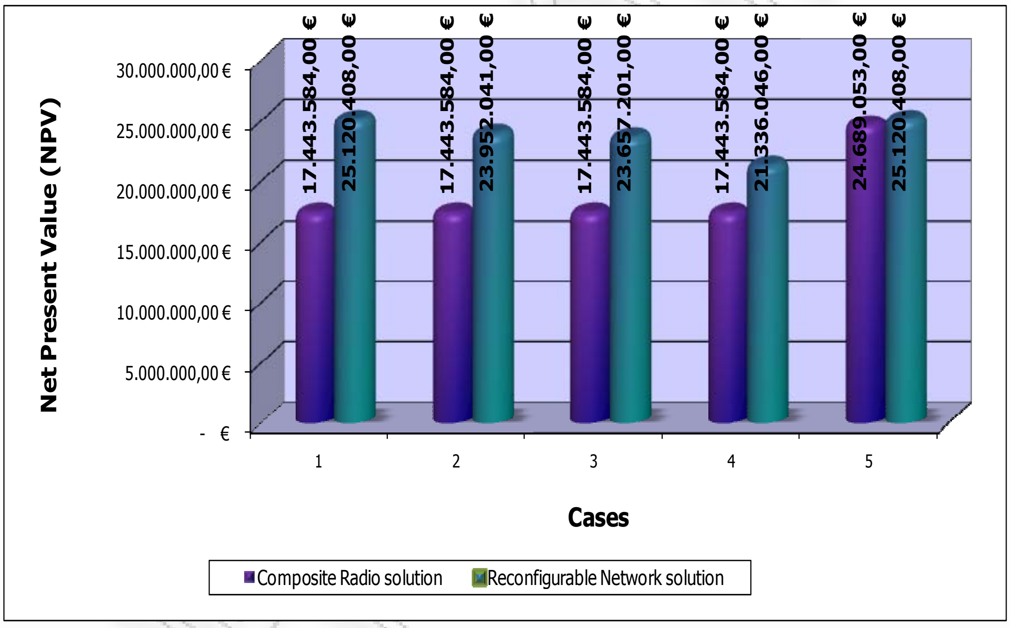


Figure 2-13: Net Present value for different cases including tax and amortization effects

Table 2-9 provides a summary of the results obtained when taking into account tax and amortization effects in the calculations.

Figure 2-13 additionally provides a graphical summary of the results for the NPV of Composite Radio and Reconfigurable Networks when taking into account tax and amortization effects.

Table 2-10: Summary of results for NPV without tax and amortization

Cases	Types of Networks	
	Composite Radio	Reconfigurable
Case 1: Lower OPEX for Reconfigurable Network	27.695.138 €	38.601.400 €
Case 2: Same OPEX for both solutions		36.631.985 €
Case 3: Same OPEX, increased CAPEX for Reconfigurable Networks		34.816.189 €
Case 4: Increased CAPEX and OPEX for Reconfigurable Networks		33.193.469 €
Case 5: Upgrading an existing network	36.545.138 €	38.601.400 €

As can be observed when moving from case 1 to case 4 the Net Present Value for the Reconfigurable Network solution decreases. This consequently leads to a smaller difference between the NPV of the Reconfigurable Network and the corresponding outcome of the Composite Radio deployment option (case 1 and case 5 are the same for Reconfigurable Networks). This reduction is due to the fact that the costs (CAPEX and OPEX) for Reconfigurable Networks are assumed to increase going from case 1 towards case 4. However, as can be seen in Table 2-9 and Figure 2-13, even under such relatively unfavourable conditions, the NPV of Reconfigurable Networks is higher than that of Composite Radio for all cases.

In an analogous manner, Table 2-10 presents results for the various cases when tax and amortization effects are excluded from the calculation of the NPV.

Figure 2-14 additionally provides a graphical summary of the results for the NPV of Composite Radio and Reconfigurable Networks without taking into account tax and amortization effects. The conclusions that can be derived are similar to the ones drawn in the previous, when considering tax and amortization. In other words, for all cases investigated, Reconfigurable Networks appear superior in terms of expected investment return (i.e. NPV) with respect to Composite Radio. Results show that even under auspicious cost assumptions, Reconfigurable Networks are a financially preferable solution for the implementation of B3G networks.

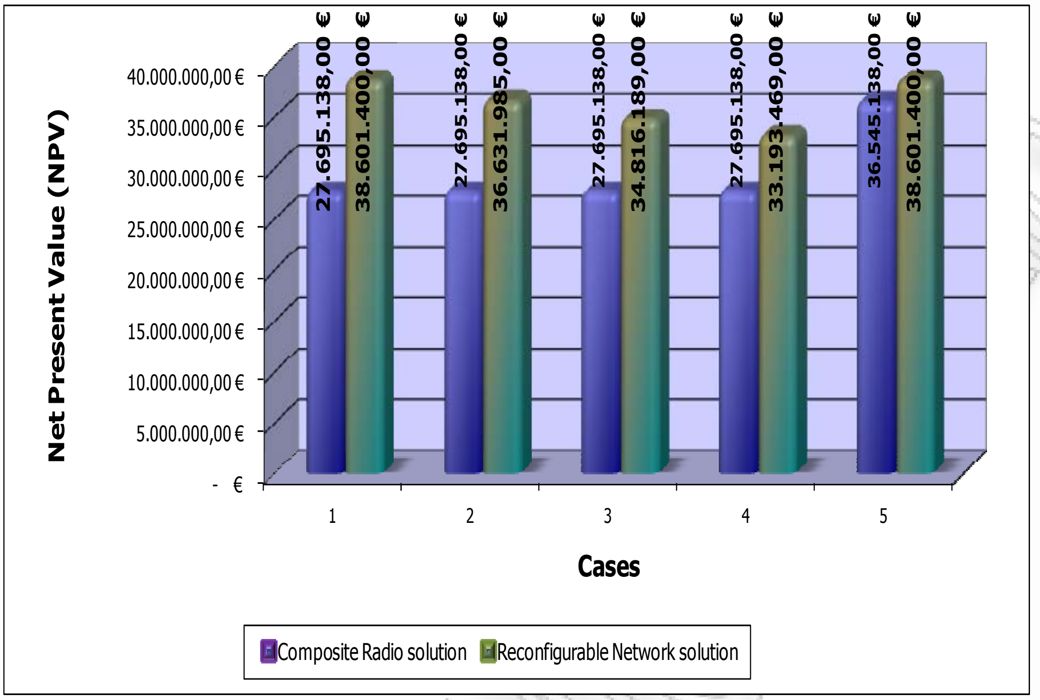


Figure 2-14: Net Present value for different cases without taking into account tax and amortization effects

It should be noted that these results can be regarded as being independent from the Radio Access Technologies taken into account. Regardless of the technologies assumed, the main differentiation between Composite Radio and Reconfigurable Networks, which lies in the structure of the respective cost models, remains the same. As was already mentioned, in the case of Composite Radio networks one hardware element per Radio Access Technology is required, whereas in the case of Reconfigurable Networks one hardware element is sufficient, as it comprises reconfigurable transceivers capable of switching to the desired Radio Access Technologies. In other words, Reconfigurable Networks require less hardware due to the ability of reconfigurable elements to simultaneously operate in more than one mode. As a result, changes or upgrades in the network infrastructure necessitate fewer hardware additions in Reconfigurable Networks, thus leading to a decreased CAPEX over the years in comparison to Composite Radio networks. This holds even for the case of augmenting an existing network infrastructure with additional technologies.

2.6. Conclusions and Future Work

2.6.1. Overall Summary

One of the most recent trends in the area of wireless access communications is the migration towards the Beyond the 3rd Generation (B3G) era. The motivation is to exploit the variety of technologies available in the current and future wireless landscape in the most effective manner.

Two solutions may be considered for the implementation of a B3G infrastructure: 1) the integration of diverse radio access technologies into one Composite Radio environment and 2) the deployment of *Reconfigurable* (adaptive) Networks. Composite Radio networks have served as an excellent first step towards the realization of B3G systems. However, the implementation of a B3G infrastructure by means only of network co-operation may not be effective, in terms of cost and Quality of Services provided, especially on a long-term basis. Reconfigurable Networks on the other hand are envisaged to lead to a reduction of capital and operational expenditures, thus offering important business benefits for Network Operators.

The work presented in this chapter has been targeted to the presentation of proof on the business perspectives that the deployment of Reconfigurable Networks can bring to Network Operators. In order to achieve this goal, a popular investment evaluation tool has been applied, namely the *Net Present Value (NPV)* criterion. This investment appraisal technique has been used for the analysis of the investment in a Composite Radio infrastructure on one hand and in a Reconfigurable Network on the other hand. In this context, the factors that influence the estimation of the NPV were analyzed, presented and calculated for each case, in order to prove in financial terms that Reconfigurable Networks are more profitable to invest in.

The results derived from the calculations show that the NPV of the investment in Reconfigurable Networks is significantly higher than in the case of the investment in Composite Radio. This is mainly due to the important decrease in CAPEX brought by Reconfigurable Networks.

The work of this chapter can be extended with the analysis of additional case studies. Moreover, it can be studied whether the model presented in this chapter for the calculation of the NPV can be enhanced with additional parameters. Finally, the analysis on the financial benefits that can be derived from Reconfigurability can be extended on other business players of the wireless markets such as manufacturers.

2.6.2. Linking Technoeconomic Analysis and User Profile Management

This chapter presented a technoeconomic analysis and comparison of the results between Composite Radio and Reconfigurable Networks, in order to comply with users' expectations, exploiting the advantages offered by B3G networks and taking into consideration user preferences for estimating Quality of Service. This work is complemented by the work in the forthcoming chapters.

More specifically, the next chapters aim at learning user preferences, through user profile management. Therefore, the appropriate Quality of Service is defined and the most suitable functionality of different applications of such systems is identified, taking always into consideration user preferences and requirements for each specific service. Both these research areas lead to increasing user satisfaction, by at the same time enhancing system's effectiveness and user centricity.

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3. LEARNING USER PREFERENCES IN A MOBILE SERVICE CONTEXT

Abstract

The focus of this chapter is more on the end-user side, thus deals with issues related to the utilisation of a heterogeneous composite radio environment with the aim of improving the user experience, by learning user preferences. More specifically, the chapter presents a Cognitive Terminal Management System that comprises mechanisms for retrieving and managing user information, as well as predicting elements of a user's behaviour and preferences, so as to dynamically configure the user terminal. This is achieved by using two methods, namely Bayesian Average and Bayesian Networks. Results are presented for both cases, outlining their differences and comparing the outcomes of these methodologies. Conclusions are provided in the end of this chapter.

Keywords

Bayesian average, Bayesian networks, mobile service, user profile, utility volume

3.1. Introduction

The continuous evolution of wireless systems has resulted in a number of new and powerful wireless networking standards. The concept of Beyond the Third Generation Systems (B3G) emerged in an attempt to exploit the variety of the available access standards to the benefit of end-users, operators and manufacturers. In this context, a key topic in the research area of B3G/4G networks is related to mechanisms and strategies to efficiently realise the complementary use of the diverse Radio Access Technologies (RATs), through their convergence into one composite radio environment. One of the most important features of these evolving systems is the availability of multiple access technologies, which will allow users to enjoy wireless services at any time, at any place. Evidently in order to truly enhance the experience of all users, even technology agnostic ones, functionality is required, on both the network and the user-device side, for providing the "always best connection" in a transparent manner. In this direction, cognitive [1]-[3] and reconfigurable systems [4]-[6] have appeared as a complementary concept to B3G networks. Cognitive systems determine their behaviour, goals, principles, experience and knowledge, reactively or proactively and acting in response to external trigger [7]. The focus of this chapter is more on the end-user side. In this sense, the chapter presents a Cognitive Terminal Management System (CTMS) that comprises mechanisms for retrieving and managing user information, as well as predicting elements of a user's behaviour and preferences so as to dynamically configure the user terminal in a seamless and transparent manner. This can be realized through appropriate management functionality that takes into account (in addition to user requirements) environment characteristics, configuration policies and experience established through machine learning mechanisms [8]. In more detail, the chapter is constructed as follows. Related work in the field of cognitive terminals and learning user preferences is presented. The requirements for the proposed system are outlined followed by the description of the architecture of the system and the related components. An approach for modelling user preferences is presented as a key part of the proposed CTMS, using concepts from Bayesian statistics, namely Bayesian Networks as well as Bayesian Average. A comparison of the results of the two methods is presented as well. Finally, the chapter concludes with a summary of the main points as well as directions for future extension of the work presented.

3.2. Related Work

A number of studies have been made in the field of mechanisms for managing heterogeneous radio access networks with the goal of achieving the best Quality of Service possible and therefore increasing the user' satisfaction, using an economic and user differentiated approach [9] and emphasizing on the requirements of a cognitive equipment management system [10]. Furthermore, related research work also includes the use of Bayesian Networks in support of User Modeling, as a method for evaluating, in a qualitative and quantitative manner, elements of the user behavior and accordingly updating the User Profile. Such researches include the approach to construct and handle statistical models [11], the issues that arise in achieving user-intent ascription through dynamic User Model construction with Bayesian Networks [12], Bayesian Networks' application inferring user's learning styles [13] and the ability to merge partial user models [14]. Bayesian Networks have also been employed to derive user characteristics [15]. Systems using weighted parameters have also been studied, using Bayesian Networks and other methods from decision theory as well [16]-[18]. Yet, a method to measure and dynamically infer user preferences in wireless systems has not been examined yet, which is the scope of this research.

3.3. System Requirements

The general business level objective is to offer a set of services able to serve multiple types of users, being in various locations (residential, public, or business) and in a variety of time zones. Services can include voice/audio/data/video content, which is communicated in a conversational, interactive, streaming, or background manner. Within the different locations and time zones a user may adopt various roles during the daily routine, e.g., at work, private-life, social life etc. In any case, services should be provided at the best possible Quality of Service (QoS) and cost levels. QoS levels are related to reference performance metrics (e.g., bit-rate, delay, etc.), availability (e.g., low blocking probability, capacity), reliability (e.g., low dropping or handover blocking probability), as well as security/safety [19].

In order to achieve this business level objective, the utilisation of the wireless B3G infrastructure is subject to a number of key requirements. These are the need for *personalization*, *context awareness*, *always best connectivity*, *ubiquitous provision* and *seamless mobility*. More specifically:

- Personalization derives from the need to support different user types and roles. This means that each service is adapted according to individual preferences and needs. This information is derived from user's past activity using this service, as well as directly from the user,
- Context awareness derives from the need to consider the state of the served user, terminal and environment. The basic contextual information consists of the user identity and roles, terminal capabilities, location and time zone. In other words, context awareness is the ability of the system to know at any time where the specific user is, what type of terminal this user has and the time zone the user is in,
- Always best connectivity derives from the need to optimally offer the diverse services, in terms of QoS and cost, taking into account personalization and context information,
- Ubiquitous provision is the requirement to offer always best connectivity everywhere,
- Seamless mobility hides the complexity of the underlying infrastructure from the user. This features benefits user by providing the same type of service, as requested, regardless the equipment, time zone, location.

In order to meet the abovementioned requirements, a Cognitive Terminal Management System (CTMS), incorporating the following features is required. The first feature is management of user preferences, equipment capabilities and network policies. This capability refers to the accurate description and representation of this information as well as configuring and updating the respective profiles and policies [10]. Acquisition of context information is a second feature that has to do with the collection of information pertaining to the current state of the terminal and the user. The target of context acquisition is to assess the necessity of reconfiguration and provide input to the relevant process of selecting the most appropriate configuration. Finally, the election of the most appropriate reconfiguration action for the equipment may result into a switch from one network/ RAT to another. This action should be consistent with user preferences and equipment capabilities, and should also take into account specific service area region conditions and time zones of the day (seamless mobility requirement). The selection process may obtain additional information from the network side through the negotiation of offers with the various available networks.

3.4. System Design

This subsection gives an overview of the components that comprise the CTMS. The components are mapped to the requirements (specified in the previous) that the CTMS system has to fulfil in order to be able to identify and adapt to elements of the user behaviour and preferences. These components are *Profiles Management*, *Policies Derivation*, *Context Acquisition* and *Configuration Negotiation and Selection*.

As presented in Figure 3-1, these components are able to dynamically learn the preferences of the user, identify changes in terminal capabilities or policies and estimate future contextual situations, so as to enhance terminals with cognitive functionalities.

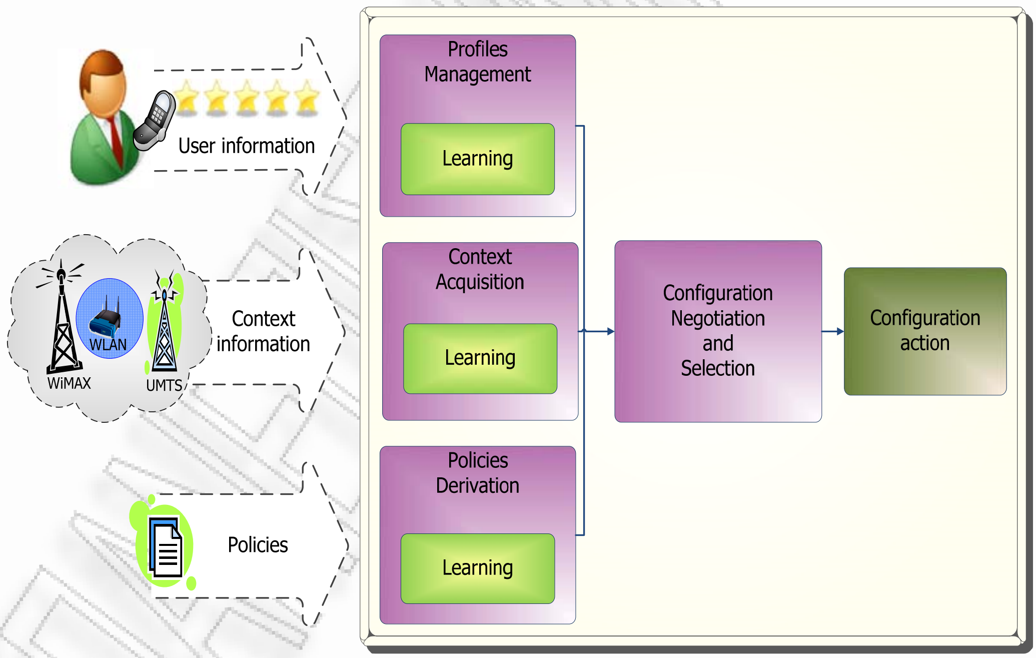

Figure 3-1: Overview of CTMS

Furthermore, the CTMS can learn and immediately apply the solutions that were found in the past and have been recorded as being effective. Thus, optimisation mechanisms related to the selection of the most appropriate configuration action(s) can become faster.

3.4.1. Profiles Management

The role of this component is to manage the information regarding the preferences of the user in accordance with the capabilities of the terminal. This component uses mechanisms to develop knowledge on the preferences, requirements and behaviour of the user. It is important to accurately represent the preferences of the user for QoS levels, when a certain service is used, at a certain location and time of day.

User preferences are expressed through the utility value associated with each application and QoS level. This component is the main focus of this chapter and will be further analysed in the following sections.

3.4.2. Policies Derivation

This component is responsible for the provision and management of information related to policies. Policies are used as an input during the decision process for selecting the most appropriate configuration, based on user profile (preferences) and the context (network capabilities). More particularly, a certain policy specifies a set of rules that the terminal must follow. The goal of policies is to refine the input provided in the profiles and the context. In case negotiations are realised, policies may also specify a list of networks that may be used by the Configuration Negotiation and Selection component. In other words, policies can influence available services and respective QoS levels, as well as the subset of available configurations for the device.

3.4.3. Context Acquisition

The functionality of this component can be split into two sub-tasks: discovery and monitoring. The main goal of discovery is to periodically perform checks in order to determine whether or not a new and/or more appropriate configuration has become available. In other words, it should be possible to identify the entrance of a new RAT in the service area, offering better service features (e.g. higher QoS provision, lower cost per QoS level and service). Monitoring refers to the collection of statistics on the current network connection in order to assess its status and the performance level of service provisioning. Furthermore, in order to enhance the reliability of the monitoring and discovery processes and capabilities are required for inferring supplementary information on the current context. More specifically, in order to deal with the dynamic nature of a heterogeneous and reconfigurable infrastructure, mechanisms are required for learning the typical capabilities of configurations, in certain contexts (e.g., locations, time regions).

3.4.4. Configuration Negotiation and Selection

This component decides on the most appropriate configuration(s) for the terminal in terms of the obtained QoS levels. This is realised through an optimisation process that takes into account the user and terminal profiles, the current context, and policies from network management entities. Information regarding the provision of certain services can be obtained through negotiations with networks complying with policies. In the case of this component, learning is required for selecting configurations faster and in a more reliable manner. The initial step towards achieving this goal is to store solutions applied for the handling of a certain situation. The next step is the evaluation of solutions after they have been applied in order to assess whether they were effective or not, in terms of achieved user satisfaction and system performance. Finally, comparison of the current situation with previous situations encountered is required. If a matching situation exists and the corresponding solution was rated as being good, the Configuration Negotiation and Selection component may apply it without running the optimisation process again.

3.5. User Profile Modelling

As already mentioned in the previous Sections, this work focuses on the continuous measuring of preferences of a certain user in order for the system to be able to adapt accordingly in various context states. Moreover, methods for the prediction of future preferences of the user are investigated. The first step is the definition of User profile parameters that can be mapped to user preferences and thus be used in order to adapt the configuration of the user equipment. The component responsible for managing User profile information, as was already mentioned, is the Profiles Management component. User profile parameters can be split into two categories; *observable parameters* and *output parameters*.

Observable parameters are countable parameters, which can be inferred by the system at a very specific time period, or provided by the user with the minimum interaction. User feedback can be obtained in the following manner. The user initiates a specific service. At the initial stages the Profile Management component considers that the user does not have any particular preferences, in other words the user is initially considered to be indifferent between service provision choices. Thus, configurations are selected mainly based on contextual information and policies (information retrieved by the respective components). Every time the user obtains a service, a rating facility (embedded in the Profiles Management component) allows the user to rate how much he liked the particular service provision. A Likert Scale [20] is used for the rating. In this way even the non-technology expert users can provide the system with feedback on their preferences. The user is also given the choice to decline providing a rating. Observable parameters and their potential values are presented in Table 3-1.

Table 3-1: Observable parameters and their potential values

Observable Parameters	**Potential Value**
Service	Audio, Video, Data, Voice
Quality of Service level	High, Medium, Low
Location	Value retrieved by Context Acquisition component
Time Zone	Value retrieved by Context Acquisition component
User Role	At home, at work
User fb	1- Awful, 2- Poor, 3- OK, 4- Good, 5- Excellent

Output parameters depend on the value of observable parameters. Their value is dynamically updated over time. Output parameters are used in the selection process in order to decide on the most appropriate configuration for the specific user in a certain context (location, time zone, user role). Table 3-2 presents the output parameters and the values they can be attributed with. The following section describes the way that observable and output parameters can be combined, so as to

a. reliably represent user preferences and

b. enable personalised service delivery.

Table 3-2: Output parameter and its potential values

Output Parameters	Potential Value
Utility Volume	$u_{l,tz,ur}(s_1,q_1)$, $u_{l,tz,ur}(s_2,q_2)$, $u_{l,tz,ur}(s_1,q_2)$...
where s_i denotes service i, q_j denotes QoS level j, and l, tz, ur stand for location, time zone and user role respectively	

3.6. Learning User Behaviour and Preferences

Functionality related to developing knowledge on user preferences and behaviour can be divided in two phases. The *initial phase* is collecting information on user preferences. The *second phase* deals with the prediction of future user preferences based on the information collected.

One method for modelling such prediction mechanisms is using the concepts of Bayesian Networks (BNs). A BN is a graph that depicts a set of variables and their probabilistic dependencies [11]. In this case, a BN represents the probabilistic relationships between output parameters and observable parameters. The corresponding dependencies are depicted in Figure 3-2.

The rest of this chapter focuses on the initial learning of user preferences. Two methodologies are going to be investigated. First, the methodology using the *Bayesian Average* will be presented. The second methodology uses the *Bayesian Networks*, which will be presented subsequently.

For the initial phase, the approach proposed in this chapter is to collect feedback from the user and calculate rankings of Services and QoS combinations. This approach applies for both methodologies to be presented in the forthcoming sections. As presented in Figure 3-2, given observable parameters, the value of output parameters is calculated. These output parameters, can then be used to decide on the most appropriate configuration for the user device. In the following, the calculation of the Utility Volume (output parameter) is described in detail.

The Utility Volume is used to represent *user preferences for QoS levels* when making use of a certain service. In other words, the Utility Volume provides a ranking (by order of preference) of Service and QoS pairs. The range of the Utility Volume values is a set of real numbers. The actual values of the Utility Volume have no importance. It is the *ranking* of these values that is significant for the personalised selection of the most appropriate configuration. User preferences may vary depending on the contextual situation. Therefore, the Utility Volume depends on a range of context-related parameters as depicted in Figure 3-2.

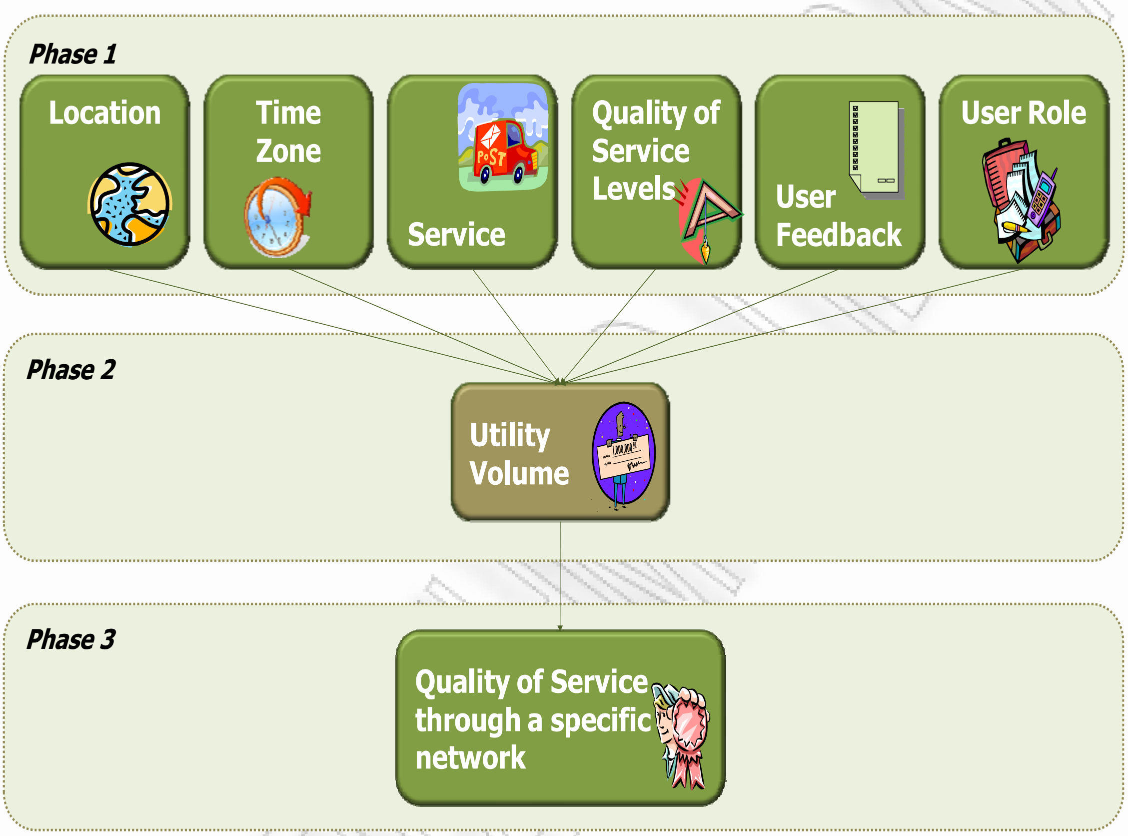

Figure 3-2: Inference of user preferences

More specifically, the Utility Volume, apart from the Service and QoS level, may be related to the location of the user, the time zone, the user role and the feedback obtained from the user. User preferences may also change over time. In order to take this into account the Utility Volume is calculated based on the methodology of Bayesian Average [21] and the methodology of Bayesian Networks [22]-[25]. The aim is to have a "weighted" ranking of QoS levels per service. In both cases, the weight of each parameter combined in a specific way that will be analysed in the forthcoming sections, provides information on the user's preference for a specific type of service (regarding the set of parameters that compose the service, e.g. the set of Service-QoS level).

3.7. Bayesian Rating for Discovering User Preferences

3.7.1. Description of the Bayesian Rating Methodology

In order to test and validate the previously presented learning user preferences procedure, in this section we use the Bayesian rating methodology. Bayesian rating is applied through the following formula:

$$br = \frac{(avg\_num\_fb \cdot avg\_rating) + (this\_num\_fb \cdot this\_rating)}{avg\_num\_fb + this\_num\_fb} \qquad (18)$$

Where:

- avg_num_fb is the average number of feedbacks provided by user, within a certain time period (phase),
- avg_rating is the average rating that a service received (through the feedback), within a certain time period (phase),
- $this\_num\_fb$ is the number of feedbacks provided for a specific value,
- $this\_rating$ is the rating that a certain value of feedback received.

The feedback value of the user can be attributed with an integer number in the interval [1, 5], where 1 represents user's strong dissatisfaction and 5 represents user's strong satisfaction (Likert scale), as discussed in section 3.5. Taking into consideration the parameters presented previously, along with this section's methodology, the following scenario is formed.

We consider a user that requests a specific service (e.g. audio) during various phases, each of which has certain sub-phases that reflect the times the user requests for the specific service within the period of a phase.

In this case, 500 sub-phases are considered, consisting 50 phases, that is 10 sub-phases per phase. Yet, the number of sub-phases in a phase may vary, as the number of service delivery within a phase may be different for each phase. Moreover, the service is provided at a specific *Quality of Service* (QoS) and its values may be *high*, *medium* and *low*.

Table 3-3: Example of the monitoring procedure for learning user preferences

		Service	QoS	User Role	User FB
Phase 1	*Sub-phase 1*	Audio	Medium	Personal	1
	Sub-phase 2	Audio	Low	Professional	5
	Sub-phase 3	Audio	Low	Personal	5
	Sub-phase 4	Audio	Low	Professional	1
	Sub-phase 5	Audio	High	Personal	1
	Sub-phase 6	Audio	Low	Personal	1
	Sub-phase 7	Audio	Medium	Professional	5
	Sub-phase 8	Audio	Low	Personal	1
	Sub-phase 9	Audio	Low	Personal	4
	Sub-phase 10	Audio	Medium	Professional	4
Phase 2	*Sub-phase 11*	Audio	Low	Personal	2
	Sub-phase 12	Audio	Medium	Professional	4
	Sub-phase 13	Audio	Low	Personal	3
	Sub-phase 14	Audio	High	Professional	5
	Sub-phase 15	Audio	Low	Professional	2
	Sub-phase 16	Audio	High	Professional	4
	Sub-phase 17	Audio	High	Professional	1
	Sub-phase 18	Audio	High	Professional	3
	Sub-phase 19	Audio	Medium	Personal	5
	Sub-phase 20	Audio	Low	Personal	1
Phase 3	*Sub-phase 21*	Audio	Medium	Personal	1
	Sub-phase 22	Audio	Medium	Personal	5
	Sub-phase 23	Audio	Medium	Personal	3
	Sub-phase 24	Audio	Low	Professional	3

	Sub-phase 25	Audio	Low	Personal	1
	Sub-phase 26	Audio	Low	Professional	4
	Sub-phase 27	Audio	Low	Professional	5
	Sub-phase 28	Audio	High	Personal	5
	Sub-phase 29	Audio	High	Personal	5
	Sub-phase 30	Audio	Medium	Personal	5
Phase 4	*Sub-phase 31*	Audio	Medium	Personal	1
	Sub-phase 32	Audio	High	Professional	5
	Sub-phase 33	Audio	Medium	Personal	4
	Sub-phase 34	Audio	Low	Professional	3
	Sub-phase 35	Audio	Low	Professional	5
	Sub-phase 36	Audio	High	Professional	1
	Sub-phase 37	Audio	Low	Professional	5
	Sub-phase 38	Audio	Medium	Professional	4
	Sub-phase 39	Audio	Medium	Professional	5
	Sub-phase 40	Audio	Low	Personal	3

At each phase the system calculates the Bayesian rating (*br*) in the way presented previously. This rating denotes user's satisfaction, or in other words, *Utility Volume*. This means that after calculating *br*, the system concludes which QoS the user preferred the most. Practically, in this way the system learns user's preferences, regarding the *QoS*, for a given *Location*, *User Role* and *Service*. User Role is a generalized parameter to include time zone and context. In other words, it is taken into consideration that the time zone and context cannot be precisely defined within a certain time zone within a day. For instance, a user may work during the weekend or late at night, whereas during the noon the user may be in a personal context.

An example of the collected information on these elements is depicted in Table 3-3.

The following section presents the results of the application of Bayesian Rating methodology.

3.7.2. Results using Bayesian Rating Methodology

In Bayesian Rating methodology the system separates the phases taking into consideration the User Role and calculates the *br* for Personal and Professional User Role, distinguishing the calculations also by QoS provided (high, medium or low). Therefore, six tables are created so as to calculate user's preference for each of the service instances, namely *"Audio-Personal-High"*, *"Audio-Personal-Medium"*, *"Audio-Personal-Low"*, *"Audio-Professional-High"*, *"Audio-Professional-Medium"* and *"Audio-Professional-Low"*. In this way, the CTMS system creates knowledge on user's preferences, when the Audio service is requested. For instance, in order to calculate the *br* for the Phase 3 of the Table "Personal-High" (Table 3-4) the system follows the subsequent steps.

Table 3-4: Information collected for "Personal-High"

		Service	QoS	User Role	User FB
Phase 3	*Sub-phase 28*	Audio	High	Personal	5
	Sub-phase 29	Audio	High	Personal	5

For this example, formula (18) is formed as follows:

- $br = \frac{((2,333 \cdot 5) + (3 \cdot 12))}{(2,333 + 3)} \Rightarrow br = 8,9375$, as
- $avg\_num\_fb = \frac{7}{3}$ (times personal was selected)/ (the amount of values for high>0),
- $avg\_rating\_high = \frac{5+5}{2} = 5$ (the summary of the rating of high) / (the amount of feedbacks received for high),
- $high\_num\_fb = 3$ (the times high was selected so far, including previous phases),
- $high\_rating = 5+5+2 = 12$ (the total rating that high received, including previous phases).

The results for Personal-Medium, Personal-Low, Professional-High, Professional-Medium and Professional-Low are calculated in the same way. Figure 3-3 graphically presents the results regarding user's preferences, when using the Audio service, for User Role Personal, Qos High, Medium and Low.

This result seems reasonable, as it is verified, by graphically depicting user feedbacks for the same Time Zone and Quality of Service values. Figure 3-4 presents these results.

It is inferred that the user prefers low quality for the service, when using Audio at a personal level. On the other hand, when the user is in a professional context, it seems that QoS is more important (Figure 3-5).

User feedback also confirms user's preferences, as depicted in Figure 3-6. It may be noted that it is obvious when comparing the set of the two graphs of both cases that the user prefers the low or high QoS, respectively. Yet, in both cases, user feedback processing makes the results more clear and robust and provides the system with knowledge, based on proved theories and not assumptions by user's behaviour within the system.

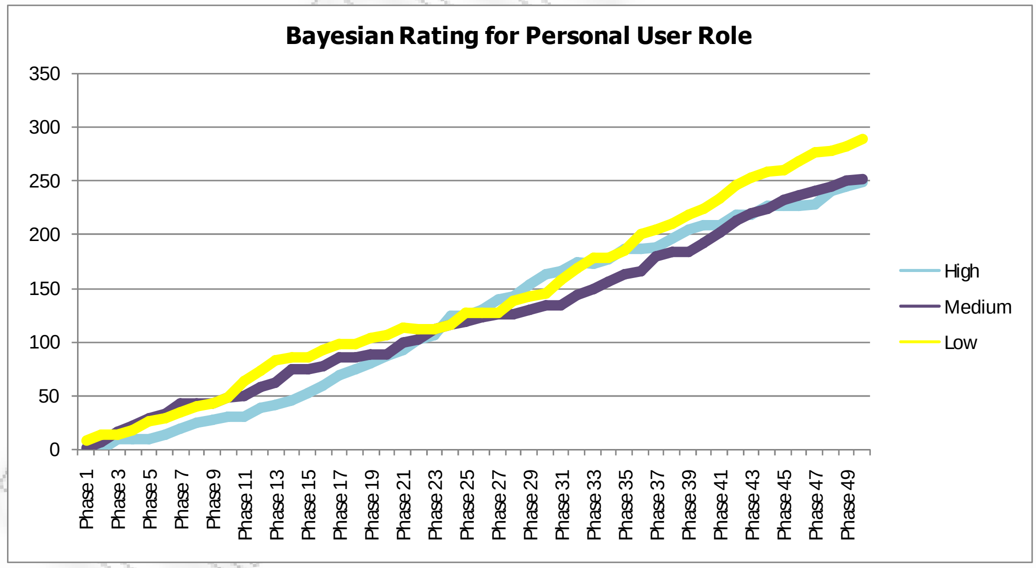

Figure 3-3: Utility Volume (through Bayesian rating) results for QoS level High, Medium and Low and Time Zone Personal

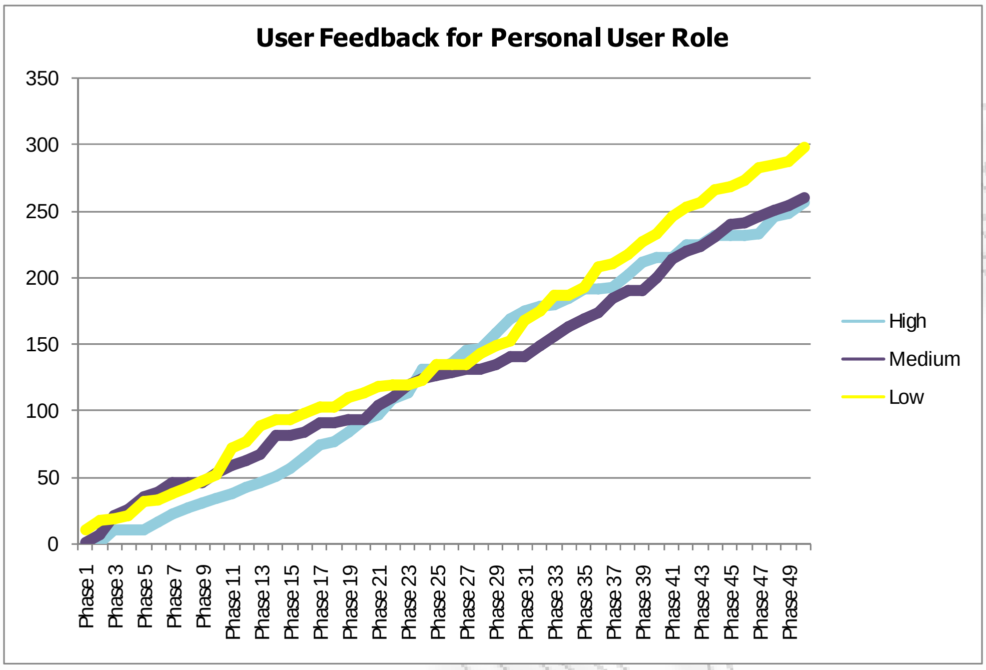

Figure 3-4: User feedback (through Bayesian rating) results for QoS level High, Medium and Low and Time Zone Personal

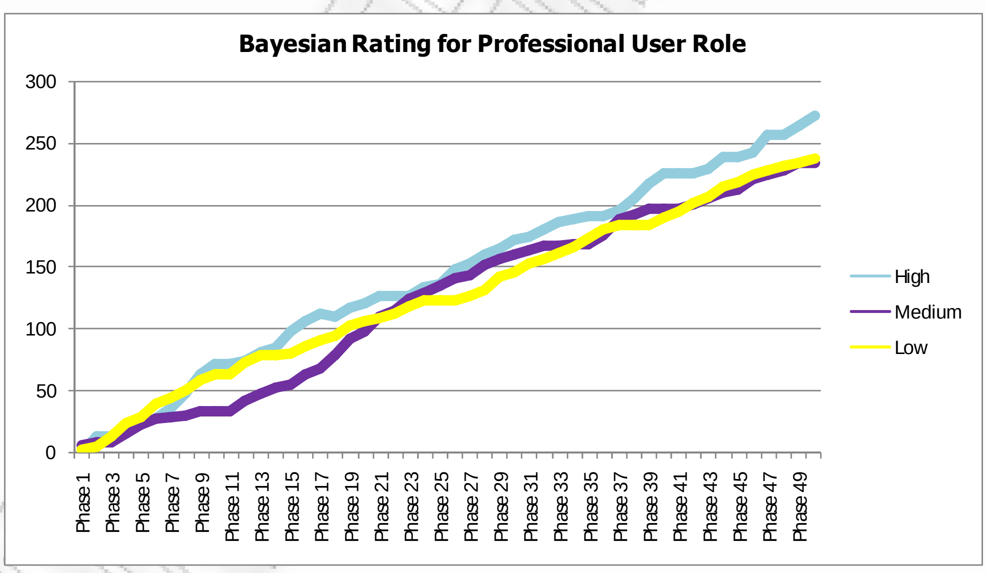

Figure 3-5: Utility Volume (Bayesian rating) results for QoS level High, Medium and Low and Time Zone Professional

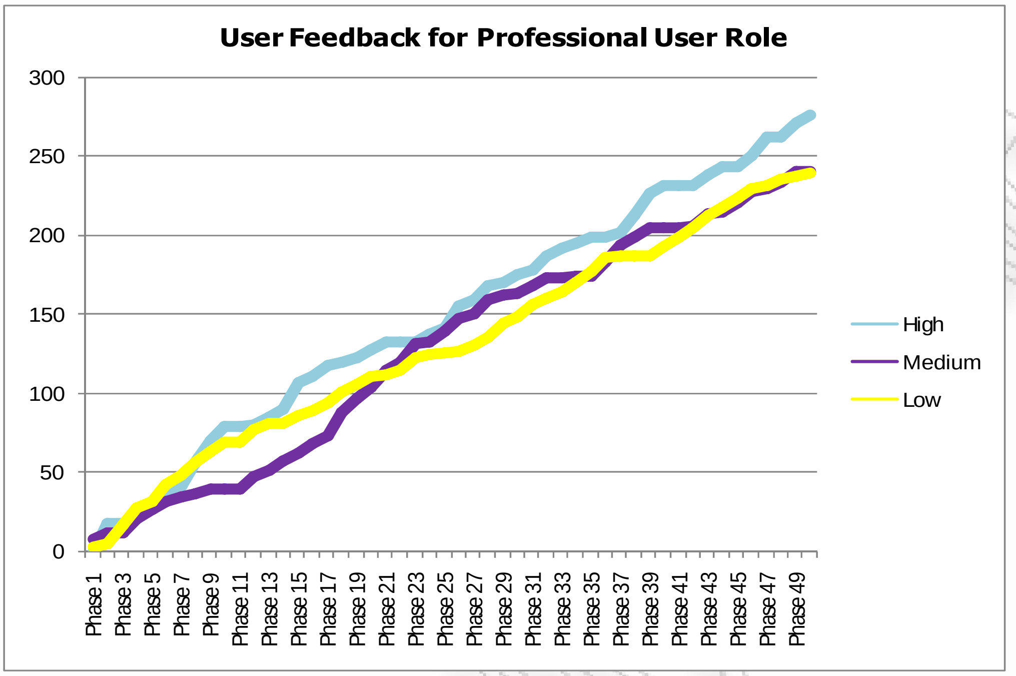

Figure 3-6: User feedback (through Bayesian rating) results for QoS level High, Medium and Low and Time Zone Personal

3.8. Bayesian Networks for Discovering User Preferences

3.8.1. Description of the Bayesian Networks Methodology

The process of developing knowledge regarding user preferences is comprised of two phases, as already introduced. The initial phase is the collection of information on the user. For the initial phase, the approach proposed in this section is to collect feedback from the user and calculate rankings of Services and QoS combinations. The next phase is the approximation of future user preferences based on the gathered feedback, using Bayesian Network method.

Concepts from Bayesian statistic are applied in order to estimate the probability of the level of user satisfaction (or the maximum acceptable cost) for a specific service and QoS level provided, given a certain location and time zone. More specifically, a method is presented according to which instantaneous estimations are updated by taking into account existing information on the user [15], [25].

The first step of the application of this methodology is to create the Conditional Probability Table (CPT) for the Utility Volume (Table 3-5).

This Table is produced with the use of the MSBNx Bayesian Network editor and toolkit [26], based on the network of Figure 3-2.

It is assumed that values for the observable parameters are recorded for various instances (steps), as also presented depicted in Table 3-3. Respectively to Bayesian Rating (Section 3.7), 500 sub-phases are considered, consisting 50 phases, that is 10 sub-phases per phase. These values constitute the "Observable Parameters Evidence".

Table 3-5: Conditional Probabilities for Utility Volume

Parent Node(s)			UtilityVolume					
Service	QualityOfService	UserRole	1	2	3	4	5	bar charts
Audio	High	Personal	0,35	0,25	0,15	0,15	0,1	
		Professional	0,1	0,15	0,2	0,2	0,35	
	Medium	Personal	0,05	0,2	0,25	0,3	0,2	
		Professional	0,05	0,2	0,3	0,2	0,25	
	Low	Personal	0,05	0,1	0,2	0,25	0,4	
		Professional	0,15	0,3	0,2	0,2	0,15	

Practically, the CPT Table serves as an input to the instantaneous estimated probabilities of utility volume, which is the second step of this methodology. As the user is being delivered with a specific service, the instantaneous estimations are changing, depicted by and depending on the feedback the user provides the system. This means that the instantaneous probability estimations are changing in time and act as input to the estimation of the adapted probability, for a certain Service, QoS and User Role.

The third step of this procedure is the calculation of adapted probabilities. The calculation of these probabilities is based on the following formula:

$$p_{adapted,n} = w_{hist} \cdot p_{adapted,n-1} + w_{instant} \cdot (1 - | p_{adapted,n-1} - p_{instant,n} |) \cdot p_{instant,n} \qquad (19)$$

Where:

- $|x|$: represents the absolute value of x,
- n : denotes the current instant,
- $p_{adapted,n}$: represents the adapted probability estimation at moment n,

- $p_{adapted,n-1}$: represents the adapted probability's previous value,
- $p_{instant,n}$: stands for the current instantaneous estimation and
- w_{hist} and $w_{instant}$: reflect the weights attributed to the historical estimation and the current instantaneous estimation, respectively. Their value is in the interval $(0,1)$ and the formula $w_{hist} + w_{instant} = 1$ is always true.

As mentioned in Section 3.6, the feedback provided by the user influences the value of Utility Volume probability. This is realized through formula (19) by attributing the appropriate weight to the adapted and instantaneous estimations, accordingly, based on the obtained user feedback. A set of results is presented, focusing on the estimation of the Utility Volume.

The aforementioned formula is applicable to the estimation of the probability of the feedback given. For instance, should the user selected to rate the service delivered to him with a "2", then the formula is going to be used to calculate the adapted probability for "2". Yet, it is essential to adapt the remaining feedback values, in order their sum to equal 1. Thus, the following formula is used.

$$p^{Y}_{adapted,n} = p^{Y}_{adapted,n-1} - \frac{(p^{X}_{adapted,n} - p^{X}_{adapted,n-1})}{4} \qquad (20)$$

Where:

- $p^{Y}_{adapted,n}$ represents the adapted probability of each of the potential feedback values that where not selected (Y), at the moment *n*.
- $p^{Y}_{adapted,n-1}$ represents the adapted probability of each of the potential feedback values that where not selected (Y), at the moment *n-1,* that is the previous time slot,
- $p^{X}_{adapted,n}$ represents the adapted probability of the feedback selected (X), at the moment *n*,
- $p^{X}_{adapted,n-1}$ represents the adapted probability of the feedback selected (X), at the moment *n-1*.

In order to provide personalised and adapted results, taking into consideration every single instance of the service delivery, separate results for each of this service delivery have been created. In this case, Audio is the service delivered, distinct results for all the potential combinations of the parameters have been created, namely *"Audio – Personal – High"*, *"Audio – Personal – Medium"*, *"Audio – Personal – Low"*, *"Audio – Professional – High"*, *"Audio – Professional – Medium"*, *"Audio – Professional – Low"*. Ergo, the special preferences of the user for each instance of the service may be better comprehended, so as to adapt to his preferences accordingly and create knowledge on his preference, which will be of extreme use for the preference on Quality of Service identification.

Five different cases have been elaborated, based on the weights of the historical and instantaneous estimations attributed each time. More specifically, in Case 1 the ratio of W_{hist} and $W_{instant}$ is considered to be equal. This means that W_{hist} and $W_{instant}$ are equal to 0,5, as their sum must always be equal to 1, as mentioned previously. In Case 2, the ratio the ratio of W_{hist} and $W_{instant}$ is considered to be 2, which means that W_{hist} is equal to 0,8 and $W_{instant}$ is equal to 0,2. Case 3 is the reverse case of Case 2, considering W_{hist} to be equal to 0,2 and $W_{instant}$ to be equal to 0,8. Case 4 considers W_{hist} to be equal to 0,6 and $W_{instant}$ is equal to 0,4, while Case 5 is the reverse case of Case 4 taking into account that the ratio of W_{hist} is equal to 0,4 and $W_{instant}$ is equal to 0,6.

Moreover, it has to be noted that the instantaneous estimations are the same for all five cases examined in this work. This seems reasonable, as W_{hist} and $W_{instant}$ affect only the Bayesian Networks formula, which is used to create the adapted estimations table. This means that Instantaneous Probability Estimations results are presented in Case 1 and remain the same for all cases. Thereof, for brevity's sake, Instantaneous Probability Estimations results (Figure 3-7, Figure 3-9, Figure 3-11, Figure 3-13, Figure 3-15 and Figure 3-17) are not presented in the Case 2 to the Case 5.

The following section presents the results of the application of Bayesian Networks methodology.

3.8.2. Results using Bayesian Networks

3.8.2.1 Case 1: $W_{hist}=W_{instant}$

In this case it is considered that the weight of the historical estimations is equal to the adapted estimations. Since their sum is equal to 1, *each of the weights is equal to 0,5*. Taking "Audio-Personal-High" as an example, the instantaneous estimations table is formed as follows, based on the procedure described in the previous. The example presents the first 15 phases of the Service instance (Table 3-6).

Table 3-6: Instantaneous Estimations for "Audio-Personal-High" Instance

Instantaneous Estimations					
	1	**2**	**3**	**4**	**5**
Phase 0	0	0	0	0	0
Phase 1	0,99000	0,00250	0,00250	0,00250	0,00250
Phase 2	0,49000	0,00333	0,00333	0,00333	0,49000
Phase 3	0,32333	0,00333	0,00333	0,00333	0,65667
Phase 4	0,24000	0,00500	0,24000	0,00500	0,49000
Phase 5	0,19000	0,00500	0,39000	0,00500	0,39000
Phase 6	0,15667	0,00500	0,32333	0,00500	0,49000
Phase 7	0,13286	0,00500	0,27571	0,00500	0,56143
Phase 8	0,11500	0,01000	0,24000	0,11500	0,49000
Phase 9	0,10111	0,01000	0,32333	0,10111	0,43444
Phase 10	0,10000	0,10000	0,30000	0,10000	0,40000
Phase 11	0,09091	0,18182	0,27273	0,09091	0,36364
Phase 12	0,08333	0,25000	0,25000	0,08333	0,33333
Phase 13	0,07692	0,30769	0,23077	0,07692	0,30769
Phase 14	0,07143	0,28571	0,21429	0,14286	0,28571
Phase 15	0,99000	0,00250	0,00250	0,00250	0,00250

Applying formula (19) to the results of Table 3-6, the following table of adapted probabilities estimations is created (Table 3-7). More specifically, collecting data from Table 3-3 and Table 3-6, formula (19) is evolved:

$$p_{adapted\,(1),n} = (0,5 \cdot 0,2) + 0,5(1 - |\,0,2 - 0,99\,|) \cdot 0,99 = 0,20395$$

This value is going to be set to the second cell of "1", for Phase 1. The rest of the cells are filled with the values that come up using formula (20). More precisely:

$$p^2_{adapted,2} = 0,2 - \frac{0,20395 - 0,2}{4} = 0,19901$$

Table 3-7: Adapted Estimations for "Audio-Personal-High" Instance

Adapted Estimations					
	1	**2**	**3**	**4**	**5**
Phase 1	0,20	0,20	0,20	0,20	0,20
Phase 2	0,20395	0,19901	0,19901	0,19901	0,19901
Phase 3	0,18540	0,18046	0,18046	0,18046	0,27321
Phase 4	0,16894	0,16401	0,16401	0,16401	0,33904
Phase 5	0,16172	0,15679	0,19288	0,15679	0,33182
Phase 6	0,14669	0,14176	0,25300	0,14176	0,31679
Phase 7	0,13565	0,13071	0,24196	0,13071	0,36096
Phase 8	0,12466	0,11972	0,23097	0,11972	0,40492
Phase 9	0,12532	0,12038	0,23163	0,11709	0,40558
Phase 10	0,11756	0,11263	0,26266	0,10933	0,39782
Phase 11	0,11930	0,10568	0,26439	0,11107	0,39956
Phase 12	0,10950	0,14488	0,25459	0,10127	0,38976
Phase 13	0,09965	0,18430	0,24474	0,09142	0,37990
Phase 14	0,08897	0,22701	0,23406	0,08074	0,36922
Phase 15	0,08231	0,22036	0,22740	0,10736	0,36257

This value is the same for "2", "3", "4" and "5". Of course, as the phases proceed, these values are not always the same, as their value depends on the Feedback of the user selected in each sub-phase/ phase.

After applying the previously presented calculations for all instances of the service, certain results are produced. In this particular case the results are presented for both instantaneous and adapted probabilities, for all instances of the service.

Personal User Role

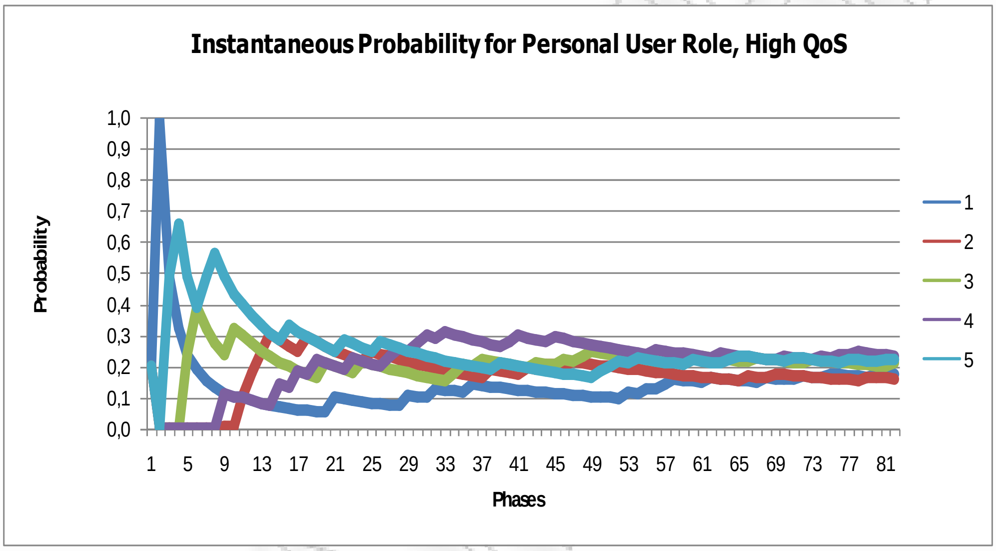

Figure 3-7: Instantaneous Probability for Personal User Role and High QoS, W_{hist}=0,5, $W_{instant}$=0,5

As it can be noted in Figure 3-7, in the first phases of the application of this methodology, the instantaneous estimations are very variant, causing the system sharp deflections. At this point, the system applies the Bayesian Networks algorithm, in order to smooth this variation.

The target is to maintain an as uniform as possible estimation, so as to deliver the user a specific service, whose characteristics will not have enormous deviations amongst the phases. In this way, the user will be able to select the type of service he prefers, without being confused with significant changes in the characteristics of the service from one phase to another.

Figure 3-8 presents the adapted probability estimations for this specific instance of the Service, which is "Personal User Role and High QoS" for Audio Service. It may be observed that the application of the Bayesian Networks formula ((19)) smoothes the sharp deviations of the Instantaneous Probability estimations and provides the user with a more unvarying result.

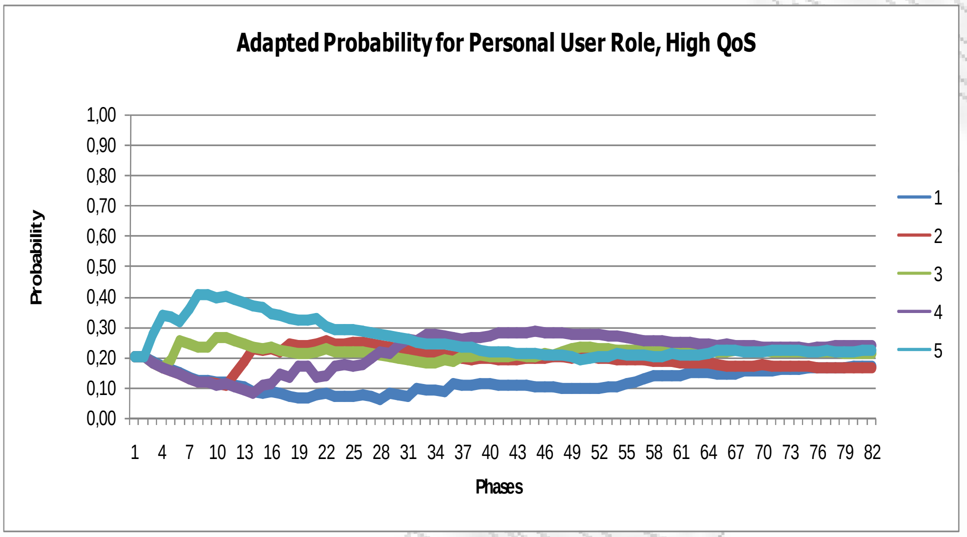

Figure 3-8: Adapted Probability for Personal User Role and High QoS, W_{hist}=0,5, $W_{instant}$=0,5

The following Figures, Figure 3-9 to Figure 3-12, present the remaining instances for Personal User Role, namely Medium and Low QoS, both for instantaneous and adapted probability estimations.

As mentioned previously, Instantaneous Probability estimations are prickly, while soon after the implementation of the Bayesian Networks methodology the result is blunter.

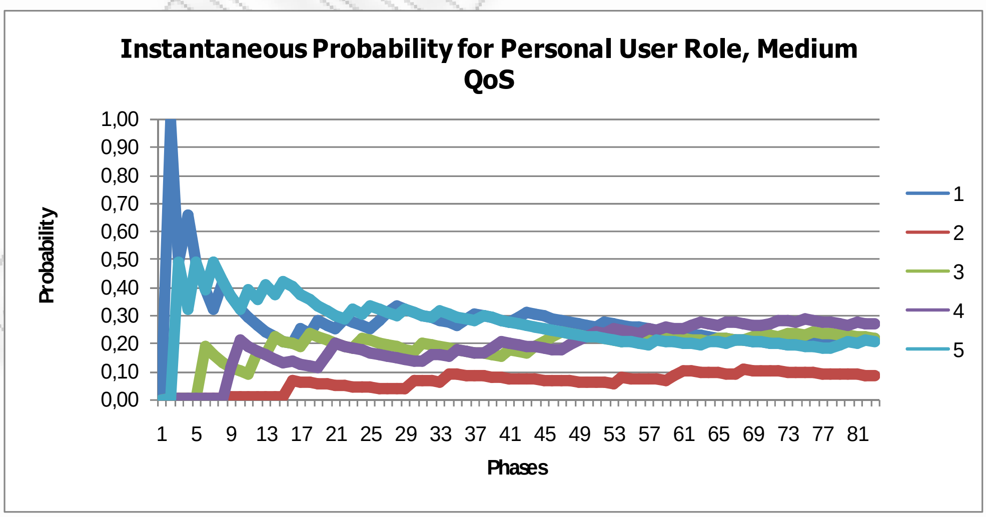

Figure 3-9: Instantaneous Probability for Personal User Role and Medium QoS, W_{hist}=0,5, $W_{instant}$=0,5

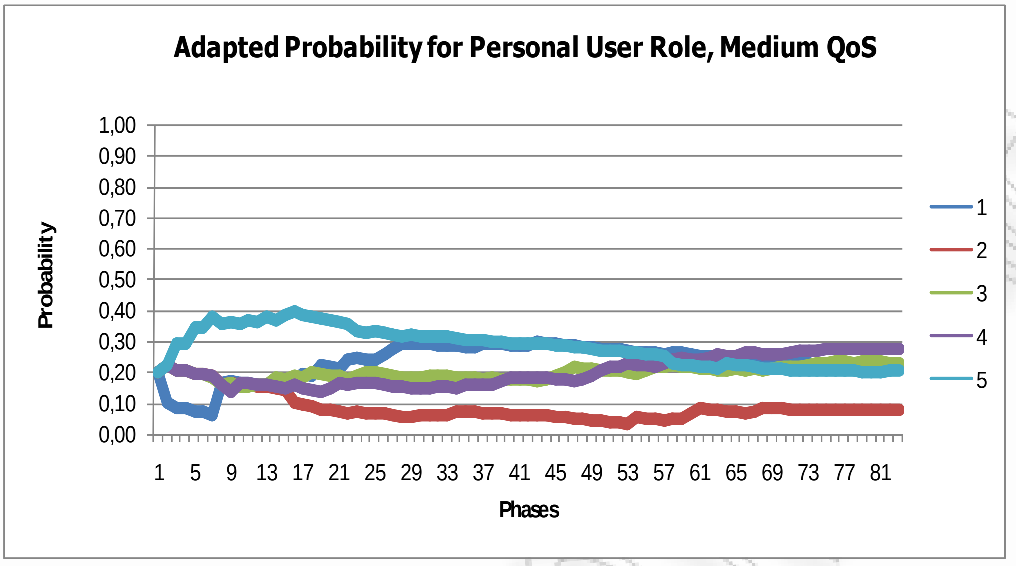

Figure 3-10: Adapted Probability for Personal User Role and Medium QoS, W_{hist}=0,5, $W_{instant}$=0,5

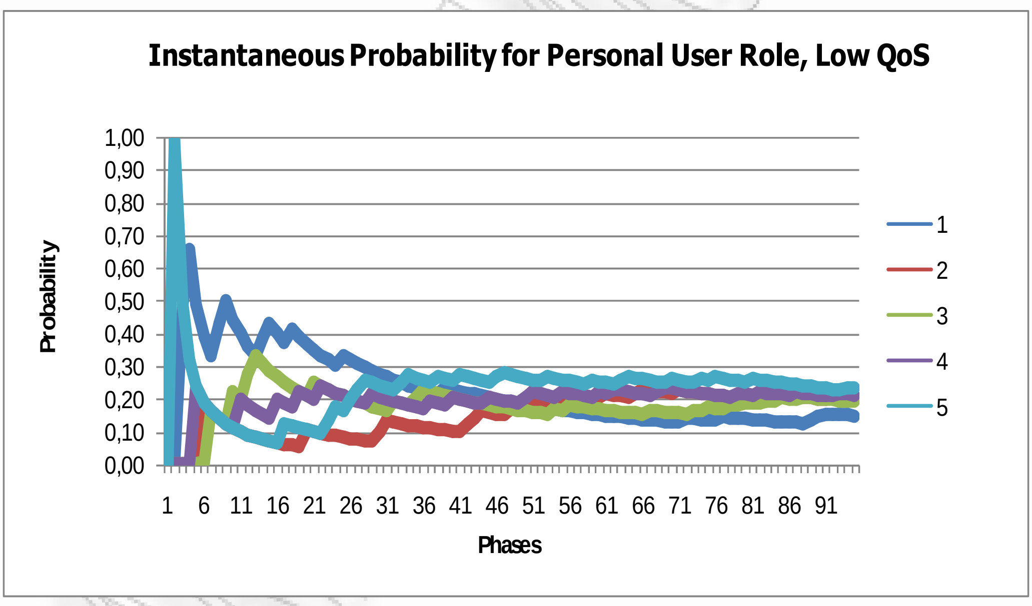

Figure 3-11: Instantaneous Probability for Personal User Role and Low QoS, W_{hist}=0,5, $W_{instant}$=0,5

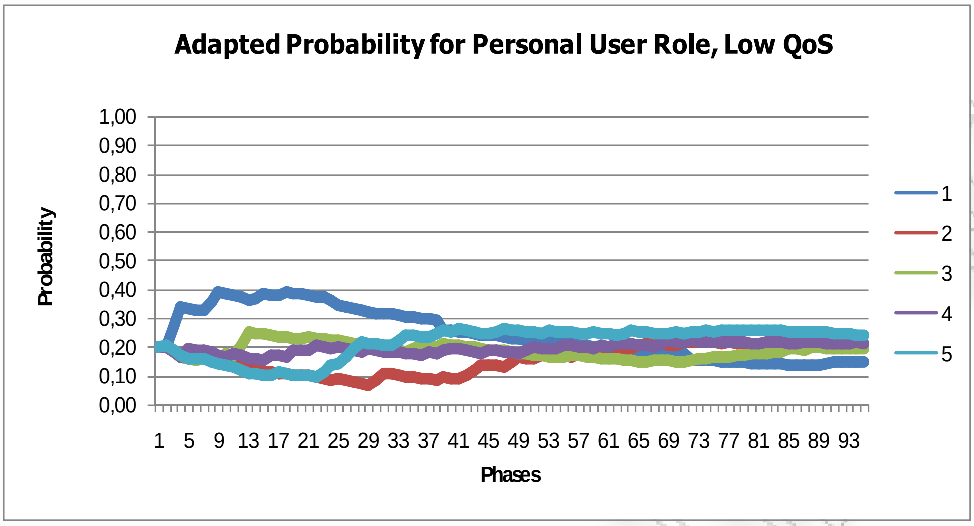

Figure 3-12: Adapted Probability for Personal User Role and Low QoS, W_{hist}=0,5, $W_{instant}$=0,5

Professional User Role

Figure 3-13 to Figure 3-18 showcase the results for Instantaneous and Adapted Probability estimations for the Audio Service, Professional User Role and High, Medium and Low Qos, respectively.

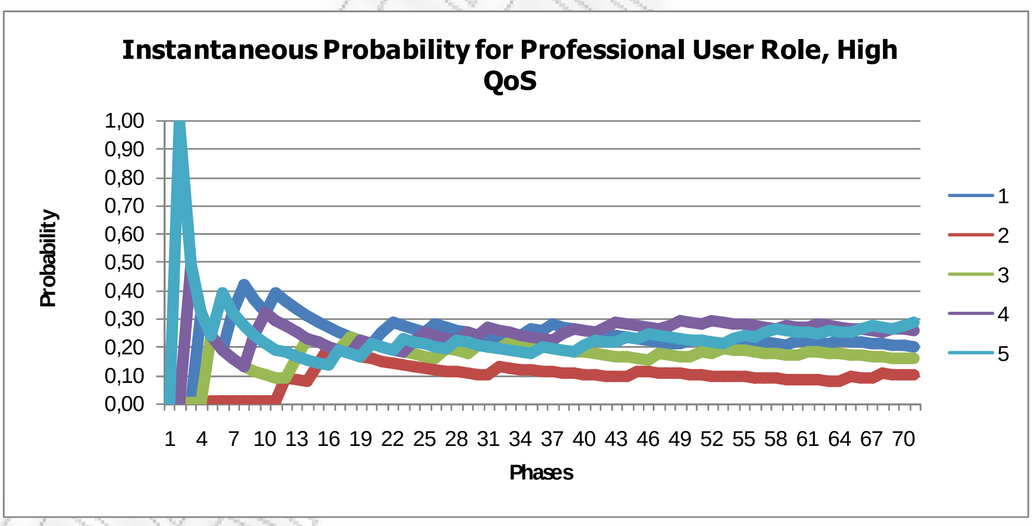

Figure 3-13: Instantaneous Probability for Professional User Role and High QoS, W_{hist}=0,5, $W_{instant}$=0,5

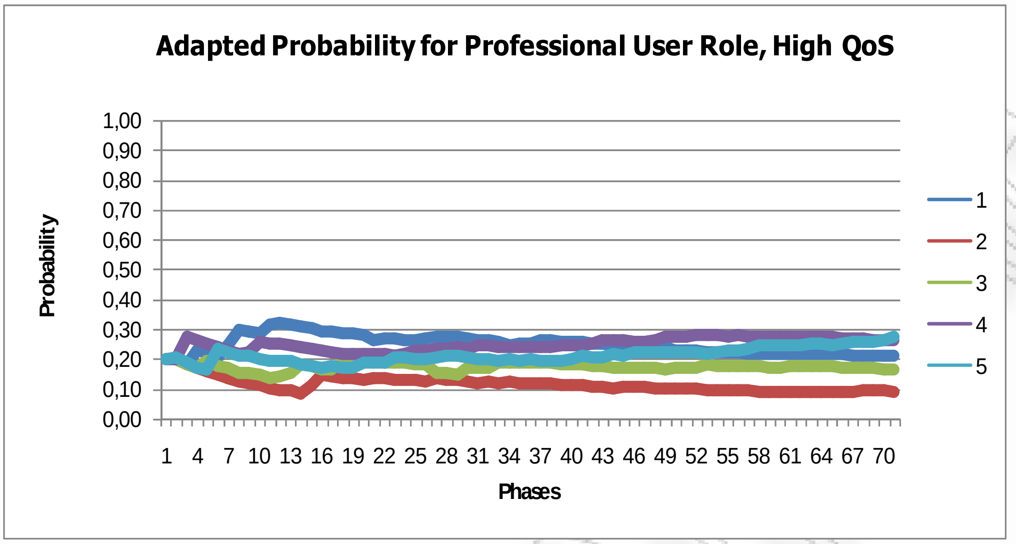

Figure 3-14: Adapted Probability for Professional User Role and High QoS, W_{hist}=0,5, $W_{instant}$=0,5

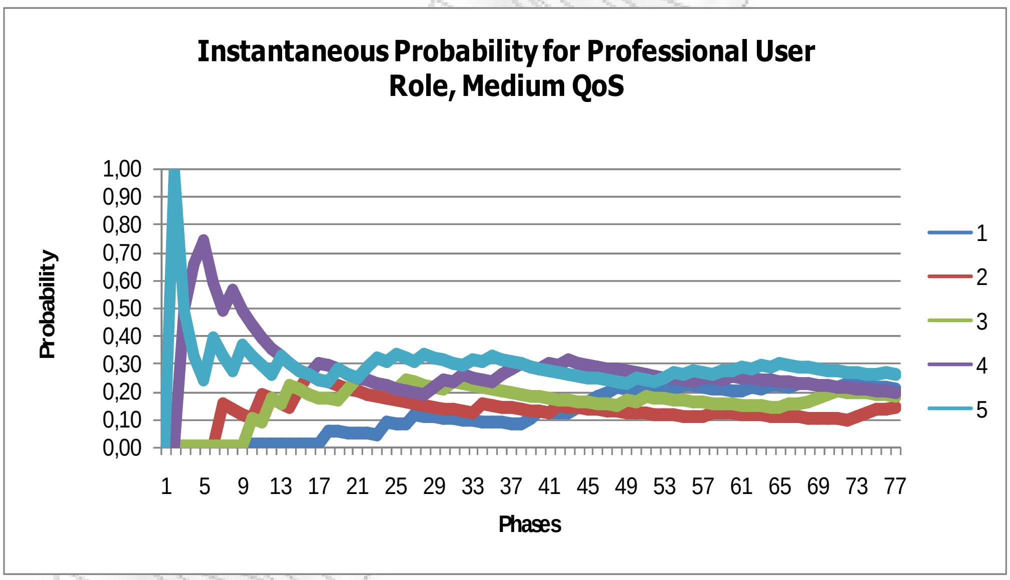

Figure 3-15: Instantaneous Probability for Professional User Role and Medium QoS, W_{hist}=0,5, $W_{instant}$=0,5

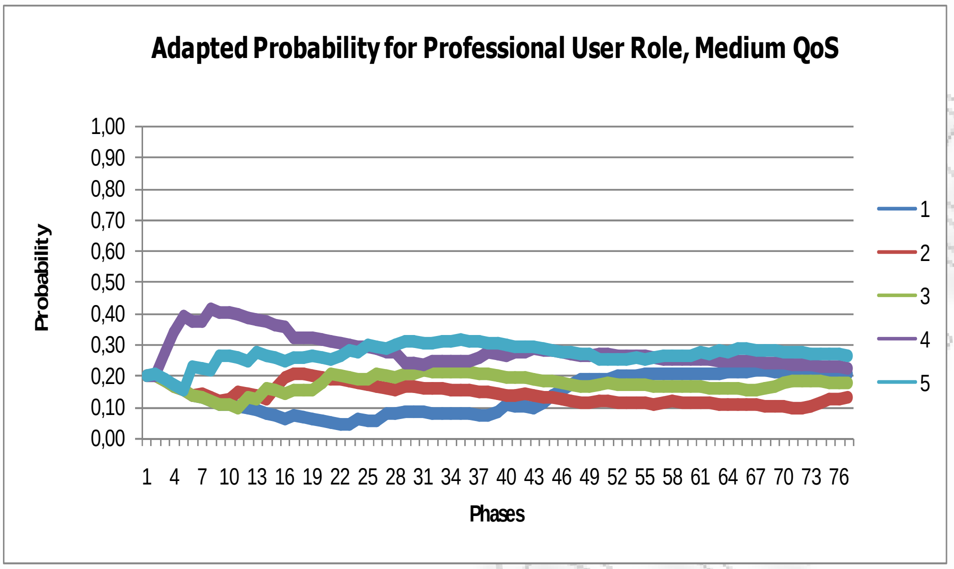

Figure 3-16: Adapted Probability for Professional User Role and Medium QoS, W_{hist}=0,5, $W_{instant}$=0,5

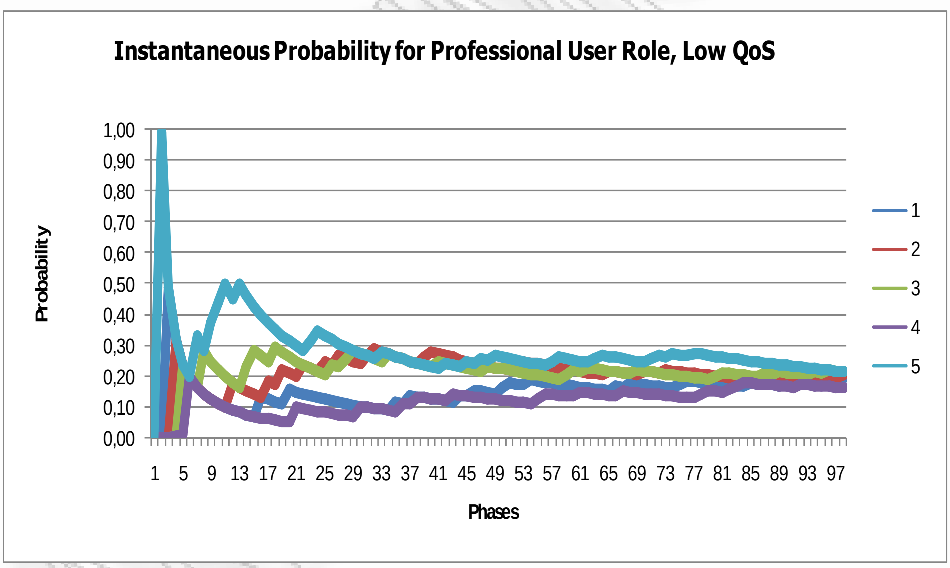

Figure 3-17: Instantaneous Probability for Professional User Role and Low QoS, W_{hist}=0,5, $W_{instant}$=0,5

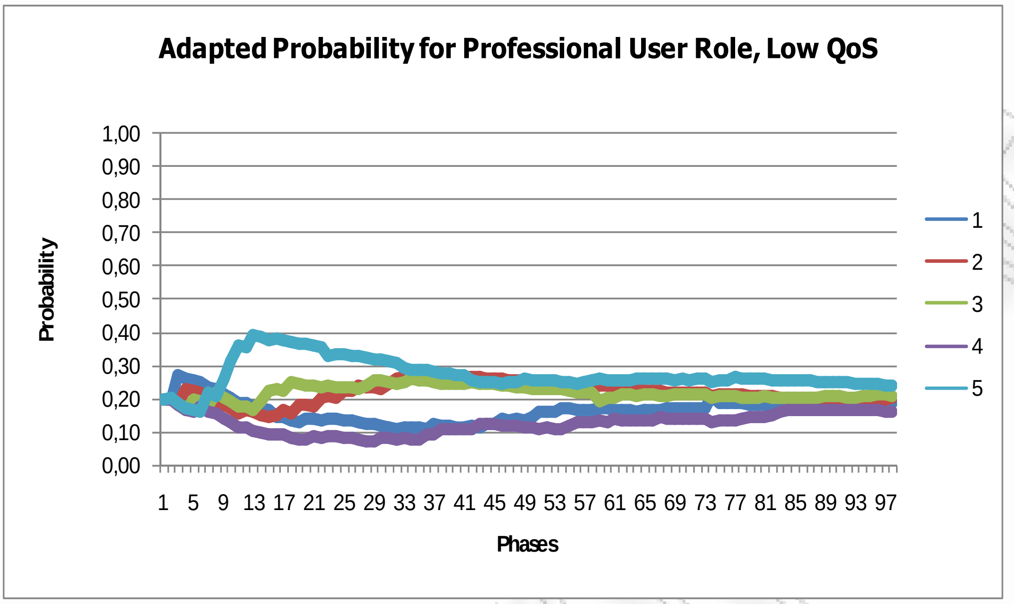

Figure 3-18: Adapted Probability for Professional User Role and Low QoS, W_{hist}=0,5, $W_{instant}$=0,5

Conclusively, as it can be deduced by Figure 3-7 to Figure 3-18, the Bayesian Networks approach smoothes out the sharp fluctuations that are recorded during the phase of Instantaneous Probability estimations.

More precisely, it can be inferred that, when taking into account that $W_{hist}=W_{instant}=0,5$, the user prefers *Low QoS for "Audio-Personal"*, as the percentage of this instance during the evaluation phase is clearly higher than the rest potential values (Medium and High). For *Professional context*, the user prefers *High QoS*.

3.8.2.2 Case 2: W_{hist}=0,8 and $W_{instant}$=0,2

As described in Section 3.8.1, the Instantaneous Probability estimations Tables remain the same in all phases. Therefore, for Personal User Role the Instantaneous Probability estimations Figures are Figure 3-7, Figure 3-9 and Figure 3-11 for High, Medium and Low QoS, respectively. For Professional User Role Figure 3-13, Figure 3-15 and Figure 3-17 represent the Instantaneous Probability estimations for High, Medium and Low instances of the Service. According to Case 1, Adapted Probability estimations tables are formed for $W_{hist}=0,8$ and $W_{instant}=0,2$. The results after applying Bayesian Networks formula (19), are as follows.

Personal User Role

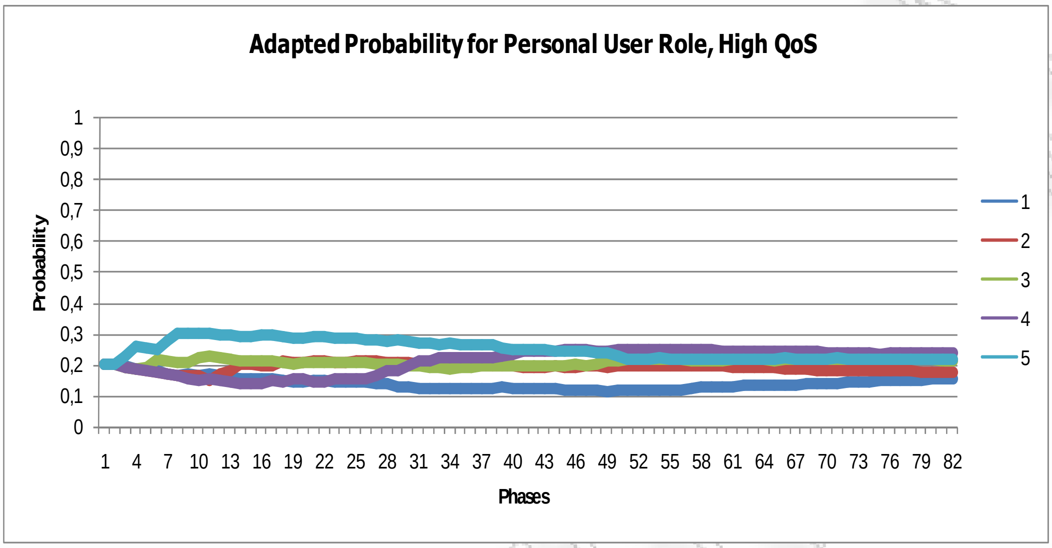

Figure 3-19: Adapted Probability for Personal User Role and High QoS, W_{hist}=0,8, $W_{instant}$=0,2

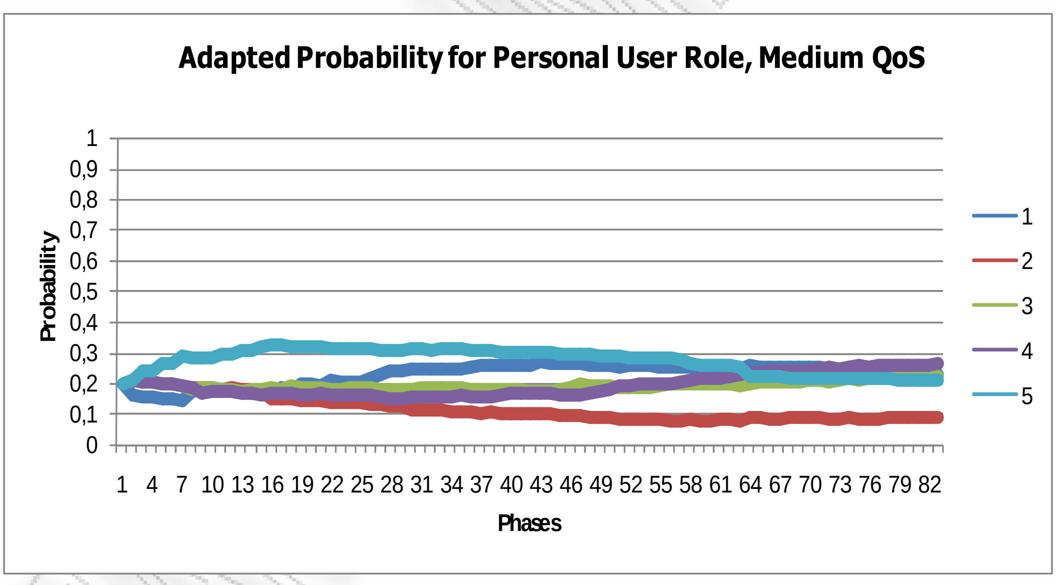

Figure 3-20: Adapted Probability for Personal User Role and Medium QoS, W_{hist}=0,8, $W_{instant}$=0,2

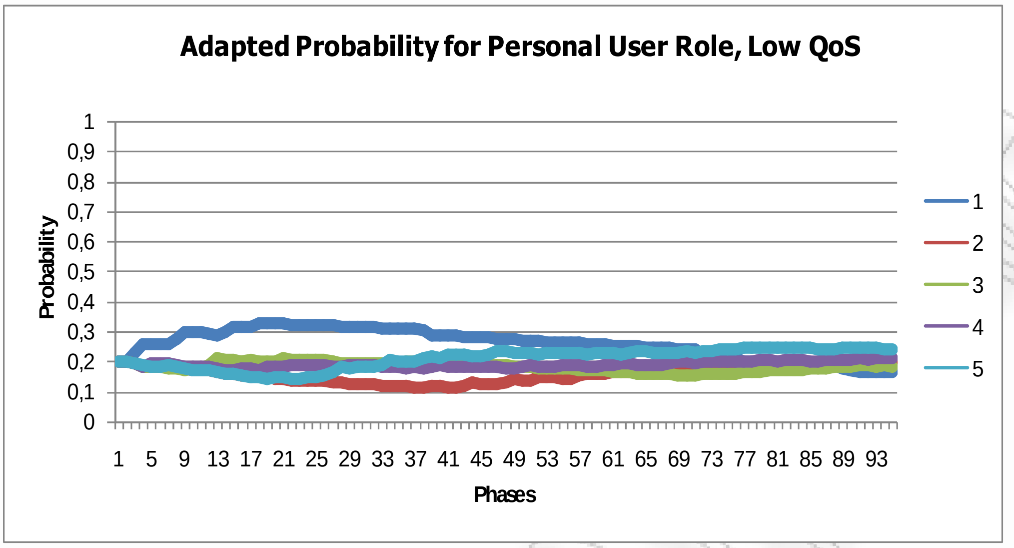

Figure 3-21: Adapted Probability for Personal User Role and Low QoS, W_{hist}=0,8, $W_{instant}$=0,2

Professional User Role

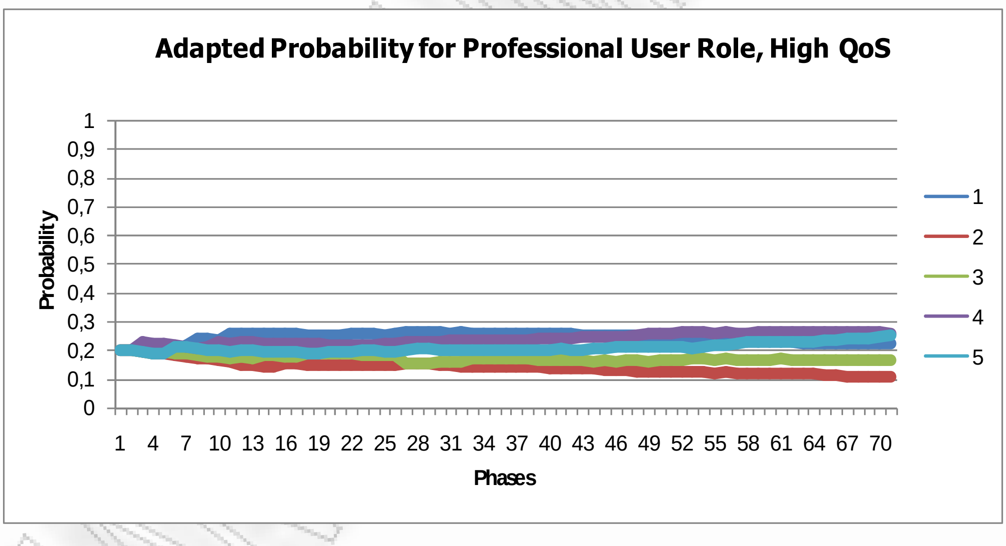

Figure 3-22: Adapted Probability for Professional User Role and High QoS, W_{hist}=0,8, $W_{instant}$=0,2

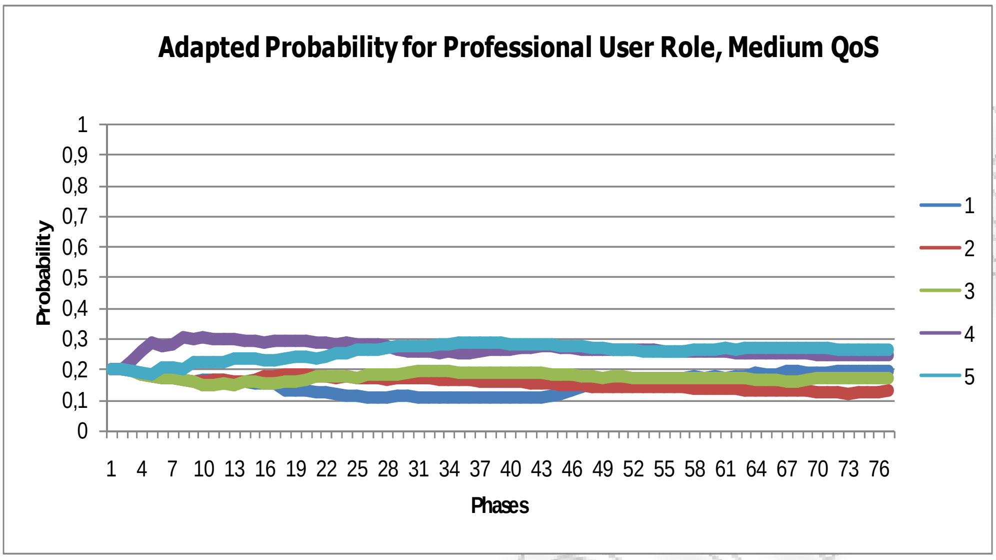

Figure 3-23: Adapted Probability for Professional User Role and Medium QoS, W_{hist}=0,8, $W_{instant}$=0,2

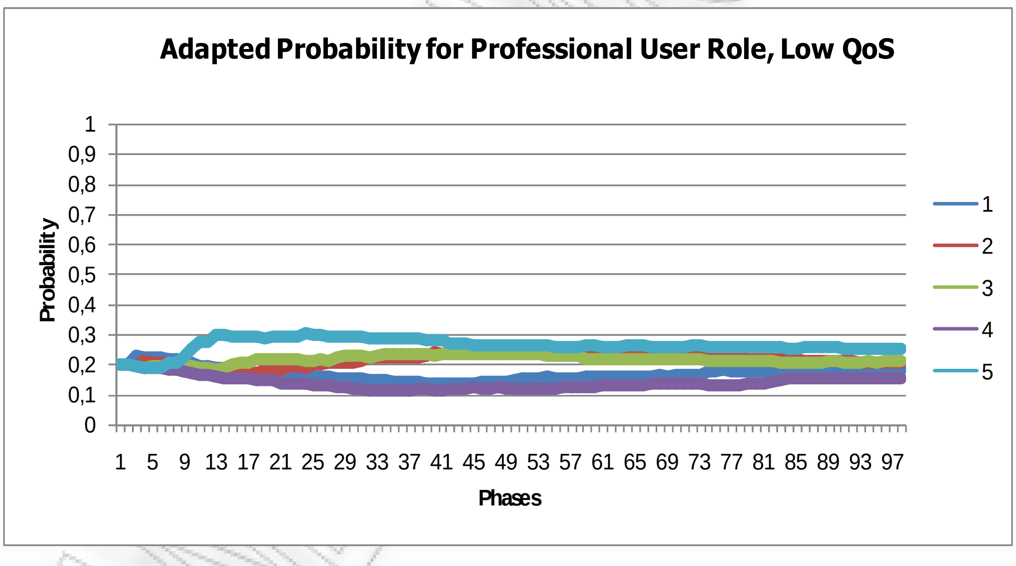

Figure 3-24: Adapted Probability for Professional User Role and Low QoS, W_{hist}=0,8, $W_{instant}$=0,2

As in Case 1, the sharp fluctuations are smoothed and the Service is therefore delivered in a more equable manner. More specifically, for the instance "Audio-Personal-High" it is deduced that the user prefers by "4" the instance, when attributing $W_{hist}=0,8$ *and* $W_{instant}=0,2$. For the instance "Audio-Personal-Medium" is in favour of "4" and "5". For the instance "Audio-Personal-Low" the user prefers "5". This means that comparing the results, the user for *"Audio-Personal"* is in favour of *Low QoS*. For *"Audio-Professional"*, it seems that the user prefers *Medium QoS*, as the percentage of this instance is higher than the Low instance and marginally higher than High instance. Therefore, the system now has created knowledge for this particular instance of the service. This knowledge may be used for future requests of this service, in order to satisfy user preferences, as recorded during this test.

3.8.2.3 Case 3: Whist=0,2 and Winstant=0,8

As mentioned previously, the Instantaneous Probability estimations Tables remain the same in all phases. Therefore, for Personal User Role the Instantaneous Probability estimations Figures are Figure 3-7, Figure 3-9 and Figure 3-11 for High, Medium and Low QoS, respectively. For Professional User Role Figure 3-13, Figure 3-15 and Figure 3-17 represent the Instantaneous Probability estimations for High, Medium and Low instances of the Service. According to Case 1, Adapted Probability estimations tables are formed for $W_{hist}=0,2$ and $W_{instant}=0,8$. The results after applying Bayesian Networks formula (19), are as follows.

<u>Personal User Role</u>

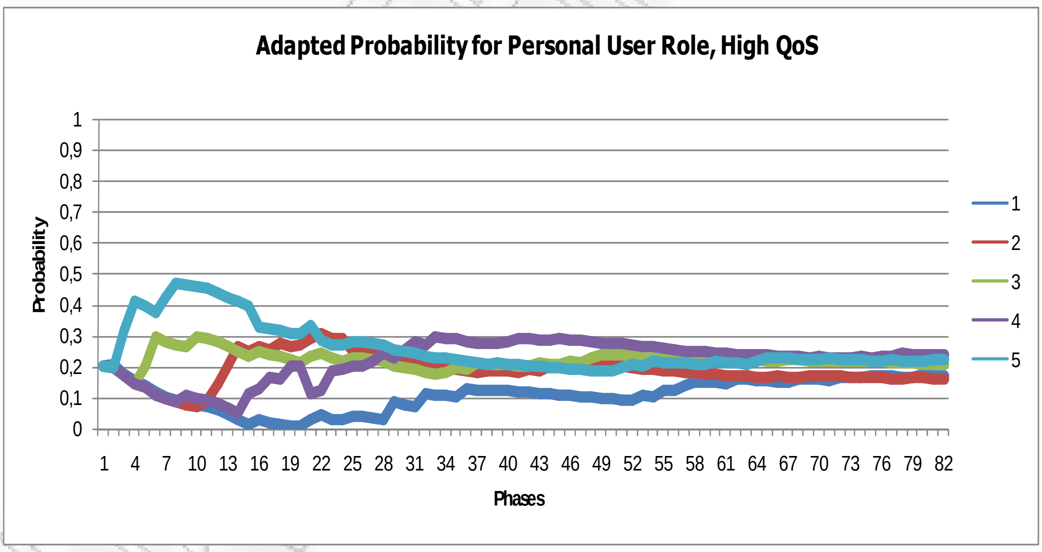

Figure 3-25: Adapted Probability for Personal User Role and High QoS, $W_{hist}=0,2$, $W_{instant}=0,8$

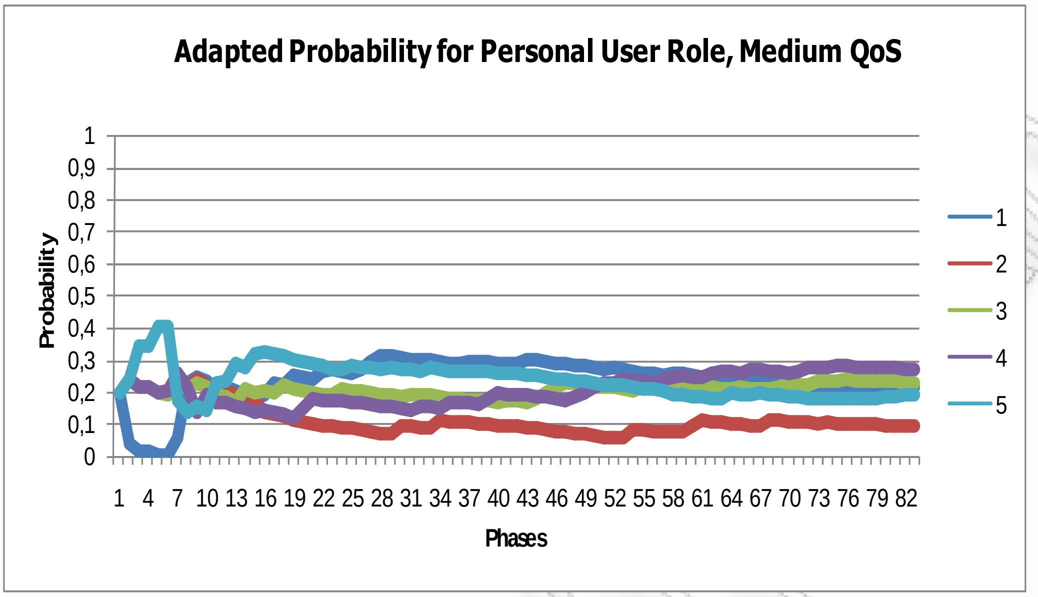

Figure 3-26: Adapted Probability for Personal User Role and Medium QoS, W_{hist}=0,2, $W_{instant}$=0,8

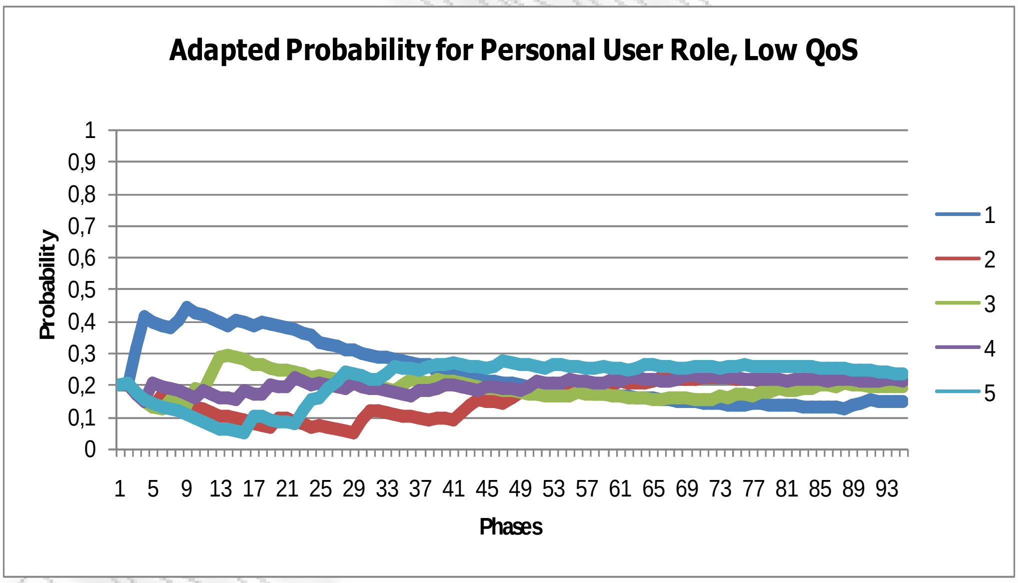

Figure 3-27: Adapted Probability for Personal User Role and Low QoS, W_{hist}=0,2, $W_{instant}$=0,8

Professional User Role

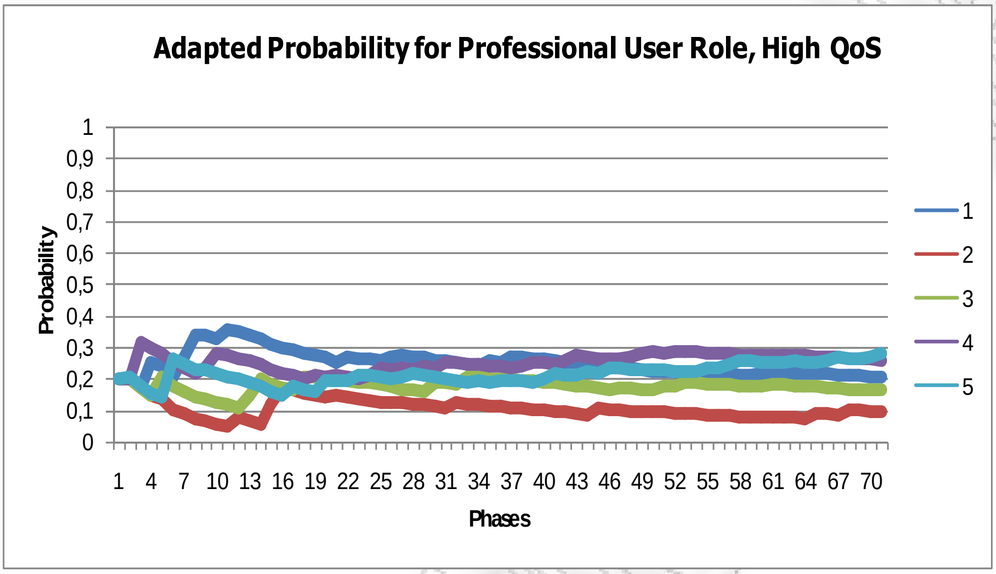

Figure 3-28: Adapted Probability for Professional User Role and High QoS, W_{hist}=0,2, $W_{instant}$=0,8

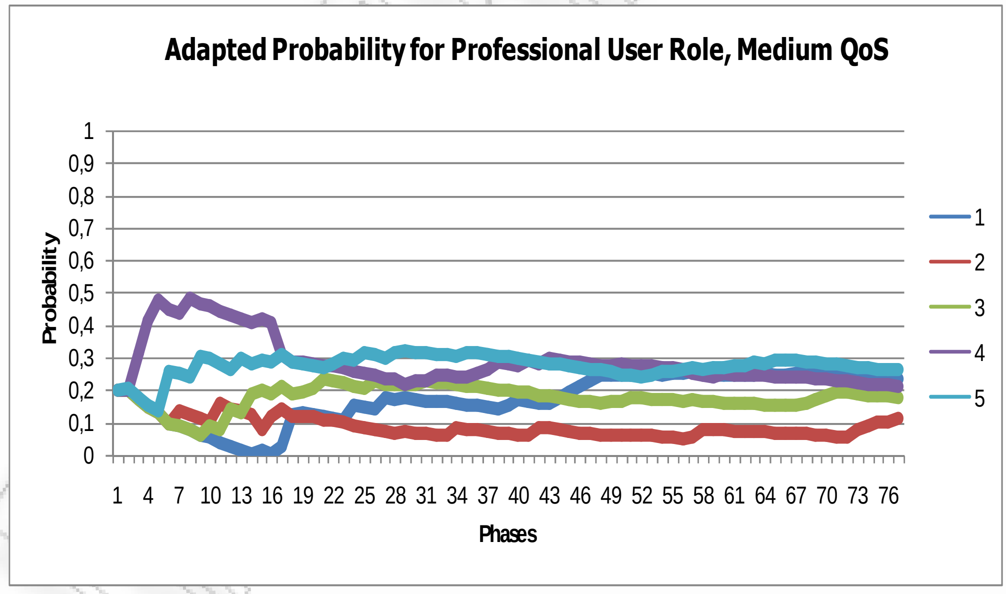

Figure 3-29: Adapted Probability for Professional User Role and Medium QoS, W_{hist}=0,2, $W_{instant}$=0,8

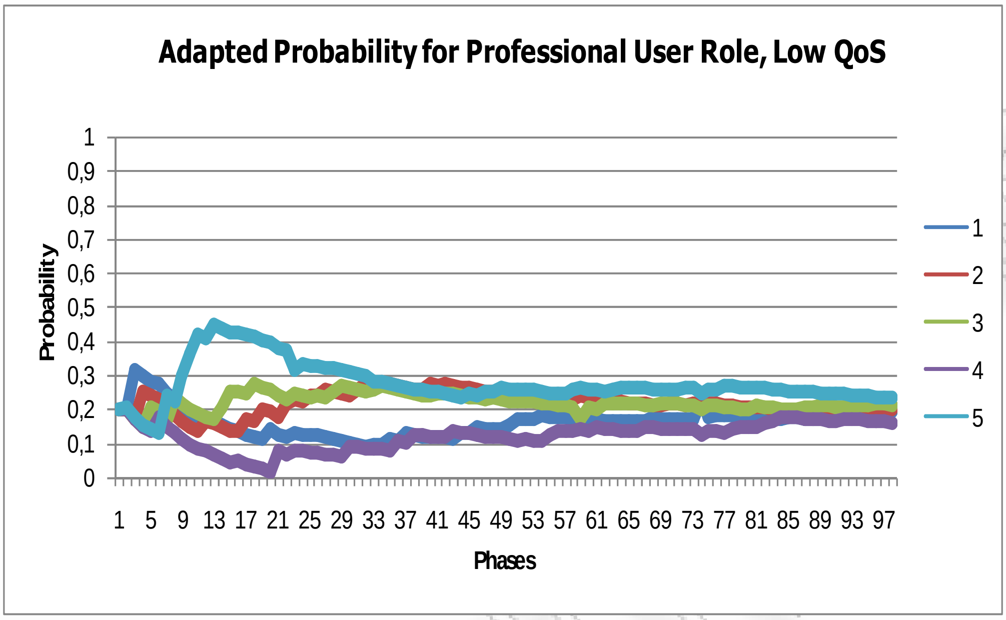

Figure 3-30: Adapted Probability for Professional User Role and Low QoS, W_{hist}=0,2, $W_{instant}$=0,8

Studying Figure 3-25 to Figure 3-30 that showcase the Adapted Probabilities estimations and comparing them with each other, we can conclude that for "Personal-High" and for "Personal-Medium" instance the probability for the user to vote "4" is higher, while for "Personal-Low" instance the probability is "5". This means that the user is more likely to be satisfied with *Low QoS*, when being in *"Personal User Role"*. For *"Professional User Role"*, is it observed that the user has higher probability to be satisfied with *High QoS*. This happens, despite the fact that the user is also satisfied with Medium and Low, as the percentage of High QoS is elevated.

Conclusively, when taking into consideration that $W_{hist}=0,2$ and $W_{instant}=0,8$, the user prefers *Low QoS in a Personal context* and *High QoS in a Professional context*.

3.8.2.4 Case 4: W_{hist}=0,6 and $W_{instant}$=0,4

According to Case 1, Adapted Probability estimations tables are formed for $W_{hist}=0,6$ and $W_{instant}=0,4$. The results after applying Bayesian Networks formula (19), are as follows.

Personal User Role

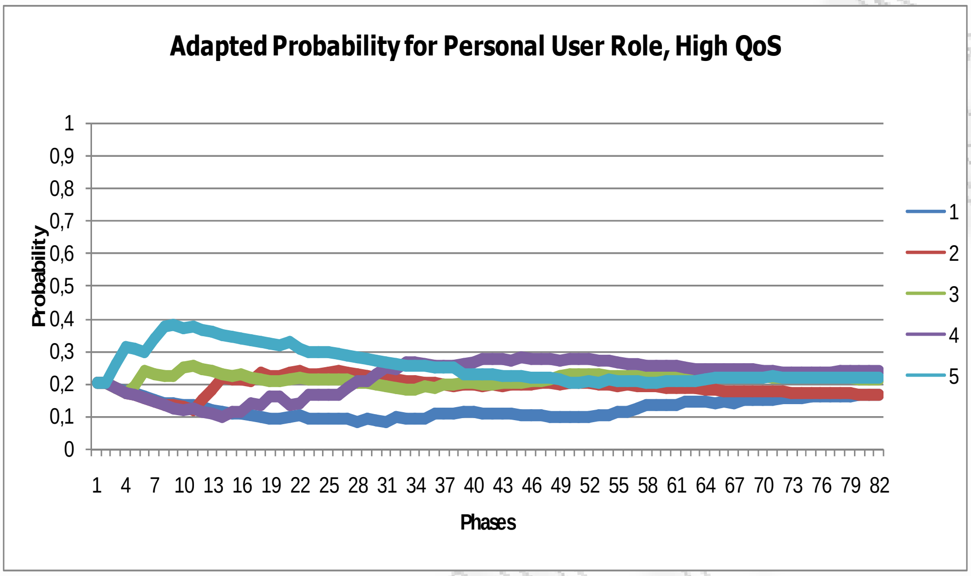

Figure 3-31: Adapted Probability for Personal User Role and High QoS, W_{hist}=0,6, $W_{instant}$=0,4

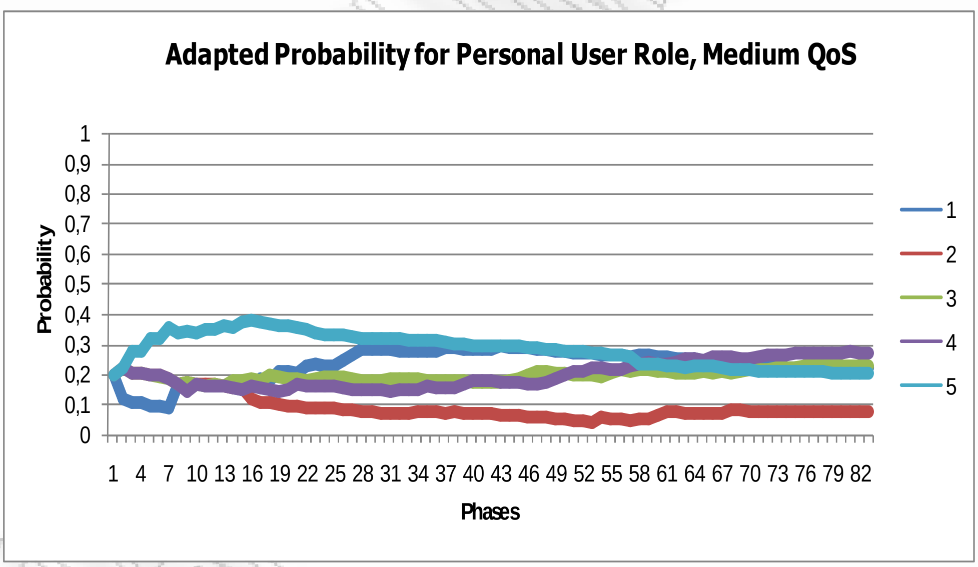

Figure 3-32: Adapted Probability for Personal User Role and Medium QoS, W_{hist}=0,6, $W_{instant}$=0,4

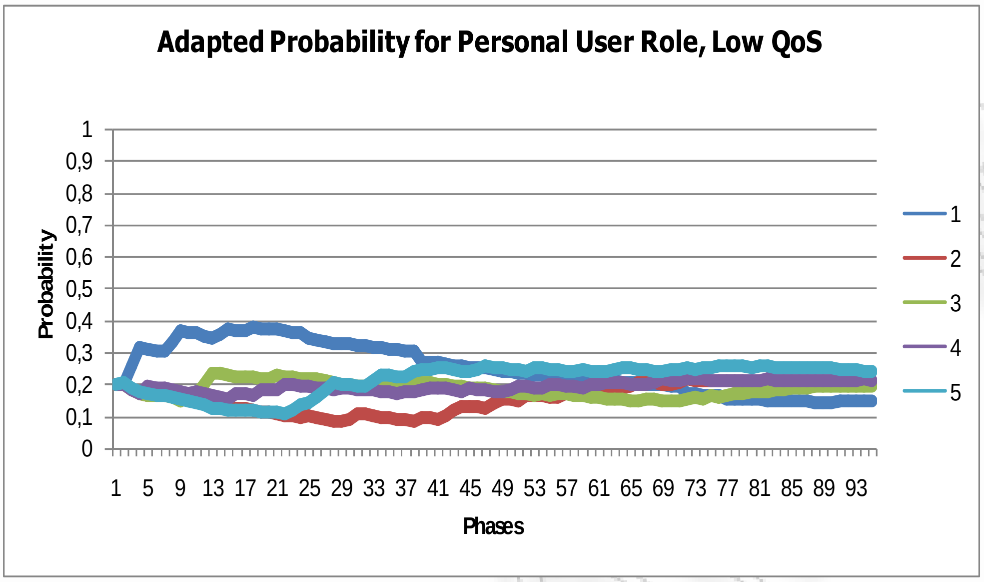

Figure 3-33: Adapted Probability for Personal User Role and Low QoS, W_{hist}=0,6, $W_{instant}$=0,4

Professional User Role

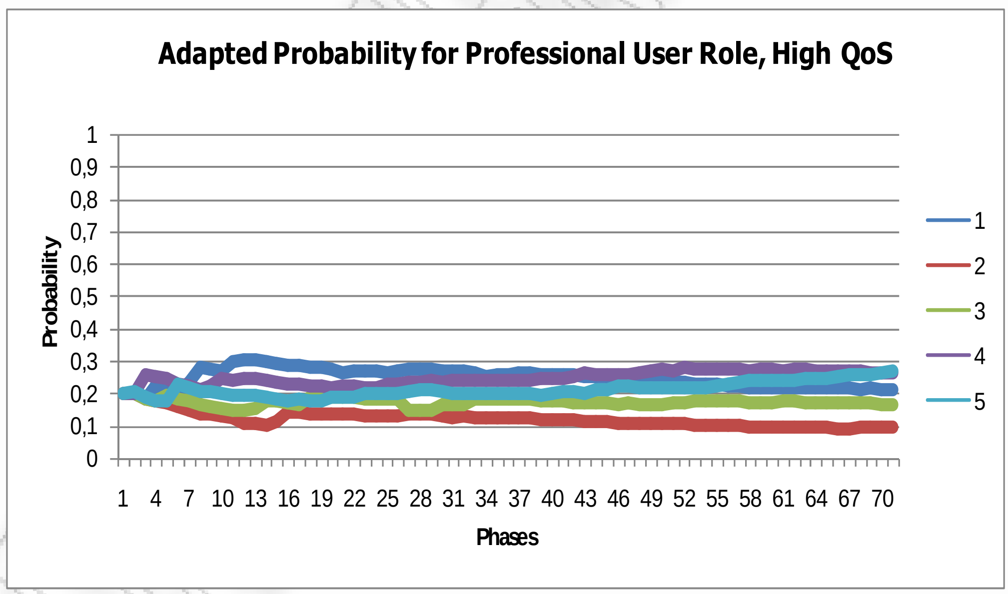

Figure 3-34: Adapted Probability for Professional User Role and High QoS, W_{hist}=0,6, $W_{instant}$=0,4

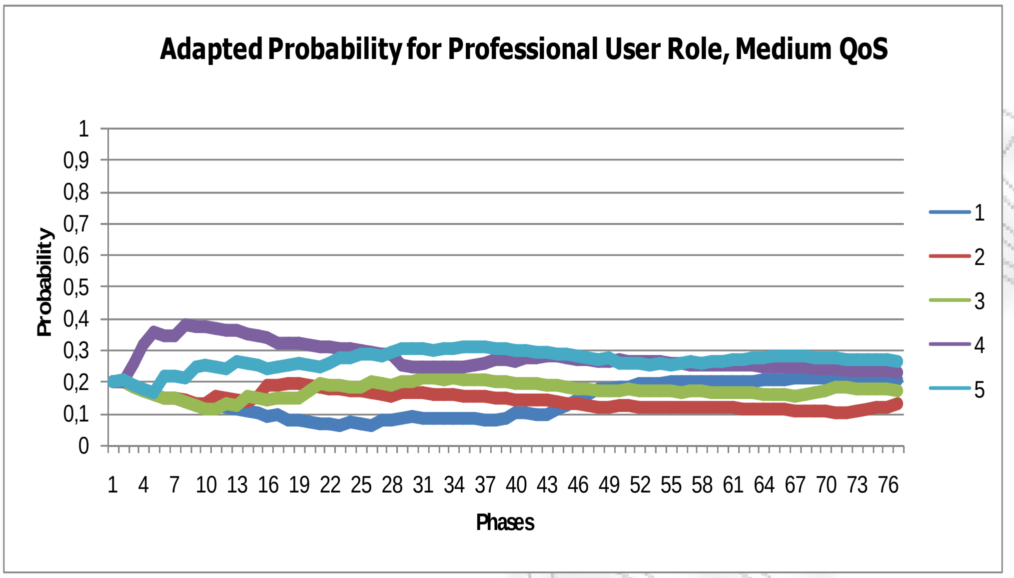

Figure 3-35: Adapted Probability for Professional User Role and Medium QoS, W_{hist}=0,6, $W_{instant}$=0,4

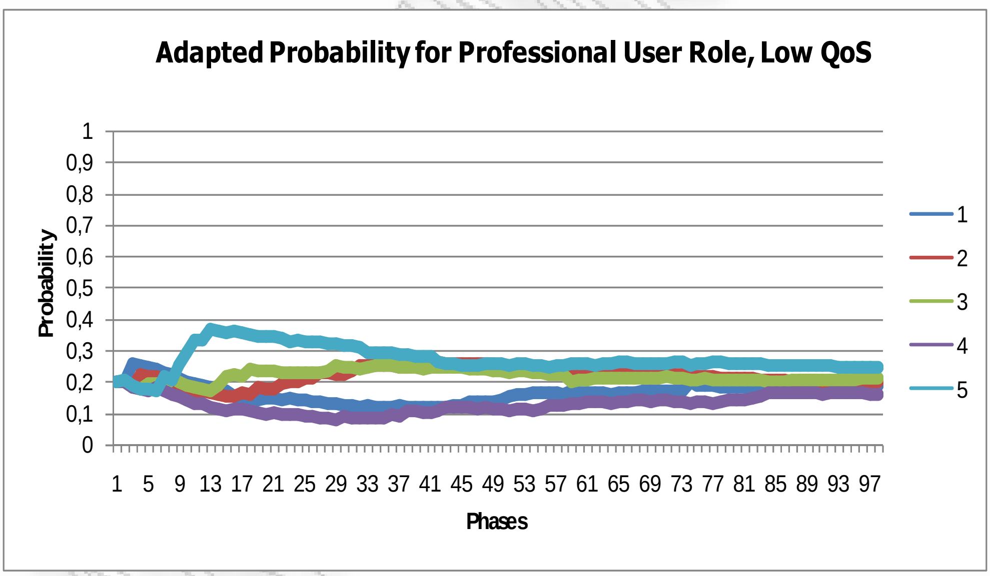

Figure 3-36: Adapted Probability for Professional User Role and Low QoS, W_{hist}=0,6, $W_{instant}$=0,4

Going through the graphical representations depicted in Figure 3-31 to Figure 3-36 and considering that *W_{hist}=0,6 and $W_{instant}$=0,4* where attributed in this case, the following conclusions may be reached. For the instance "Audio-Personal-High" it is deduced that the user prefers by "4" the instance, while for the instance "Audio-Personal-Medium" is in favour of "4". For the instance "Audio-Personal-Low" the user prefers "5". This means that the user for *"Audio-Personal"* is in favour of *Low QoS*. For the "Audio-Professional" instance, for "Professional-High" the probability of "4" is higher, for "Professional-Medium" "5" is the value that has the highest probability and finally, "Professional-Low" "5" is the value that has the highest probability, as well. Therefore, it seems that the user prefers *Medium QoS* for the *"Audio-Professional"* instance, as the percentage of this instance is higher than Low and marginally higher than High.

3.8.2.5 Case 5: W_{hist}=0,4 and $W_{instant}$=0,6

As mentioned previously, the Instantaneous Probability estimations Tables are Figure 3-7, Figure 3-9 and Figure 3-11 for High, Medium and Low QoS, respectively, for Personal User Role. For Professional User Role Figure 3-13, Figure 3-15 and Figure 3-17 represent the Instantaneous Probability estimations for High, Medium and Low instances of the Service. According to Case 1, Adapted Probability estimations tables are formed for $W_{hist}=0,4$ and $W_{instant}=0,6$. The results after applying Bayesian Networks formula (19), are as follows.

Personal User Role

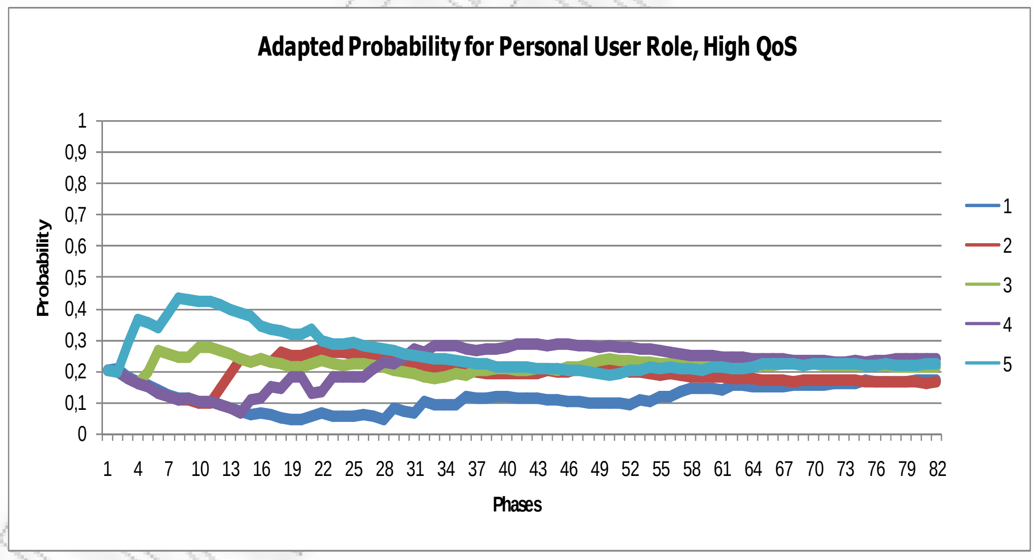

Figure 3-37: Adapted Probability for Personal User Role and High QoS, W_{hist}=0,4, $W_{instant}$=0,6

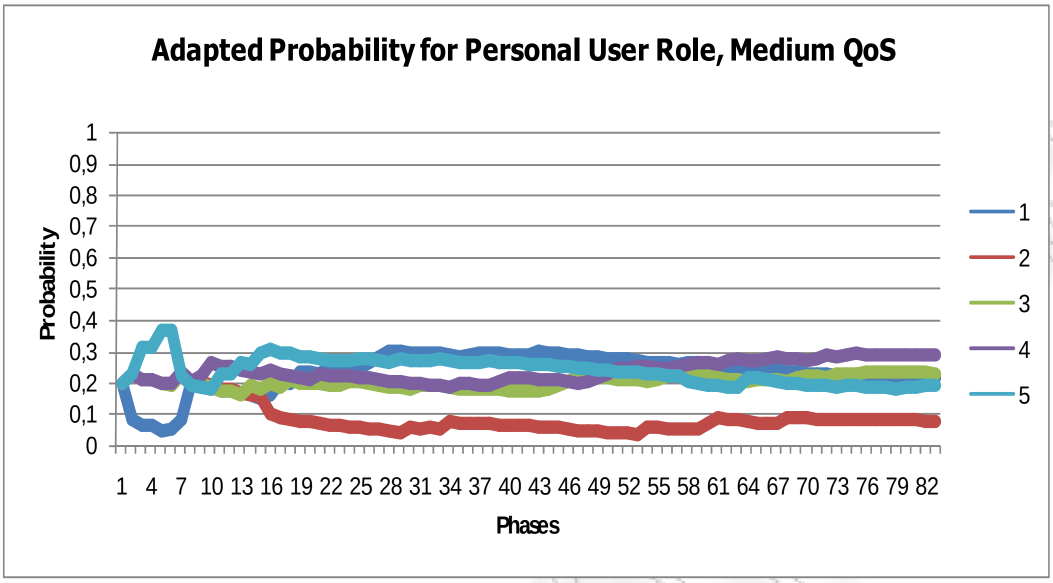

Figure 3-38: Adapted Probability for Personal User Role and Medium QoS, W_{hist}=0,4, $W_{instant}$=0,6

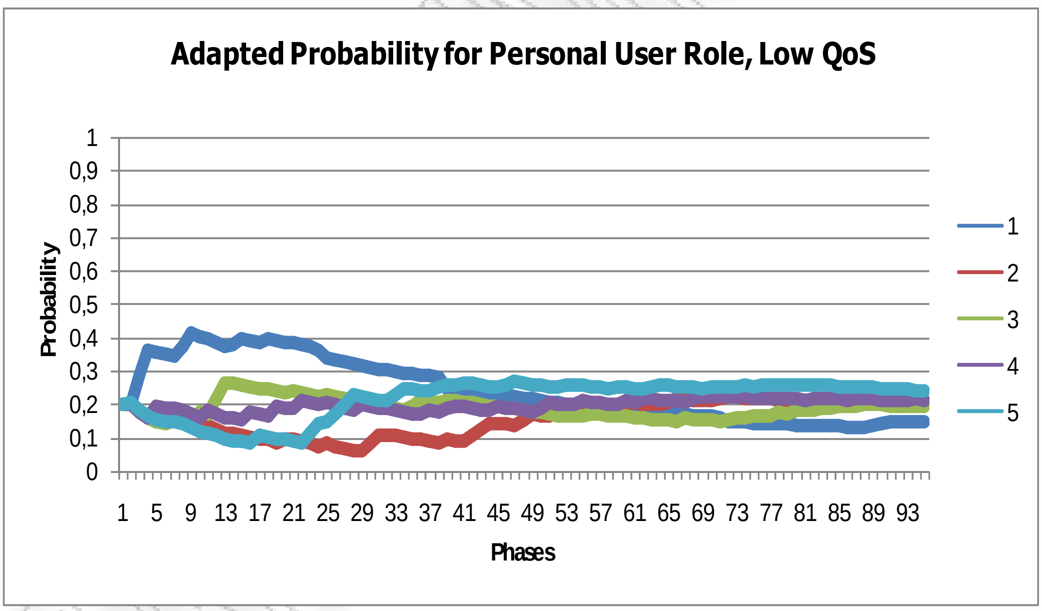

Figure 3-39: Adapted Probability for Personal User Role and Low QoS, W_{hist}=0,4, $W_{instant}$=0,6

Professional User Role

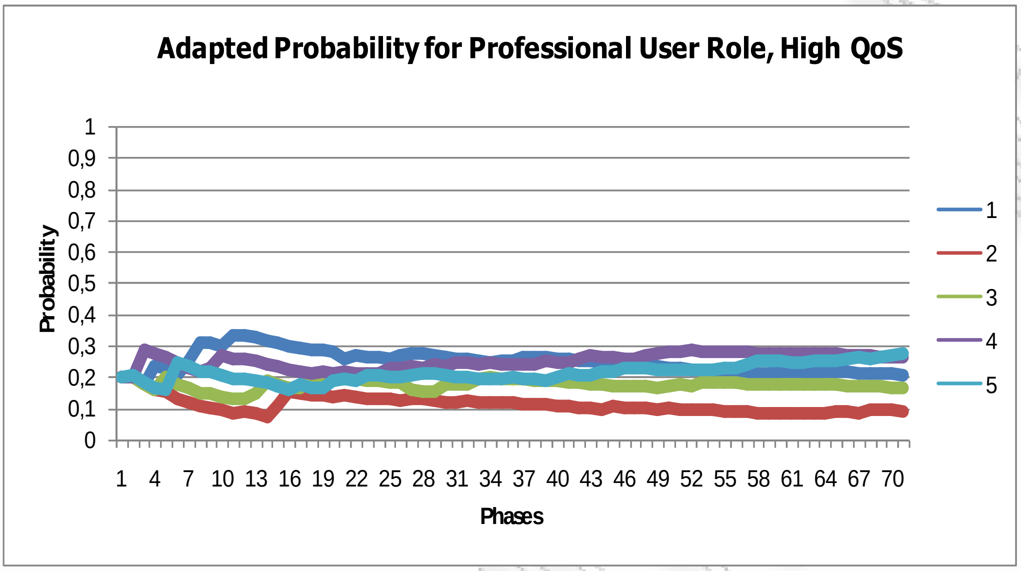

Figure 3-40: Adapted Probability for Professional User Role and High QoS, W_{hist}=0,4, $W_{instant}$=0,6

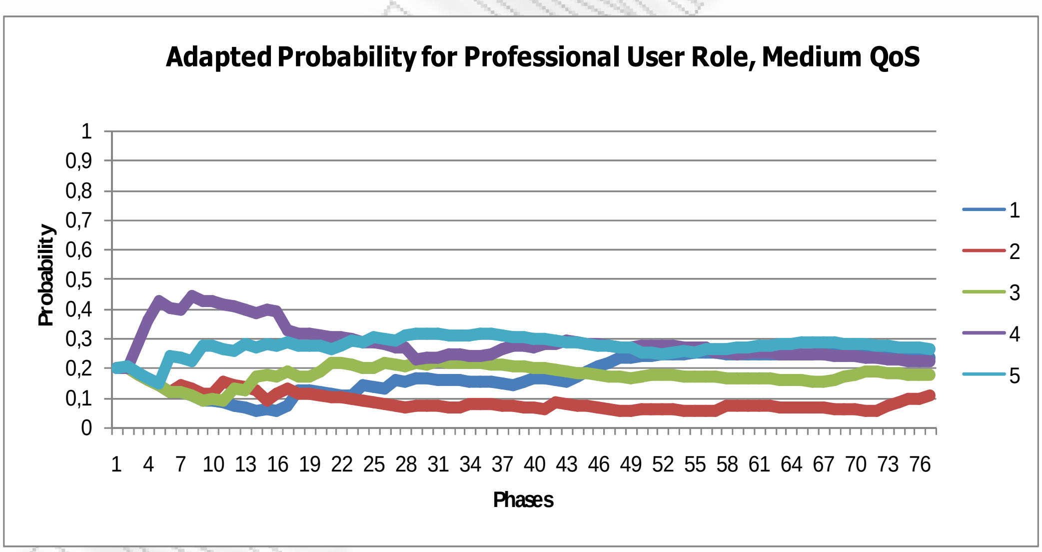

Figure 3-41: Adapted Probability for Professional User Role and Medium QoS, W_{hist}=0,4, $W_{instant}$=0,6

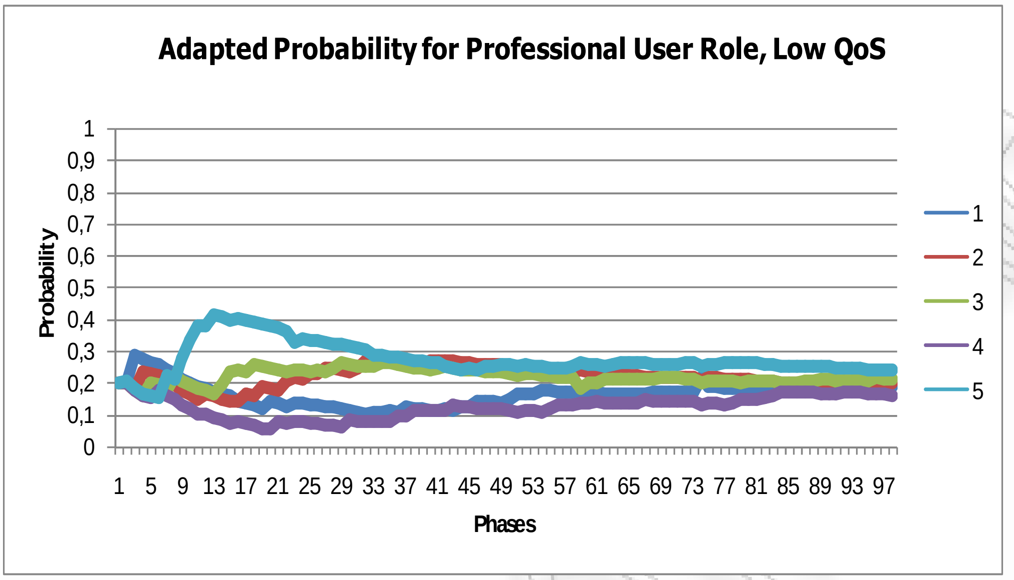

Figure 3-42: Adapted Probability for Professional User Role and Low QoS, W_{hist}=0,4, $W_{instant}$=0,6

Concluding this set of results, after attributing W_{hist}=0,4 and $W_{instant}$=0,6, the following inferences come up. For "Personal-High" and "Personal-Medium", the most probable value is "4", as for "Personal-Low" the respective probability is higher for "5". This means that the user is more likely to be satisfied when having *Low QoS* delivered to him, being in *"Personal"* User Role. For the *"Audio-Professional"* context the user seems to prefer *Medium QoS*, as the percentage of this instance amongst Low and High is elevated.

The next Section presents a summary of the results of the different cases studied within the previously described and analyzed section.

3.8.3. Summary of the Results between Bayesian Networks' Cases Examined

Summing up the various cases that were considered in the previous sections during the methodology application of Bayesian Networks, it may be concluded that in for *"Personal User Role"* the user seems to prefer *Low QoS*, despite the different cases taken for instantaneous and historical weights. On the other hand, for *"Professional User Role"* when equal weights are taken into consideration, the result is in favour of *High QoS*. Yet, especially on cases where the historical information is highly taken into consideration, the result is marginal, between Medium and High.

The following section provides a discussion on the results of the two methodologies/ approaches used in this Chapter, so as to predict user preferences.

3.9. Comparison of the Results between Bayesian Rating and Bayesian Networks' Cases

The following table (Table 3-8) summarizes the results produced by applying Bayesian Rating and Bayesian Networks methodologies. The initial input was the exact same for both methodologies, in order to have a common background and be able to compare the results.

As may be observed in Table 3-8, the results of both cases are really close. More specifically, in three cases the result is borderline Medium, for the Professional User Role, while for the rest cases the result is definitely High. For Personal User Role, the result is Low for all cases, no matter the weight taken into consideration. This has happened as the user might have been certain right from the beginning on the QoS he preferred to be delivered, when being in a Personal Context. On the other hand, for Professional User Role, the user might have been hesitant on the QoS most suitable for him. Yet, he definitely did not want to choose Low QoS for Professional User Profile. As the user proceeds using the Service he would lean more obviously on the QoS of his preference.

Table 3-8: Summary of Bayesian Networks and Bayesian Rating Results

		Cases				
Bayesian Networks		**Case 1** Equal Weights	**Case 2** Whist=0,8 and Winst=0,2	**Case 3** Whist=0,2 and Winst=0,8	**Case 4** Whist=0,6 and Winst=0,4	**Case 5** Whist=0,4 and Winst=0,6
	Personal	Low	Low	Low	Low	Low
	Professional	High	Medium/ High	High	Medium/ High	Medium/ High
Bayesian Rating	Personal	Low				
	Professional	High				

3.10. Conclusions and Future Work

This chapter presented a Cognitive Terminal Management System (CTMS), with a specific focus on functionalities for obtaining and dynamically managing information related to user preferences and elements of the user behaviour. More specifically, the chapter presented an approach for the design and implementation of mechanisms that may enable the delivery of services to users according to their personal preferences, as well as to predict future preferences, based on past observations. The requirements for the proposed system were outlined. The components of the system, targeted to addressing these requirements, were specified. Moreover, this chapter focused mainly on the Profile Management component. In this direction, the modelling of the User Profile was discussed in detail. The structure of the User Profile organised in observable parameters and output parameters, was explained in detail. The Bayesian Rating method for enabling the CTMS to learn user preferences and provide personalised services was described in detail. Furthermore, the implementation of Bayesian Networks for the prediction of future user preferences facilitating proactive functionality of the CTMS was also discussed in detailed. More specifically, for the solution of Bayesian Networks five different cases were examined, so as to have a more global view of the methodology application. The results of the implementation of both methodologies were presented and compared. The next step of this ongoing work is to implement this system using both methodologies in an integrated mobile service delivery system.

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4. LEARNING USER PREFERENCES IN AN E-LEARNING SERVICE CONTEXT

Abstract

As competition in the professional field is continuously increasing and there are numerous new information fields to explore, lifelong learning is imposed. This is supported by internet, a tool that has brought all kinds of information at the convenience of the personal context (home, work, leisure), only by few clicks. Learning by exploiting the availability of internet is made available through e-learning platforms, which have been developed, in order to make particular sets of information available to the users, depending on the information they want to know. Yet, since the needs, the expectations or the familiarization of a user with a specific field of knowledge may differ amongst users, personalisation seems to be imposed. This feature adds value to the e-learning service by forming it as the user prefers is to be, taking into consideration his personal preferences on content difficulty, content volume, level of interactivity and lesson interface. The following chapter presents a methodology on the way user preferences may be identified, with minimum user interaction, and the way the service may be adapted according to these preferences, enhancing systems' functionality. This methodology is based on Bayesian Networks, which constitute a concrete method for predicting the values of the desired parameters, based on another - much easier to measure - set of parameters. The results of the application of such methodology are also presented.

Keywords

Adaptation, Bayesian networks, e-learning service, user preferences

4.1. Introduction

There is no doubt that the era we are running is characterized by the explosion of information and knowledge, needed to be reached everywhere and at any time. Time in peoples' everyday schedule becomes even more little year by year and, therefore, the need to save as much time as possible is a necessity. Consequently, the amazingly rapid development of technology during the recent years has the power to facilitate this call for web based systems regarding information and knowledge, using devices to introduce e-learning systems [1]-[4]. The e-learning systems, able to satisfy the requirements of both novice and advanced users, are an area of interest which is always under the spotlight of research efforts. Today, significant steps have been made towards the direction of providing enhanced web-based learning systems, known as personalized educational services. Yet there is still a great volume of research that is to be further conducted with a view to rendering these services fully personalized and adaptive [4]-[7]. In this context, the user preferences should hold a primary role in personalization and should dictate the structure and functionality of the entire adaptive educational system [8]-[13].

Embedded in a so called User Profile, one of the issues that must be addressed is the prediction of the user preferences and, in general, the modeling of the user's profile, taking into consideration user's overall performance, content and system/ platform characteristics. This can prove to be a really complex and difficult task, as the values of certain attributes and characteristics of the user's profile are unknown, yet follow an implicit logic which we are trying to approximate, based on certain evidence and feedback originating from the user's navigation through the system. A further parameter to be taken into consideration is the way information should be presented to the end-user. This happens as the user is navigating through a system that provides a large and possibly overwhelming volume of information and therefore is an issue that poses extra limitations and corresponding challenges for application designers and usability specialists. Cognitive overload [14], [15] and disorientation [14], [16] are the main ones [17], [18].

Consequently, the goal is to develop an e-learning platform, which will accelerate the learning process and render it more efficient, by diminishing the emerged problems, thanks to its enhanced functionality to dynamically plan lessons and personalize both the communication and the learning strategy [19].

This section embraces the idea of the development of such an e-learning platform, capable of adapting to each user group's specific needs. In particular, section 4.2 outlines some interesting related work that can be found in the literature. Section 4.3 discusses on the structure of an e-learning system and, more specifically, introduces the main requirements of an advanced e-learning system, explains the way a user navigates in such a system, presents the architecture of a novel e-learning system, and describes its main components. These components are namely, User Model (User Profile), Domain Model, User Monitoring and User Interface. Finally, it elaborates on the User Model component and its functionality in the e-learning system. In section 4.4, the parameters comprising a typical user profile are presented. Section 4.5 discusses on User Profile Modeling, by defining a 3-layer model which makes use of Bayesian Networks, with a view to predicting user preferences. Section 4.6 presents the results of four scenarios revealing the system's performance, while section 4.7 concludes this section of the chapter.

4.2. Related work

The field of e-learning systems has received significant research attention over the past years. More specifically, numerous web-based learning systems [1]-[3], have been developed, aiming at being ubiquitously available and therefore facilitate user's learning by saving time. For such web-based learning systems research has proposed different architecture approaches and usage of distinct components to make up the architecture of the system and contribute to system's personalization. More particularly, in [10], [12], [13], [20] it is followed a similar pattern in the architecture, as using Learner Model (User Profile), Adaptation Model (Adaptation Filter), Detection Mechanisms, Instructional Views (Display Engine), Content Domain (Lesson Plan) and Feedback, as the components of an architecture to realize an e-learning platform. Moreover, [8], use as main architecture components Value-Added Services, Student Modeling Servers, and Topic Based Inference Agents. In [11] Context interpreter is used in addition to the typical architecture [10], [13], as a component which helps in the "translation" of the context and automatically process the "annotated content". In [9] it is used a layered model, using a more complex architecture consisting of the components Conceptual model (domain model), Goal and constraints model, User model, Adaptation model and Presentation model.

Furthermore, many approaches have been made with regard to e-learning system's personalization in order to achieve adaptation. This is accomplished by using monitoring and evaluation methods during the learning procedure. For instance, it can be used a student modeling server [8], explicit or implicit input by user in the Detection Mechanism [10] or an adaptation filter, which "cuts" the implied unnecessary information for the user [13]. Another method is used in [18], where it is supported that web navigation can be modeled by studying individual differences and behavioral metrics, using Latent Semantic Analysis (LSA) [21]. On the other hand research has also been done in Bayesian Networks in support of User Modeling, as a method of qualitatively and quantitatively evaluating users' behavior in the system and updating User's Profile. This means that Bayesian Networks method provides us with a simple yet effective approach to construct and handle statistical models [22]. More specifically, the problems and issues that arise in achieving user-intent ascription through dynamic User Model construction with Bayesian Networks are presented in [23]. In [24] Bayesian Networks' application infers user's learning styles according to the modeled behaviors, while [25] discusses on the ability to merge partial user models using Bayesian Networks. Bayesian Networks have also been employed to derive learner characteristics [26].

As a sequel of the abovementioned research studies, this work advocates the implementation of an e-learning platform that is able to adapt to the user's personal needs and requirements, using information not only provided directly by the user, but also derived by user's overall behavior during the navigation in the e-learning system. In particular, the proposed system is in position to predict the user's future preferences and interests, making use of Bayesian Networks, which constitute a concrete method for predicting the values of the desired parameters, based on another - much easier to measure - set of parameters. In other words, the e-learning system extracts information, by monitoring the user's actions within the system through specific parameters. Therefore, the system is able to predict user's preferences and adapt platform's characteristics in order to be consistent with the user's preferences.

Hereinafter, our focus is to include an extended set of requirements, which are essential in the development of the e-learning platform.

4.3. E-learning system structure

4.3.1. System requirements

An advanced e-learning system has to comply with the following requirements:

Personalization: This requirement suggests that the learning process needs to take into account the user's preferences and personal needs. This implies either that the user is in position to explicitly specify these preferences or that the system has the ability to infer them through a monitoring process. The latter is far more convenient for the end-user and, thereby, constitutes a highly desirable feature.

Adaptivity: The user's preferences change over time and the system must be able to track them and properly adjust to them. By 'properly' it is implied that the whole history of the user's learning behavior must be taken under consideration, and not just user's latest (most recent) actions.

Extensibility: An e-learning system has to be extensible in terms of the learning material it provides. The incorporation of new courses and resources must be an easy to accomplish task.

Interoperability: An e-learning system must be able to both access content from and provide content to digital libraries and other e-learning systems. In this way, the provision of enriched and updated content is feasible. Regarding the client side, the interoperability requirement imposes that there should be no need of specific software, in order for a user to gain access to the e-learning platform.

While the latter two requirements can be fulfilled by adopting open, web-based interfaces and following XML standards, the former two ones call for the presence of a robust probabilistic scheme, capable of inferring the user's preferences, at any time, based on monitored data and previous experience. As mentioned in Section 4.2 as well, many methods for platform adaptation have been examined and presented by experts. The use of Bayesian Networks has further potential for approaching the adaptation of an e-learning platform. In the following section we discuss on the navigation of the user in such a system, the architecture of the system, and we concentrate on the User Model component, so as to have a more complete view of the platform discussed.

4.3.2. User navigation

The goal of an e-learning platform is to effectively interact with users, offering them the appropriate information, while conforming to their preferences and needs, in order to evolve their knowledge and skills on certain topics. To this end, the development of an efficient system, which will contribute to users' effective learning, is a challenging research task.

Within this framework, Figure 4-1 represents the way an e-learning system works, and, more specifically, the user navigation procedure.

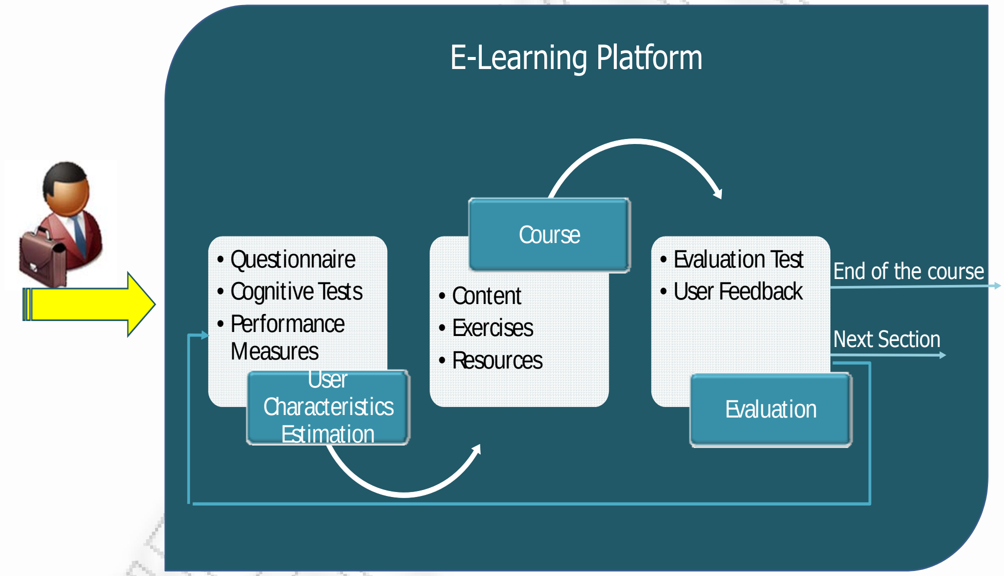


Figure 4-1: User's navigation in the e-learning platform

In such a system, the user enters the educational platform for the first time. Then, the user is asked to participate in a set of questionnaires, cognitive tests and performance measures [27]. These questions aim at extracting some initial clues regarding the user's preferences, skills and personal goals. Using these features, the system forms an initial profile for the user in the system. This profile classifies each user in a particular group of users, assigned with specific attributes. The socio-cultural status, the interests, the previous experience in working with computers and the expected outcomes of studying the particular material are some indicative attributes that characterize a group of users

[18], [28], [29]. In this sense, categorization may classify a user in "novice", "intermediate" or "expert" group, based on user's previous experience on the specific field of knowledge. As soon as a user completes a course, the system is, with the help of Bayesian Networks, in position to infer whether there needs to be a change in user's group. If the answer to this question is affirmative, the system changes user's group accordingly and caters to present the appropriate (of the specific group's) information, as it is also discussed in Section 4.5.2. The main idea of user grouping is to reduce the complexity of the system and make it more flexible regarding the amount of information stored, as well as the time it takes to process this information and provide user with the appropriate learning material. In this work we use specific parameters for characterizing a user and classify this user in a certain group, namely Context, System Characteristics and User Performance, as presented in Section 4.1 and further discussed in Section 4.5.2.

After completing the set of provided questions, and being integrated in a specific group, the user starts navigating in the system, as depicted in Figure 4-1. The user explores the available material, studies the courses and the given resources, and takes the correspondent exercises, following the path considered more interesting and spending time on. Issues the user thinks worth studying and are likely to enrich user's knowledge are also examined, as the system provides material for further knowledge enhancement, covering each of the sub-fields presented to the user.

At this point, the system has developed specific mechanisms, so as to detect the user's reactions to the incentives given by the e-learning environment. For instance, in case the system has noticed that the user is viewing a page for a much longer time than expected, it may use a pop-up window to clarify the user's opinion about the specific material. Thus, the system communicates with the user and defines whether it is difficult to understand the meaning of the page, or it is very interesting and needs further information on the topic. Consequently, the system will have to provide the user with some additional and simplified information, so as to make the learning material more comprehensible, or, on the other hand, offer extra resources for further studying and increasing user's knowledge on the subject. The system updates user's profile after this interaction between them with the appropriate information, which may result to a simple enhancement of user's profile with additional information, or even to changing user group, as the system can understand what are user's needs or targeted skills have changed (i.e. a user may be characterized as an "expert", after being "intermediate"). This update is realized through the according parameters, which help the system in monitoring user's behavior. The methodology used to update user's profile is extensively discussed in section 4.5.

When completing a chapter or a lesson, it is assumed that user's knowledge on the particular field involved is enhanced. This can be certified by a test taken at the end of the course. The answers given to the questions reveal the depth, in which the user has understood the material went through, and indicate an evolution or modification in user's preferences, skills and expected outcomes for future content. Along with this, the user is provided with some feedback designed from the course tutors/ experts, according to the answers to the questions. The role of this feedback (pop-up windows) is to direct users to further study the lesson's section they did not fully comprehend, as well as emphasize the points they have managed to absorb as expected. Similarly to pop-ups, is treated system's feedback; the system monitors (with the help of parameters) user's acceptance of the feedback or not and responds accordingly. By taking into account the questionnaire and test results, the answers provided to the pop-up questions during the lesson, it is possible to adapt the material that is to be displayed to the user in the next lesson to be virtually attended, as well as update the user's profile. The practical way in which the user's profile is updated, so as to conform to the user's changing needs and skills, is examined thoroughly in section 4.5.

This procedure takes place every time a user enters the e-learning system, taking into account both user's already formed profile, as well as the path of information the user chooses to follow during each course. Needless to say that the initial test, mentioned in the beginning of the chapter, is taken only at the very beginning of user's navigation in the system. Then the system stores the information in User Profile and forms it accordingly when needed.

4.3.3. The proposed e-learning system and its components

In the previous section, the navigation of a user in an e-learning system and the interaction with it during this navigation were described. This section intends to define the architecture of such a system, as well as the components that comprise it, with the aim to provide users with a compact platform, rich and comprehensible content, and apposite feedback.

The e-learning system proposed in this work is comprised of four main components: *User Model (Profiles)*, *Domain Model (Content)*, *User Interface* and *User Monitoring*, as illustrated in Figure 4-2.

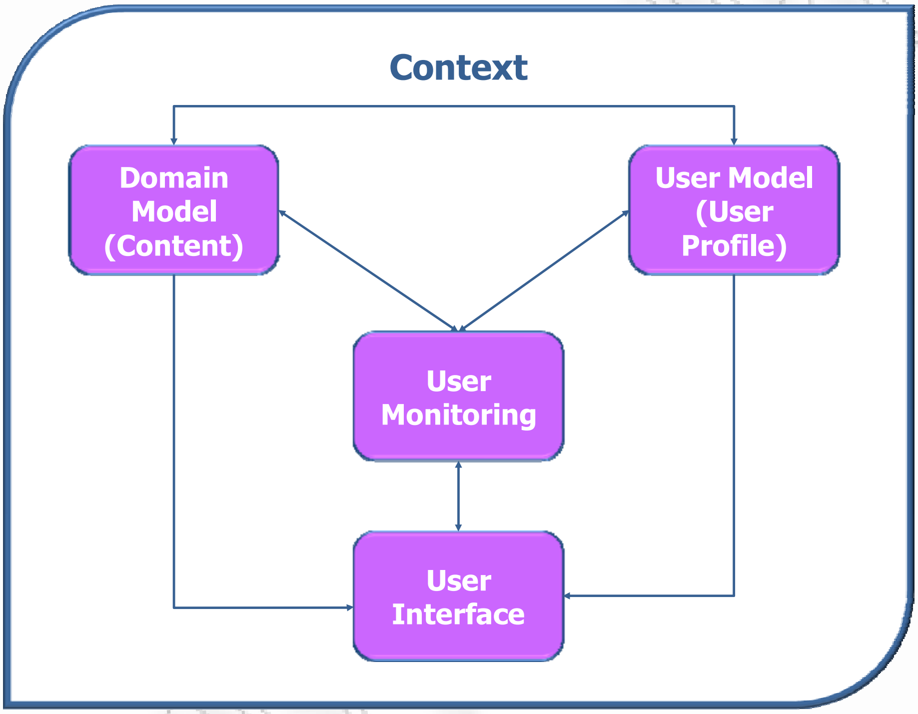


Figure 4-2: E-learning system's architecture

Each of these components has an irreplaceable role in this system, rendering its presence mandatory for the system's functionality [10], [13], [14], [29], [30].

The *User Model* component stores all user-related data, such as the users' profiles, including personal information, preferences, monitored user actions and user performance related data. This component enables the system to deliver customized instruction, on the basis of the individual student's, or student group's, learning style [29]. Learning (or cognitive [14] styles [31], as they are one of the factors composing user grouping, presuppose different people perform differently and reach to different learning outcomes, given the same learning content. This is mainly attributed to unequal previous knowledge, motivation and intellectual properties [25]. Thus, cognitive styles are an important part of a learner's personality [32]. Several groupings regarding learning styles [33]-[38] have been proposed. The aim is to define the best way people learn and apply it to teaching method. This is achieved by providing a set of simple questions in the beginning of the first course (as a part of the questionnaire). Some of these questions refer to user's learning styles, and more particularly to the way that people prefer knowledge to be presented to them, the way they feel more comfortable with the learning procedure and content's structure. The system receives a first picture on the learning style of the user and classifies this user in a user group. Of course, the system keeps monitoring user's behavior and may accordingly change user's group, in case it infers that the user needs a different (more advanced) context in order to be able to work and perform better. In the forthcoming sections, focus is given on this component, since it plays an integral part in rendering the e-learning system adaptable and user-centric, and therefore truly cognitive.

The *Domain Model* component stores information about the material that is to be delivered to users. In particular, learning theories [39] that have been evolved the last two decades, as well as learning styles [40] that have been identified, have shown that not all users learn in the same way, due to socio-cultural and educational differences and different life experiences. Thus, the educational material will have to be expressed and presented in different ways, aiming at fulfilling the users' special needs. The Domain Model stores the learning segments (learning courses) in XML format and, when notified, provides the appropriate information to the User Interface component, utilizing the instructions sent by the User Model, about each user group's preferences.

The *User Interface* is the component that exploits information from the User Model (Profiles), in which the users' preferences are stored, and the Domain Model (Content), in which each lesson's structure is stored, and forms the final content to be delivered to the user. This content is formed in pages using Java Servlets [41], and comprises the material to be finally presented to the user.

Finally, the architecture comes full circle with the *User Monitoring* component. This mechanism monitors each user's behavior during the navigation in the e-learning system, detecting the user's interest on certain subjects, or weaknesses of understanding in some others. The data collected in the User Monitoring component are transferred to the User Model, in order to serve as input for the adaptation of the user profile.

Summarizing the above, the proposed e-learning system's architecture consists of four main components, which aim at rendering the system easy to navigate, interesting and attractive to the user, as well as adaptable to particular characteristics and learning style preferences, imposed by each user group.

4.3.4. Role of the User Model component

In the previous subsection, the User Model component was briefly outlined. In this subsection, the User Model's role, the parameters that characterize it and its function in the system will be analyzed.

The main objective of the User Model is to tailor the learners' information space, by presenting learning material according to each group's cognitive level/progress, socio-cultural attributes, goals, plans, tasks, preferences, and beliefs [42]-[44].

In more detail, the user is initially provided with a certain amount of questions and cognitive tests to fill in when entering the system, as also stated in section 4.3.3. This set of tests aims at tracking some primary characteristics regarding the user's preferences. More specifically, the system wants to identify what are the reasons that impelled the user to take the particular course, what the user expects to learn, how much is the user familiarized with the content of the course and, thus, whether the user is considered to be a novice, an intermediate or an expert in the subject. Later on, the way the user wishes the material to be presented, the level of interactivity preferred with the system, and the depth of content complexity desired, are also essential information for the system.

In summary, the User Model has to infer the following information:

a. the users' preferences concerning the content of each course, and

b. the users' preferences regarding the structure of the user interface/ platform.

Furthermore, it has to store the following information:

a. the users' profiles, i.e. personal information about each user,

b. information about each user group, i.e. which members it consists of, what are its main characteristics (e.g., group of novice or expert users),

c. log files about each user's behavior during navigating the system,

d. the answers each user provided to the set of questions and tests, when entering the system for the first time, and

e. the scores in the exercises and evaluation tests, when completing a lesson, as well as the feedback provided by the administrator of the course, for each user.

4.4. User Profile parameters

A user's preferences are constantly changing, as progressively studying the offered courses, enhancing the knowledge and viewing different aspects of a subject. This means that the system should revise certain aspects of the offered learning procedure, in order to better meet the user's evolved needs. Each of these aspects is influenced by one or more factors that reflect the user's behavior within the system.

More specifically, user profile parameters aid the system to effectively monitor user's navigation in the system and also to record specific information regarding user's preferences and needs. Several articles have been presented over the last years [27], [43], [45], [46], [47] proposing or implying parameters that influence User Profile. For instance, in [43] it is supported that "in general, the pedagogical agent provides unsolicited hints when the probabilities in the student model indicate that the student is missing key pieces of knowledge to learn from her current move." This states clearly that an agent is used to monitor user's behavior, report and update his Profile and consequently provide the missing material. Thus, for instance, the parameter "Lesson Duration" used in this chapter, which will be presented in the next section, represents the aforementioned procedure, as it triggers monitoring and system interacting with the user when exceeding a specific time limit and therefore influences parameters Content Difficulty, Content Volume and Lesson Interface. Claypool concludes that "updating and improving such user models is possible, since each user action counts as a re-diagnose of the user" [46], [47]. This means that user's behavior can be monitored through parameters concerning the navigation in the system and certain points of user's behavior and, by being kept in log files, this information can be updated accordingly.

Hence, following the previously presented methodology, we use parameters categorization following [27], [45] example in order to make User Profile parameters' evaluation more effective and productive. Therefore, we assume that a user's e-learning profile consists of two types of parameters: the learning procedure preferences, which will be referred to as 'target parameters', and the influential factors, which will be called 'evaluation parameters'.

In what follows, four target parameters and three evaluation parameters are presented, in order to retain the forthcoming analysis both realistic and easy to follow. More complex models may incorporate a higher number of parameters, yet the nature of the analysis does not change.

4.4.1. Target parameters

The target parameters include *Content Difficulty*, *Content Volume*, *Interactivity*, and *Interface*. By keeping these parameters updated, the system is able to provide the user with the appropriate content, in the most suitable way. The values of these parameters are modified according to the user's behavior in each didactic unit.

Content Difficulty is influenced by the level of the user's knowledge on the subject, being a novice, intermediate or expert. As the user takes more and more courses, the level of knowledge changes, from novice to intermediate, or from intermediate to expert, and consequently asks for more complex content, with more detailed information on the subject and more advanced resources to explore. *Content Difficulty* may be attributed to one of the following three values: low, medium, or high.

Content Volume refers to the amount of information the user wishes to explore in the lesson to study. Low, medium, or high are the values that *Content Volume* can be set to.

Interactivity is one of the parameters much appreciated by e-learning users. This is because Interactivity makes the user feel that the system is intelligent and able to adapt to user's preferences, as well as in position to understand the difficulties encountered and to help in solving them. *Interactivity* may also take the values low, medium, or high.

Another important profile parameter, which is the desired type of *Lesson Interface*, is influenced by user's learning styles and user preferences on content structure. Consequently, the Lesson Interface parameter is connected to the learning procedure preferences. This parameter is assumed to have four different values: Simple, Normal, Rich, or Advanced.

4.4.2. Evaluation parameters

Though it may seem as easy, it is in practice rather difficult to properly set the values of the target parameters. In most cases, even the user is not in position to realistically estimate his educational level, the level of familiarity on a subject or the expected outcomes of taking a specific course. Therefore, we need to set a number of evaluation parameters, which aid the system to predict the user's preferences, as progressing with the study of the provided material. The evaluation parameters are the *Lesson Duration*, the *Test Duration*, and the *Performance*.

More precisely, *Lesson Duration* refers to the time that a user spends for completing a didactic unit/lesson. This time is measured and then compared by the system to a set of (pre-estimated) threshold values, which depend on the particular lesson. The result is the classification of the user's time in one of the following four classes: low, medium, high, or very high. The value of *Lesson Duration* subsequently affects the determination of the target parameters' values. The *Test Duration* parameter is similar in nature, with the difference that it is related to the time that a user spends to complete a test.

What is also measured and taken into account in the process of user preferences prediction is the *Performance* parameter. By keeping the user's test scores, the system can estimate how well the user has comprehended the concepts of the course. This parameter is assumed to have four possible values: 'A', 'B', 'C', or 'D'.

Therefore, the system is adapting to user's preferences, with the help of user groups and Bayesian Networks. An example of the classification in groups used for users is presented in Table 4-1.

Table 4-1: User Groups – Target Parameters

	Novice	**Intermediate**	**Expert**
ContentDifficulty	Low	Medium	High
ContentVolume	Low	Medium	High
Interactivity	High	Medium	Medium/ Low
LessonInterface	Simple	Normal/ Rich	Rich/Advanced

In case the system has inferred after the initial short questionnaire that the user is Novice, it presents the corresponding information and it adapts accordingly, using the information by Table 4-1. Thereafter, the user takes the course and the system monitors user's navigation and behavior. This is done by measuring the evaluation parameters, as discussed previously. Comparing the values of these parameters with the data of Table 4-2, the system can conclude whether the group of user will have to be changed or not. In any case, the system consults Table 4-1 in order to define the information to be presented to the user, according to user group.

Table 4-2: User Groups – Evaluation Parameters

	Novice	**Intermediate**	**Expert**
LessonDuration	Very High, High	Medium	Low
TestDuration	Very High, High	Medium	Low
Performance	Low	Medium	Very High, High

On the other hand, in case the system receives conflicting pieces of knowledge to arrive at group – specific probability tables it uses probative pieces of information in order to define user's reaction on this (i.e. different user interface, or easier content) and adapt to the most appropriate form, through User Monitoring Component. This methodology is presented and confirmed by Scenarios 1 and 2 of Sections 4.6.1 and 4.6.2, respectively.

4.5. User Profile Modeling

4.5.1. Overview

The functionality of the proposed system for the modeling and adaptation of the user's profile comprises three different functional layers, as depicted in Figure 4-3. The role of every layer is described thoroughly in what follows.

Monitoring Layer: The role of this layer is to collect the values of certain key indicators, which will, in turn, be used for the evaluation and adaptation processes. These indicators are representative of the user's general performance and assist in forming user's profile. In other words, this layer is responsible for retrieving the corresponding measurements from the User Monitoring component of Figure 4-2.

Modeling and Evaluation Layer: The main functionality of this layer lies in retrieving the information collected from the monitoring layer and in modeling it in an efficient way. For this purpose, this layer makes use of Bayesian Networks, which have proven to be valuable tools for the encoding, learning and reasoning of probabilistic relationships [48]-[52].

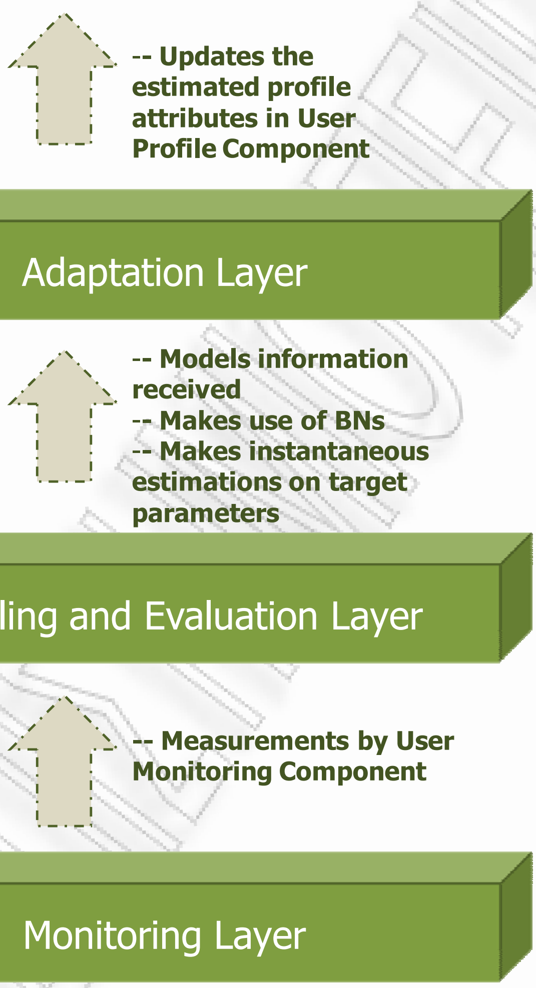


Figure 4-3: Functional layers of the user profile model

Once the values of the monitored parameters (i.e., the evaluation parameters) are retrieved through the Monitoring Layer, the Modeling and Evaluation Layer caters to providing this evidence to the model, in order to acquire some instantaneous estimation about the target parameters of the user's profile. The application of a specific model must anyhow comply with certain requirements. In particular, the selected model must reflect the actual causal relationships between the different attributes, while taking into account, at the same time, the degree of their dependency, which implies that the way different parameters are affected by the evidence varies.

Adaptation Layer: This layer is responsible for updating the estimated profile attributes according to the evidence received through the indicators of the Monitoring Layer. This evidence serves as feedback in order to acquire knowledge related to the user's behavior. What needs to be highlighted is the necessity to take into account, not only the current feedback, but also the past monitored evidence. In this way, any irregular information or any temporary performance fluctuations will not affect tremendously the estimation process. The need to encompass historical information in an e-learning system, as described in Section 4.3.4, is more than obvious, since such a system needs to evaluate not only a user's current performance, but also his overall progress.

4.5.2. Modeling and Evaluation Layer

Figure 4-4(a) depicts the Bayesian network employed for the modeling of the relationships between the target and evaluation parameters of a user's profile. As can be observed, the causal relationships between the parameters under consideration are as follows.

Content Difficulty dependencies: This parameter depends directly on the values of all evaluation parameters. The actual lesson duration, the test duration and the user's performance dictate the difficulty level of the content that should be provided in the next lesson to the user.

Content Volume dependencies: The volume of the content that should be provided in the next lesson to the user is affected by the time needed to complete both the previous lesson and the corresponding test. Content Volume parameter's dependency on the performance cannot be considered primary, since large content volume does not necessarily suggest great difficulty and therefore the amount of information provided is not an accurate factor to influence user's performance and vice versa.

Interactivity dependencies: It is assumed that the degree of the required interactivity is determined solely by user's past performance. More specifically, if a user achieves low performance, it is quite probable that further guidance is needed, thus more interactivity and knowledge communicability, through the lesson. On the other hand Lesson Duration and Test Duration are not safe factors to determine Interactivity, as the time spent on a lesson or test cannot determine in a secure manner user's view on the system's communicability of knowledge. The knowledge communicability and ability to request certain pieces of information is what we refer here to as Interactivity.

Lesson Interface dependencies: It is realistic to assume that the only indicator affecting the type of interface needed throughout a lesson is the amount of time that the user has spent in the previous lesson. This means that the way information is presented in the course (interface's appearance, complexity, etc) cannot be safely determined by the time a user spent on the respective test or user's score in the test.

With reference to the model of Figure 4-4(a), the notations depicted in Table 4-3 will be used for estimating the desired probabilities.

Table 4-3: Parameter Notations

Parameter	**Notation**
LessonDuration	LD
TestDuration	TD
Performance	R
ContentDifficulty	CD
ContentVolume	CV
Interactivity	I
LessonInterface	LI

The goal is the determination of the values of the parameters *CD*, *CV*, *I* and *LI* that maximize the following joint conditional probability:

$$P(CD, CV, I, LI \mid LD, TD, R)$$

In what follows, we will demonstrate that the calculation of the abovementioned joint conditional probability reduces to the computation of the product of four partial conditional probabilities, which is a computationally easier task.

The joint probability distribution of the network of Figure 4-4(a) can be expressed as follows:

$$P(CD,CV,I,LI,LD,TD,R) = P(CD \mid LD,TD,R) \cdot P(CV \mid LD,TD) \cdot P(I \mid R) \cdot P(LI \mid LD) \cdot P(LD) \cdot P(TD) \cdot P(R) \quad (21)$$

Based on the Bayesian product rule, it also holds that:

$$P(CD,CV,I,LI,LD,TD,R) = P(CD,CV,I,LI \mid LD,TD,R) \cdot P(LD,TD,R) \quad (22)$$

Formula (22), due to the independence of the parameters *LD*, *TD* and *R*, becomes:

$$P(CD,CV,I,LI,LD,TD,R) = P(CD,CV,I,LI \mid LD,TD,R) \cdot P(LD) \cdot P(TD) \cdot P(R) \quad (23)$$

From (21) and (23), it can be derived that:

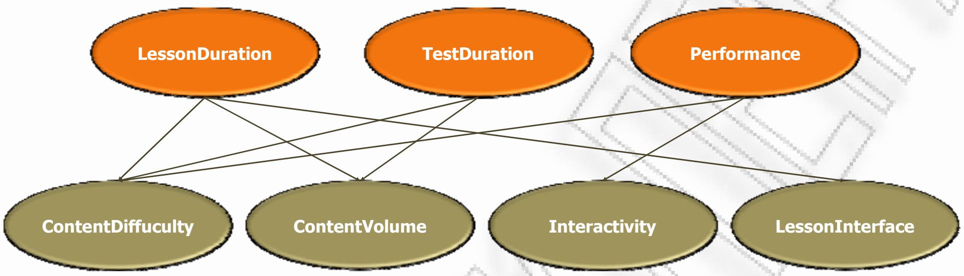
$$P(CD,CV,I,LI \mid LD,TD,R) = P(CD \mid LD,TD,R) \cdot P(CV \mid LD,TD) \cdot P(I \mid R) \cdot P(LI \mid LD) \quad (24)$$

The values of the partial conditional probabilities of formula (24), for given *LD=ld*, *TD=td* and *R=r*, can be retrieved from the model's Conditional Probability Tables (CPTs), which have, a priori, been filled appropriately by a set of experts in the domain of education (i.e., teachers, psychologists, pedagogues). Figure 4-4(b) illustrates the model's CPT for the Content Volume parameter. The CPTs for the other target parameters have a similar structure.

The final goal is the determination of the most probable set of values for the target parameters, *CD*, *CV*, *I* and *LI*, given the evidence *LD=ld*, *TD=td* and *R=r*. It is relatively easy to observe that the values of the target parameters which maximize the joint conditional probability $P(CD,CV,I,LI \mid LD = ld, TD = td, R = r)$ are those that maximize each of the four product factors separately.

As described above, every Bayesian network is associated with a set of probability tables, i.e. the probability distributions of the evaluation parameters and the CPTs of the target parameters. A learning system may employ either a unique (and generic) set of probability tables or several sets of probability tables, each one corresponding to a different user class. The latter presumes that there is an additional parameter, 'User Class', which acts as a contextual parameter [48], [52]. According to the value of this parameter, a different set of probability tables is used by the underlying Bayesian network. This extended model is depicted in Figure 4-4(c), which features the separation of the model into two different layers: the contextual layer and the predictive layer. The former defines the set of probability tables that should be used by the latter.

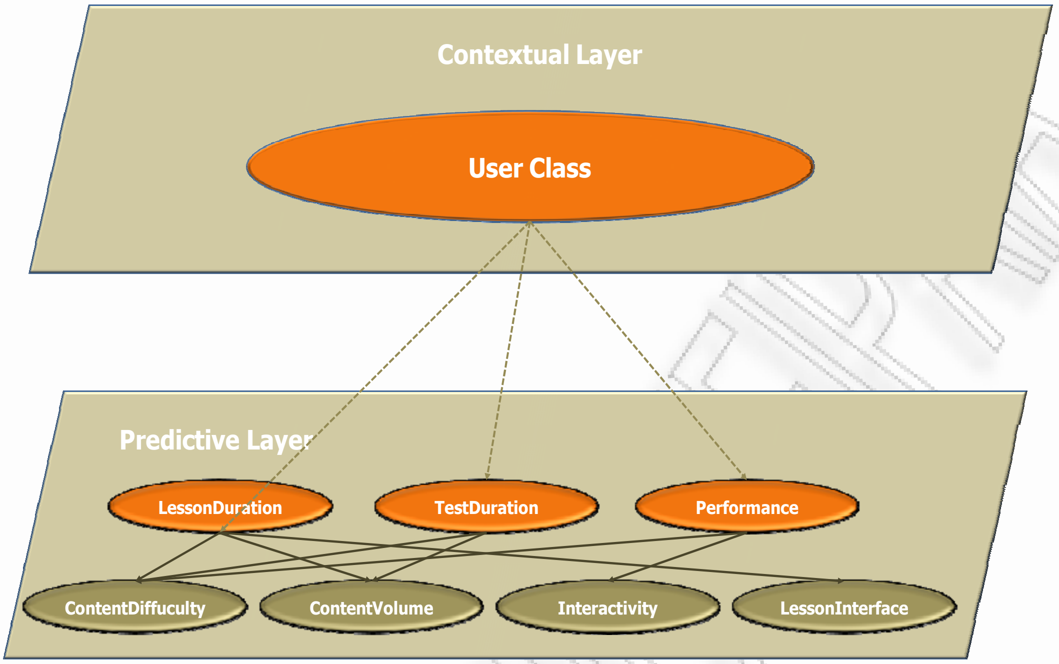
The class each user belongs to can be defined upon the user's initial entry to the educational platform, via questionnaires, cognitive tests and performance measures. This helps the system classify the user into a particular group, assigned with specific attributes, as described in Section 4.3.2.



(a)

Parent Node(s)		ContentVolume			
TestDuration	LessonDuration	Low	Medium	High	bar charts
Low	Low	0,1	0,2	0,7	
	Medium	0,15	0,25	0,6	
	High	0,25	0,35	0,4	
	VeryHigh	0,5	0,3	0,2	
Medium	Low	0,15	0,25	0,6	
	Medium	0,15	0,45	0,4	
	High	0,2	0,5	0,3	
	VeryHigh	0,4	0,45	0,15	
High	Low	0,3	0,45	0,25	
	Medium	0,35	0,5	0,15	
	High	0,5	0,4	0,1	
	VeryHigh	0,6	0,3	0,1	
VeryHigh	Low	0,3	0,55	0,15	
	Medium	0,4	0,5	0,1	
	High	0,65	0,3	0,05	
	VeryHigh	0,75	0,2	0,05	

(b)



(c)

Figure 4-4: (a) Bayesian network employed by the Modeling and Evaluation Layer; (b) The CPT for *Content Volume*; (c) Extension of model (a) in a two-level Bayesian network

4.5.3. Adaptation Layer

As stated in Section 4.2, Bayesian Networks is a method of effectively handling statistical models. Moreover, statistical models fit very well to the problem of modeling users, since they allow us to represent the intrinsic uncertainty inevitably related to any effort to model human characteristics [25]. Therefore we can achieve advanced user profile modeling by monitoring simple parameters, having also the ability to monitor past and current performance. In this section we are presenting a mechanism to update User Model information taking also into consideration historical information, with the help of Bayesian Networks.

As already discussed in Section 4.5.1, the computation of the most probable set of user profile characteristics should also encompass historical information, i.e. past monitored data regarding the user's overall performance. Therefore, a mechanism that updates the instantaneous, i.e. the most recent, estimations, on the basis of past information should be developed. A simple yet effective approach is the calibration of the estimated probability according to the following formula:

$$p_{\text{adapted},n} = w_{\text{hist}} \cdot p_{\text{adapted},n-1} + w_{\text{instant}} \cdot \left(1 - \left| p_{\text{adapted},n-1} - p_{\text{instant},n} \right| \right) \cdot p_{\text{instant},n} \qquad (25)$$

where $|x|$ returns the absolute value of x. Assuming that n represents the current time moment, $p_{\text{adapted},n}$ denotes the adapted probability estimation at moment n, $p_{\text{adapted},n-1}$ denotes the adapted probability's previous value, $p_{\text{instant},n}$ stands for the current instantaneous estimation, and w_{hist} and $w_{instant}$ reflect the weights attributed to the historical estimation and the current instantaneous estimation, respectively. Their value is in the interval (0, 1) and the formula $w_{hist} + w_{instant} = 1$ is always true. As can be observed, the right-hand part of formula (25) comprises two components, one for the employment of historical information and one for the employment of the instantaneous estimation. Thus, the proposed approach consists in modifying the previous estimation (first component) by a factor that is a function of the most recent, instantaneous, estimation (second component). To achieve this, the instantaneous estimation $p_{\text{instant},n}$ is multiplied not only by a weight $w_{instant}$, but also by a factor that depends on the difference between $p_{\text{adapted},n-1}$ and $p_{\text{instant},n}$. A small difference between these two values results in greater consideration of the second component. In this way, abrupt fluctuations can be smoothed out while the adaptive nature of the overall system is not violated.

The system's ability to adapt to the evidence received by the user, while, at the same time, perform a certain filtering of the outcome is influenced by the ratio $w_{hist}/w_{instant}$, which controls the contribution of the two components in formulating the adapted probability estimation. Larger values of the aforementioned ratio suggest slower adaptation rate, but better smoothing ability; whereas, smaller values imply faster adaptation rate yet more sensitive behavior regarding sharp fluctuations. In Section 4.6, the impact of the ratio $w_{hist}/w_{instant}$ will additionally be examined in more detail through simulation results.

4.6. Results

4.6.1. Scenario 1 – Generic example

In this scenario, we will examine the model's behavior in a random situation. The value of the ratio $w_{hist}/w_{instant}$ has been set equal to 1. Initially (step 0), as depicted in Figure 4-5(b), all the possible values of each target parameter are considered equally probable (uniform distribution). Hence, a lesson with random content difficulty, content volume, interactivity and interface is generated and delivered at this step. At the end of this lesson, the model's monitoring mechanism reports the following evidence: *Lesson Duration = Medium, Test Duration = High, Performance = C*. This set of evidence serves as input for the formation of the next lesson, i.e. the lesson of step 1, as depicted in Figure 4-5(a). At the beginning of step 1, the aforementioned evidence is utilized in order to produce a set of instantaneous probability estimations concerning the target parameters. This is carried out with the use of formula (24), as described in Section 4.5.2, after setting *LD=Medium*, *TD=High* and *R=C*. Subsequently, the instantaneous estimations of this step (step 1), in conjunction with the adapted probability estimations of the previous step (step 0), are utilized for the computation of the adapted probability estimations (Figure 4-5(c)) of the current step (step 1), on the basis of the analysis of Section 4.5.3 (formula (25)). Based on the adapted probability estimations, we come to the conclusion that, at step 1, *Low* is the most probable value for *Content Difficulty*, *Medium* for *Content Volume*, *High* for *Interactivity*, and *Rich* for *Lesson Interface*. Thus, the lesson of step 1 should comply with these suggestions, in order to best fit the user's preferences. The same method is followed for inferring the most probable values of the target parameters throughout the rest of the steps.

Step	Evidence		
	LessonDuration	TestDuration	Performance
0	-	-	-
1	Medium	High	C
2	Medium	Medium	B
3	Low	Low	A
4	Low	Low	A
5	VeryHigh	VeryHigh	D
6	Medium	Low	A

(a)

Step	Instantaneous Estimations												
	ContentDifficulty			ContentVolume			Interactivity			LessonInterface			
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Simple	Normal	Rich	Advanced
0	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.25	0.25	0.25	0.25
1	0.5	0.3	0.2	0.35	0.5	0.15	0.2	0.3	0.5	0.1	0.3	0.35	0.25
2	0.3	0.3	0.4	0.15	0.45	0.4	0.5	0.3	0.2	0.1	0.3	0.35	0.25
3	0.1	0.2	0.7	0.1	0.2	0.7	0.6	0.3	0.1	0.1	0.25	0.3	0.35
4	0.1	0.2	0.7	0.1	0.2	0.7	0.6	0.3	0.1	0.1	0.25	0.3	0.35
5	0.7	0.25	0.05	0.75	0.2	0.05	0.1	0.2	0.7	0.45	0.35	0.15	0.05
6	0.2	0.2	0.6	0.15	0.25	0.6	0.6	0.3	0.1	0.1	0.3	0.35	0.25

(b)

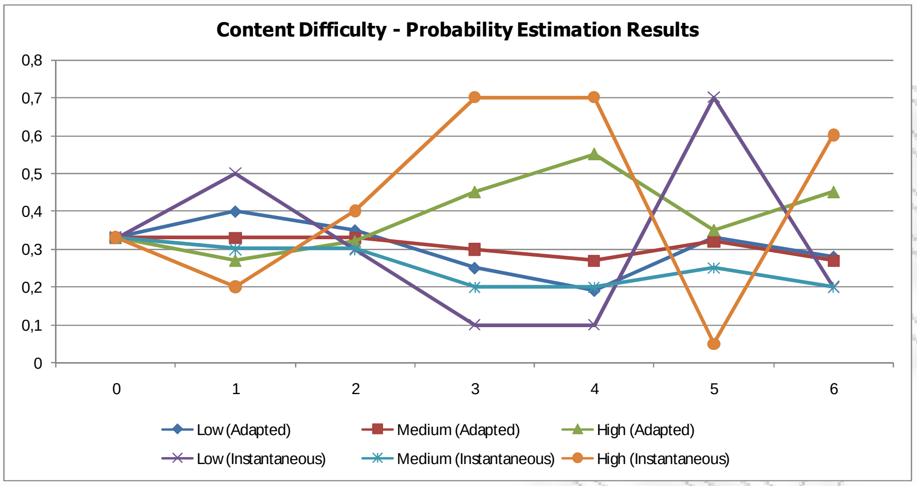
Step	Adapted Estimations												
	ContentDifficulty			ContentVolume			Interactivity			LessonInterface			
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Simple	Normal	Rich	Advanced
0	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.25	0.25	0.25	0.25
1	0.40	0.33	0.27	0.36	0.40	0.24	0.27	0.33	0.40	0.17	0.28	0.29	0.26
2	0.35	0.33	0.32	0.25	0.44	0.31	0.36	0.34	0.30	0.14	0.29	0.32	0.26
3	0.25	0.30	0.45	0.20	0.36	0.44	0.44	0.34	0.21	0.12	0.27	0.31	0.30
4	0.19	0.27	0.55	0.17	0.30	0.54	0.51	0.34	0.16	0.11	0.26	0.31	0.32
5	0.33	0.32	0.35	0.31	0.31	0.37	0.36	0.33	0.31	0.23	0.33	0.24	0.20
6	0.28	0.27	0.45	0.24	0.30	0.46	0.45	0.34	0.21	0.16	0.32	0.29	0.23

(c)

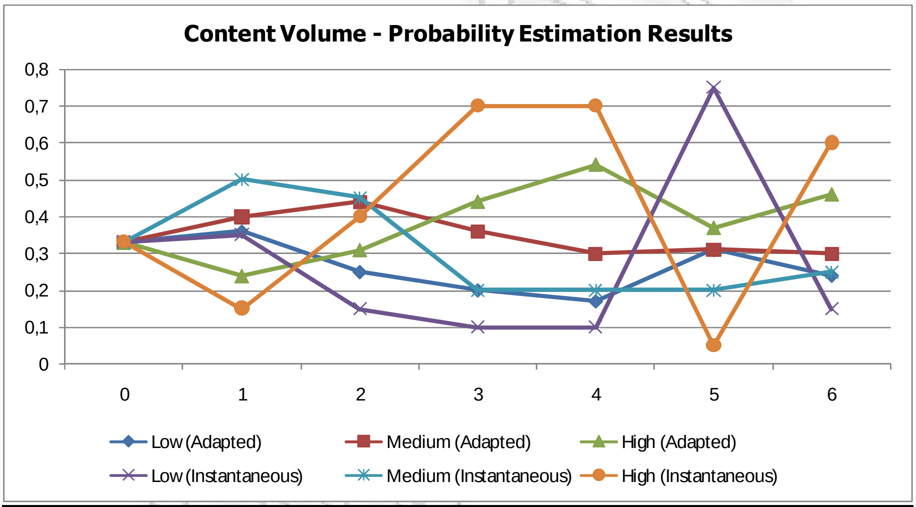
Figure 4-5: Scenario 1: (a) Evidence; (b) Instantaneous Estimations; and (c) Adapted Estimations

Based on the results of Figure 4-5(c), we construct the diagrams of Figure 4-6. As may be observed from the curves of Figure 4-6, the adapted estimations smooth out the sharp fluctuations of the instantaneous estimations, which is the desired behavior, by adapting to the evidence at a slower pace. This has the clear advantage of exploiting not only the most recent evidential data, but also knowledge about the past.

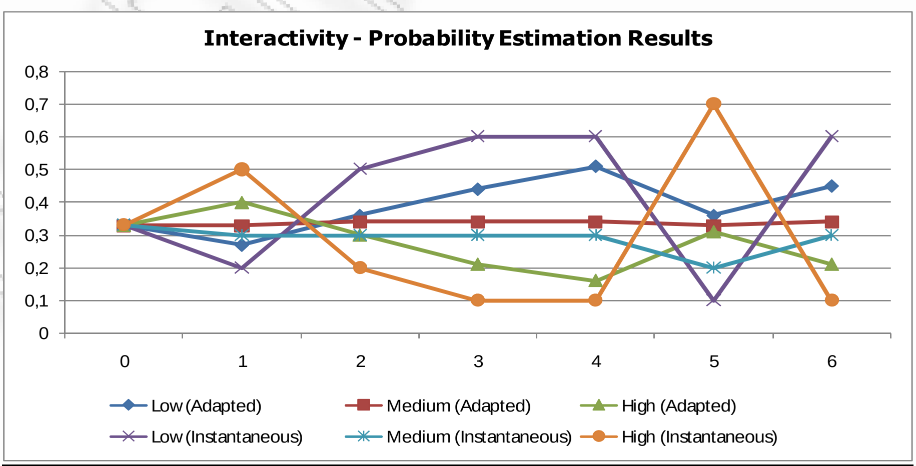
As an indicative example of this behavior, let us observe the estimation results for the *Content Difficulty* parameter, at steps 4 and 5. At step 4, we may observe that the adapted estimation indicates *High* as the most probable value. However, at step 5, a radical change is detected at the evidential data. According to the instantaneous estimations, *Low* is by far the most probable value at step 5. However, the adapted estimation takes into account the historical knowledge, by moderating this oscillation, and suggests again *High* as the most probable value; this time, of course, the probability of value *High* has significantly been decreased. This gradual adaptation to the evidence allows the system to avoid temporary and impulsive oscillations.


Content Difficulty - Probability Estimation Results
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
1
2
3
4
5
6
Low (Adapted)
Medium (Adapted)
High (Adapted)
Low (Instantaneous)
Medium (Instantaneous)
High (Instantaneous)

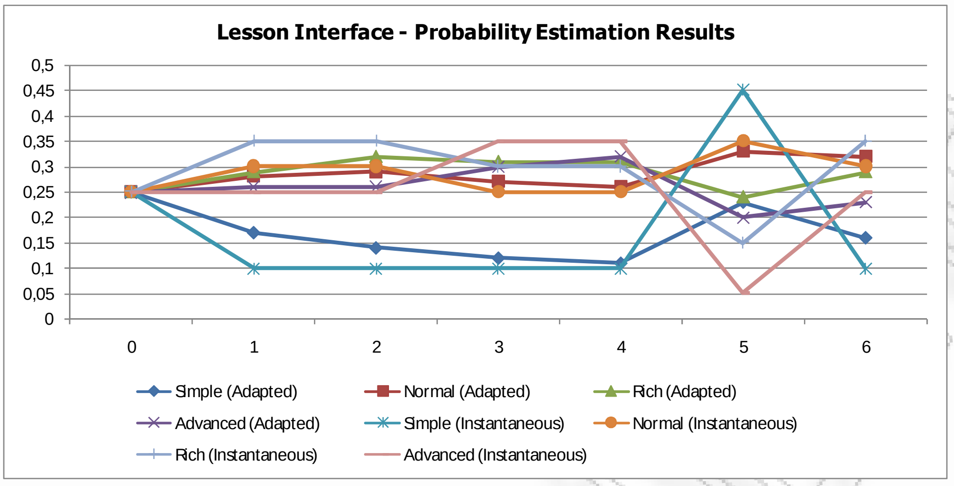
(a)


Content Volume - Probability Estimation Results
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
1
2
3
4
5
6
Low (Adapted)
Medium (Adapted)
High (Adapted)
Low (Instantaneous)
Medium (Instantaneous)
High (Instantaneous)

(b)


Interactivity - Probability Estimation Results
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
1
2
3
4
5
6
Low (Adapted)
Medium (Adapted)
High (Adapted)
Low (Instantaneous)
Medium (Instantaneous)
High (Instantaneous)

(c)



(d)

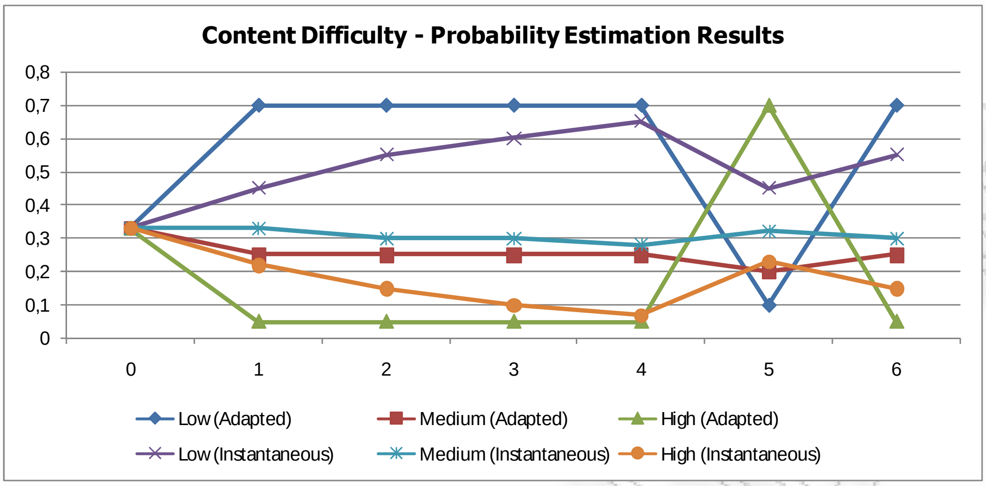
Figure 4-6: Scenario 1: Estimation results for the (a) Content Difficulty; (b) Content Volume; (c) Interactivity; and (d) Lesson Interface target parameters

4.6.2. Scenario 2 – Fluctuation smoothing

In this scenario, we examine the oscillation avoidance through a more specific example. As depicted in Figure 4-7(a), we assume that the user's performance is very low during the steps 1-4, then that there is a sudden radical improvement at step 5, while at step 6 the user continues to have a very low performance.

Step	Evidence		
	LessonDuration	**TestDuration**	**Performance**
0	-	-	-
1	VeryHigh	VeryHigh	D
2	VeryHigh	VeryHigh	D
3	VeryHigh	VeryHigh	D
4	VeryHigh	VeryHigh	D
5	Low	Low	A
6	VeryHigh	VeryHigh	D

(a)



(b)

Figure 4-7: Scenario 2: (a) Evidence; and (b) Estimation results for the Content Difficulty parameter

In this use case scenario, at step 5, it would be wrong to consider that the user has suddenly become an expert. This means that the system should avoid providing the user with content of great difficulty at this point. Examining the estimation results for the *Content Difficulty* parameter, this is exactly what is achieved by the proposed system at step 5, as may be observed in Figure 4-7(b). The results are similar for all the other target parameters, as well.

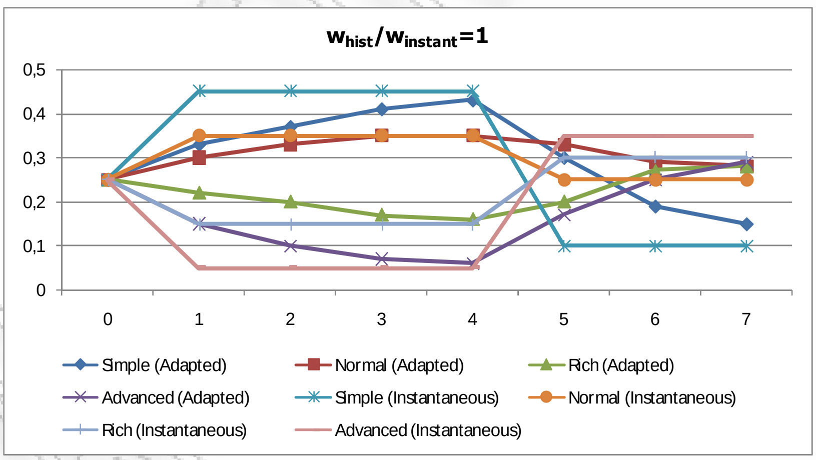
4.6.3. Scenario 3 – Measuring the adaptation speed

The goal of this scenario is to obtain results about the model's adaptation speed for different values of the ratio $w_{hist}/w_{instant}$. In this scenario, we assume that the user has very low performance in steps 1-4, but exhibits a remarkable and steady performance thereafter, as shown in Figure 4-8(a). We will study the estimation results for the *Lesson Interface* parameter, for values 1, 2, and 3 of the ratio (Figure 4-8 (b), Figure 4-8(c), and Figure 4-8(d), respectively). The results for the other target parameters are similar. At step 4, *Simple* is the most probable value of *Lesson Interface*. Our goal is to measure the adaptation speed, i.e. how many steps it takes for the model to regard the value *Advanced* as the most probable one, for the three different values of the ratio. As may observed from Figure 4-8(b), for $w_{hist}/w_{instant}=1$, 3 steps are needed by the system to reach this conclusion. For $w_{hist}/w_{instant}=2$ (Figure 4-8 (c)), 5 steps are needed, while for

$w_{hist}/w_{instant}=3$ (Figure 4-8 (d)), 6 steps are required. Hence, it is clear that larger values of the ratio result in slower adaptation speed.

Step	Evidence		
	LessonDuration	**TestDuration**	**Performance**
0	-	-	-
1	VeryHigh	VeryHigh	D
2	VeryHigh	VeryHigh	D
3	VeryHigh	VeryHigh	D
4	VeryHigh	VeryHigh	D
5	Low	Low	A
6	Low	Low	A
7	Low	Low	A
…	…	…	…

(a)



(b)

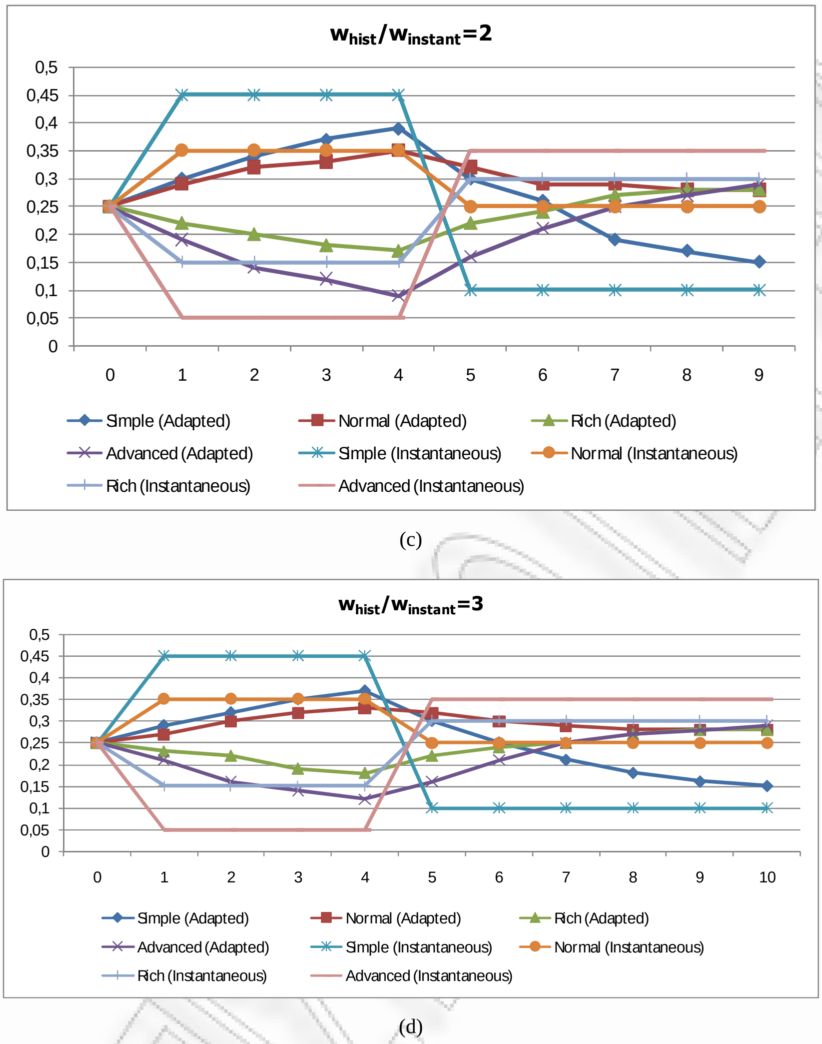


Figure 4-8: Scenario 3: (a) Evidence; Estimation results for the *Lesson Interface* parameter, for (b) $w_{hist}/w_{instant}=1$; (c) $w_{hist}/w_{instant}=2$; and (d) $w_{hist}/w_{instant}=3$

4.7. Conclusions and Future Work

In this chapter, the concept of predicting the users' preferences in an e-learning environment was established and implemented. Modern e-learning systems need to offer personalized experience to their users. To that end, the automatic inference of the users' preferences is a key issue, whose probabilistic nature can be dealt with, as demonstrated, through the utilization of Bayesian Networks.

In particular, this chapter presented the central requirements of an advanced e-learning system. Focus was given on the need for personalization and adaptivity. The structure of a novel e-learning system complying with these requirements was presented. The parameters comprising a typical user profile within the e-learning context were investigated. The central role of the system's User Model component was explained, and its encompassed functionality was thoroughly analyzed as a 3-layer model, which makes use of Bayesian Networks and appropriate fluctuation smoothing in a consistent manner. Results depicting the system's predicting behavior were demonstrated.

At this point we presented the theoretical framework of our work. Following the investigation of the behavior of our schemes, there is complete development of the platform and application on trials at various scales. More specifically, this work includes the exhaustive trial testing and fine-tuning of the implemented e-learning system with the help of a number of volunteers. The incorporation of additional parameters to the proposed model will also be investigated. For instance, the preferred type of practice (e.g., multiple choice questions, true/false questions, etc.), and the preferred learning structure (e.g., top-to-down approach, down-to-top approach, etc.) may serve as additional target parameters. Measuring a user's scroll rate (how much time it takes the user to scroll to the end of the page, i.e. how fast the user reads), or how many times a user is forced to scroll up (in order to search for a piece of information neglected at first glance) are examples of additional target parameters. Furthermore, a user's age, origin, or profession can serve as additional contextual parameters.

Another challenging future task is the dynamic determination of the optimal structure for the Bayesian Network of the Modeling and Evaluation Layer. So far, the structure of the Bayesian Network of Figure 4-4 has been considered constant and unaltered. However, one could argue that a different set of causal relationships should have been assumed.

The development of an efficient algorithm for learning the structure (i.e., causal relationships) of the Bayesian Network that is used for modeling the user preferences involves finding the structure that best suits a given set of pre-defined data, and is an NP-hard problem [53].

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5. LEARNING USER PREFERENCES IN A "TRANSPORTATION MANAGEMENT – CAR POOLING" SERVICE CONTEXT

Abstract

The continuously increasing need for mobility has brought about not only significant facilities in several aspects of human initiative, but also growing traffic congestions, a phenomenon that leads at a short time level to unpleasant everyday situations, but in the long run also to the degradation of the level of quality of living in large cities. The management of traffic stands thus as a fundamental prerequisite for confronting those issues and enhancing transportation. This chapter considers the concept of car pooling as a structured approach to this problem, by specifying, developing and validating a mobile-community-driven system for collaborative transportation, namely the "Transportation Management - Car Pooling System". The system is capable of proposing optimal, reliable and secure community matches (taking into consideration personality features, talking interests, driving style, etc.), based on user profile and context information. The chapter describes the Transportation Management - Car Pooling System, presenting its input parameters, decision making process and outcomes. Finally, indicative simulation results showcase its functionality and effectiveness.

Keywords

Car-pooling, personalisation, transportation management, utility volume

5.1. Introduction

Current socio-economic circumstances in Europe impose an increased need for mobility. Most European cities are overcrowded with vehicles, facing a continuously growing volume of traffic. Traffic congestions, an everyday phenomenon, are basically caused by the large number of vehicles, moving or searching for a parking place [1]. In addition, they are often incurred by unpredicted accidents and emergencies, which are, at the same time, associated with serious injuries/ fatalities.

These facts show that there are important inefficiencies related to transportation. Inefficiencies cause enormous losses of time (e.g., the period that drivers spend in traffic congestion or while they search for parking places), decreases in the level of safety for both, vehicles and pedestrians, high pollution, degradation of quality of life, and huge waste of non renewable fossil energy, as identified by the research community [1]-[5]. Those inefficiencies have brought up the necessity for developing systems for more efficient and safer mobility. In response to the above, transportation (also traffic) management has been lately attracting enormous research effort, being established as a key service that should be offered, in the area of transportation, by Information and Communication Technologies (ICT) [6]-[8].

A phenomenon that is quite aligned with the inefficiency of transportation is the continuously increasing level of utilization of vehicles (i.e. vehicles are used in more and more aspects of human initiative), linked to the minimization of vehicle passengers (i.e. vehicles carrying only the driver), due to the increase in vehicle ownerships [1]. Apparently, this causes a significant increase in traffic volumes. To address this drawback, only some independent solutions have been proposed in the United States, Germany, Greece and Great Britain [9]-[16]. Moreover, internet community portals provide the means to bring people together sharing the same interests and needs in order to ease poor social fabric and remove interaction barriers [17]-[21]. On the other hand, communication between drivers is until now researched in some small projects in Scandinavia [22] developed a mobile broadcast system for car drivers (ROAD TALK), while Esbjörnsson et al [23] created a mini computer for the communication between motor bikers. Both systems were highly accepted even though the tested samples were very small (about 6 participants) and the design process was intuitive. In addition to this, attempts to model drivers behavior have also taken place [24]-[26], yet these researches take into account only driver's profile and not passenger's.

Therefore, *car pooling* (sharing) services (most popular in the US [10], [13], [27] are chosen as one of the solutions for improving transportation efficiency [28]-[30]. As a definition, "car pooling is at least two people riding in a car. Each member would have made the trip independently if the carpool had not been there. Driver and passengers know before the trip that they will share the ride and at what time they will be leaving. Professional and/or commercial vehicles are excluded. Both the driver and the passenger(s) are considered as carpoolers", as stated in [1], [31].

With the vision to improve transportation efficiency and also contribute to the enhancement of social fabric, this chapter builds on the aforementioned proposals and presents an innovative, widely applicable approach that lies on the advances of telecommunications [1]. More specifically, the chapter combines the concepts of communities, mobility and car pooling into one integrated, community driven, and mobility solution. In particular, it presents an optimization method that leads to mobile-community-driven, secure, collaborative transportation, which is capable of proposing optimal, as well as reliable and safe community matches (e.g., safe driving, talking interests, etc.) and routes, based on profile and context information in mobile situation contexts.

The contribution of this work is twofold:

First, it specifies and develops a mobile-community driven optimization strategy that proposes community matches and routes, based on user profile and context information and succeeds in reducing the overall traffic loads in transportation infrastructures, through exploiting advanced transportation management solutions, improving system's effectiveness and functionality.

Second, it delivers inter-disciplinary solutions that benefit from advanced ICT technologies and the sociology and psychology sciences, contributing also to the enhancement of social fabric, since based on user profiles (drivers and passengers) that depict their preferences, people are connected, and communities are built out of these interactions. Through these communities people can share transportation and more generally support each other.

In the light of the above, the structure of the chapter is as follows: the next section presents the motivation for this work and describes in a high level fashion an optimization scheme that can efficiently manage transportation infrastructures through the concept of car pooling, namely the *Transportation Management - Car Pooling System (TM-CPS)*. Section 3 presents the TM-CPS in detail, focusing on its input and output parameters, whereas section 4 provides some indicative simulation results that showcase the system's efficiency. Finally, concluding remarks are drawn in section 5.

5.2. Motivation, Business Case and High-Level Description

5.2.1. Motivation for Transportation Management through Car Pooling

As previously mentioned, the necessity to eliminate the continuously growing volume of traffic is broadly accepted, since it involves versatile, everyday, unsatisfactory situations. A solution approach to this could be the concept of *"car pooling"*, which suggests that the passenger and the driver may agree to share the same ride to a certain destination, based on an agreement upon specific criteria. The results of such an action are to have reduced number of cars on the route and to significantly reduce the expenses for gas or parking (there is an agreement of sharing the car expenses between the passengers [32]-[35]). In addition to the above, the overall energy consumed is significantly reduced, and therefore pollution and CO_2 emissions become less. In this respect, car pooling contributes to the diminishment of atmospheric pollution, more than any state-imposed policy ([32]-[35]). Also, the participants may take turns through sharing their vehicles ([10]). Last but not least, car pooling may also provide social connections in an increasingly disconnected society ([36]). Aligned with the latter, online car pooling services offer new ways to make social connections through discussion sites and custom ride-sharing services. Moreover, car pooling services are based on user preferences, which include social status, education and age, as will be discussed in section 5.3.1 and also introduced in [17]-[21].

An important measure that has been already applied in countries that car pooling is widely accepted (i.e. in twenty states of U.S.A.) is the designated car pool lanes on highways (usually called High-Occupancy Vehicle - HOV lanes), which make traveling faster [3], [4], [10]. These lanes concern cars having more than 2 passengers. Researches have shown that such lanes operate in an encouragingly effective manner [3], [10], [21].

To this effect, car pooling seems an attractive concept that could contribute to a more intelligent management and improvement of transportation circumstances. In this respect, the next subsection indicates how a car pooling system could become of great commercial use, while subsection 2.3 gives an overview of the TM-CPS which will be analyzed in the context of this chapter.

5.2.2. Business Case

This section aims at exemplifying the role of car pooling and raising the issue of its application, to support transportation management in large cities that face congestion problems, through a system created for this purpose.

The business case assumes that a person wishing to reach a destination monitors a specific drivers' pool, seeking for a subset of drivers being directed towards the same place. The person in question (prospective passenger) interacts with all "candidate" drivers and examines whether an agreement can be established, regarding specific criteria that originate either in the passenger's preferences, or in the driver's intentions. Indicative parameters, influenced by information retrieved within literature and car pooling websites, which provide actual car pooling services [2], [5], [9]-[16], [27], [31], [33] include on one hand the requested (by the passenger) and provided (by the driver) departure and destination point, as well as the itinerary's cost, and on the other hand, user profiles (age, gender, marital status, educational level and occupation, language, nationality, smoking habits, etc.). The driver-passenger pair selected is the one that results in the best matching of parameters.

A high-level scenario corresponding to the business case is shown in Figure 5-1.

The scenario can be either passenger-, or driver-initiated and evolves in five main phases. Examining the passenger-initiated scenario, in the first phase, the passenger seeks for drivers originating at a certain place and intending to reach a desired destination (the depiction of the driver-initiated scenario is omitted for brevity). In the second phase, the passenger interacts with the identified candidate drivers and negotiates upon a set of predefined criteria. In the third phase, the driver that satisfies most of the criteria is selected for the journey. The fourth phase refers to the implementation of the journey, while the final (fifth) phase, which takes place after the journey, consists in the evaluation provided by both parties of the journey, for future reference.

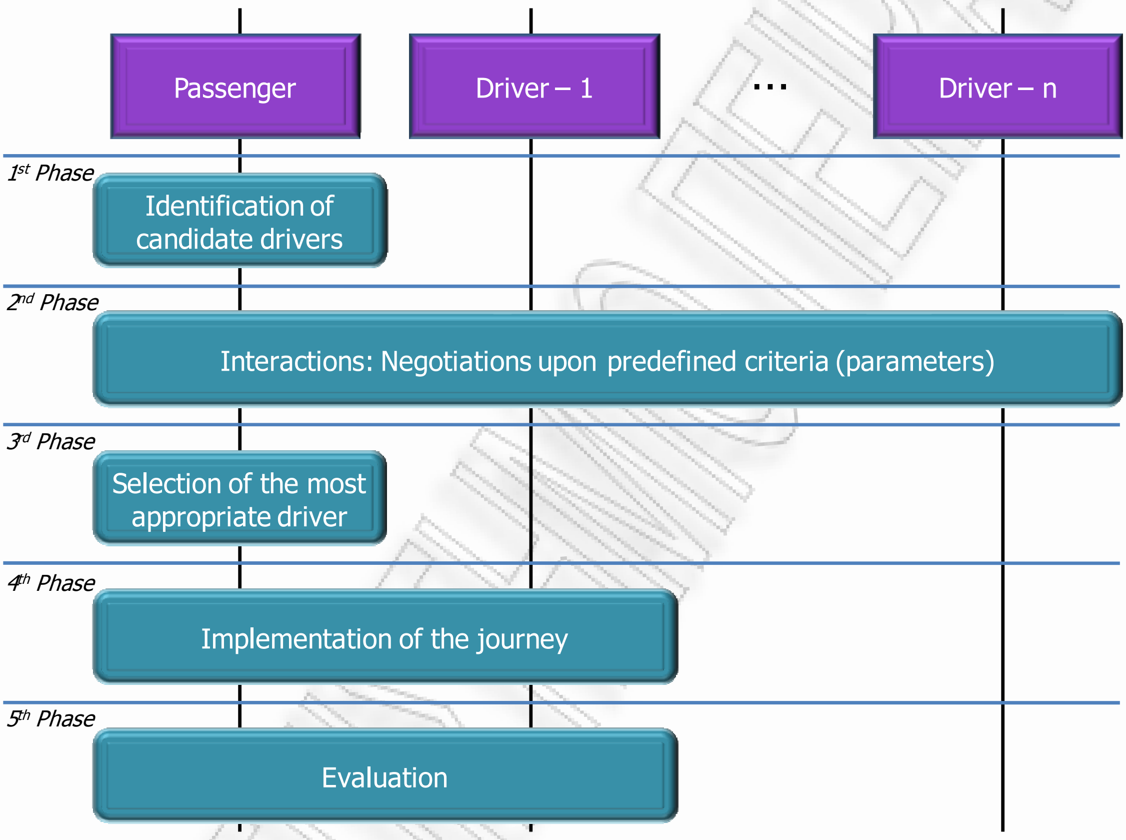

Figure 5-1: High-level car pooling scenario

5.2.3. High-Level TM-CPS Description

The opportunity to share a vehicle, when having a similar itinerary and set of matching parameters, offered by the concept of car pooling, can be guaranteed through the existence of a system, which can reside in a mobile phone or laptop/PC and, as such, it is rather easy to deploy and utilize. In general, such a system takes into consideration user's preferences and personal needs, as well as their changes as the time elapses, in order to adapt to them, taking in mind past preferences. More specifically, the user that wishes to use the car pooling service logs on to the system, through his device, and makes a request (as a driver or as a passenger). The system recognizes the specific user and has access to his personal information, specific preferences and history. This information on each user, his preferences and the past activity on the system (history) is kept in log files, in appropriately formed Data Bases. In this way, the system is in position to find the most appropriate match for the users (both driver and passenger). Moreover, knowing user's past activity on the system, the evaluations/ feedbacks the user has done and received and the previous matches he has accepted, it can avoid or prefer a certain connection between users. Social relations are consequently enforced in two ways; first, the system makes connections between users taking into consideration user personal preferences and personal information of both, driver and passenger (as will be explained in section 5.3.1) and second by knowing the users that liked each other and the ones that did not, the system prefers or rejects, respectively, to make match and has, thus, higher chance to make a successful match, that will lead to a pleasant trip.

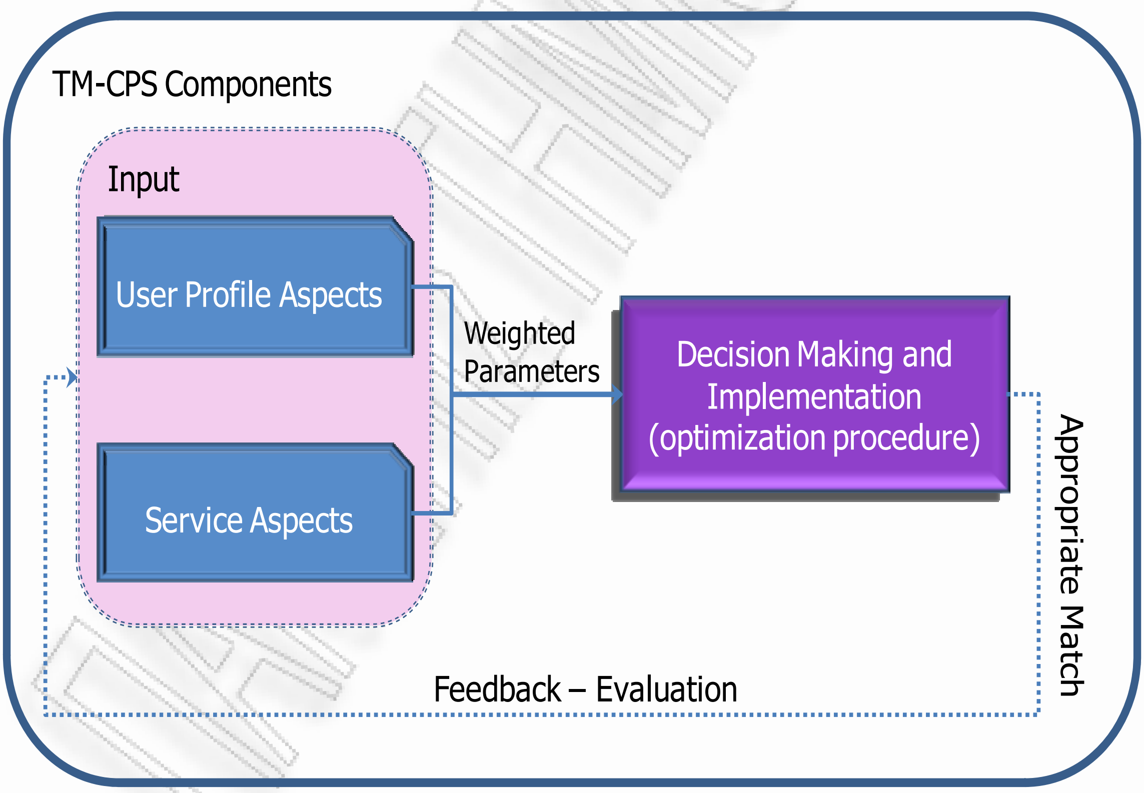

Figure 5-2: TM – CPS High Level Description

Hence, the system's two fundamental requirements are (i) personalization and (ii) adaptability, so as to effectively interact with the user [37]. In fact, the envisioned community applications (residing on the mobile phone/laptop/PC) shall be integrated in the different user-service interaction contexts (e.g. in-car, mobile).

This chapter proposes such a system, namely the Transportation Management – Car Pooling System (TM-CPS). The TM-CPS uses as input user profile aspects, as well as service aspects and aims at proposing optimal, personalized, reliable, secure and safe community matches and routes. The TM-CPS is described in a high-level manner in Figure 5-2, while its main components are thoroughly analyzed in the next section.

5.3. TM-CPS Detailed Analysis

This section elaborates on the components of the TM-CPS presented in section 5.2.3 and depicted on Figure 5-2, as well as their operation and interactions. Each of these components has an irreplaceable role in this system, rendering its presence mandatory for the system's functionality [37], [38].

5.3.1. User Profile Aspects

This component stores all user-related data, namely personal information and preferences. It enables the system to know, immediately after the user logs on to the system, the identity of the user and the data the user has provided the system with. However, it should be noted that the user's preferences may change as the user makes use of the car pooling service. For instance, in the morning a user (driver) may accept a request for a ride having destination close to his work. In the afternoon the same user (as a passenger this time) may want to go downtown in order to run some errands and request for a ride. The component allows such amendments. The information handled through it is reflected on a list of parameters, discussed below.

User Profile Parameters. In general, the parameters that depict the data contained in the User Profile Aspects component include personal data and personal vehicle data. Personal vehicle data contain information on the vehicle that the user has and the characteristics that make it unique and identifiable by the passenger. These data are the number plate, the year the car was constructed, the year the user got his/ her driving license, the type and date of expiration of the car insurance and the brand of the car. Of course, personal vehicle data are optional, since a user of the system may not possess a car, yet can make use of the car pooling service, so they are just presented here for consistency and will remain unconsidered for the rest of the chapter.

Personal data contain information regarding age, gender, marital status, educational level and occupation, language, nationality and whether the user is a smoker or not. More specifically, each user states his age, as well as the age category he wishes his co-passenger to be in. Usually the gender of the user does not make any difference, yet sometimes the gender may help people in having common interests. Being married or single is of importance for users' matching. For instance, mothers may have many common interests regarding their children, than they would have while traveling with a student. A user's educational level is important, as it can create a more convenient atmosphere for co-travelers, as the chances of having something to discuss increase, and make the journey more pleasant. Occupation is another important parameter that affects the matching between users and creates higher possibility for it to succeed [10], [39]. The languages a user speaks may include him in a wider group of users and therefore have more chances of finding an appropriate match. Nationality is also a factor that influences the matching of users and their possibility to have a pleasant trip. Being a smoker or not may be very important for a user and affect at a great extent whether he will accept a matching or not. This is the reason for which in the beginning of the trip users establish some ground rules. In general, there has to be an agreement regarding smoking, music, food, drinks etc. Discussions are possible to irritate a user, as some may like quiet time in the morning, or a user may be sensitive to strong perfumes [12]. Rules are thus important to be set and agreed between users. In this respect, two additional parameters placed within this component (however not directly linked to user preferences) are (i) the itinerary's cost (to be discussed below) and (ii) the driving competence (deriving from others' evaluations, as will be shown in the sequel).

Parameters' Weight. Apart from the aforementioned parameters, a TM-CPS user needs to specify the importance he attributes to each of those parameters. This is achieved by attributing each of the parameters with a certain weight. Of course, it is possible that parameters could have the same weight for the user. For instance, a user may consider equally important that his co-passenger speaks English, as well as the fact that he is not a smoker. Practically, the user attributes each parameter with a value between 0 and 1, with 0 implying that the parameter has a low importance for the user and 1 pointing at a high importance. In case a parameter has the same weight with another (or more than one) parameter, it is inferred that the user has equal interest in these parameters. Regarding the repetition of the match, the user does not attribute it with a certain weight, yet in the case that this user has traveled again with another user, the system can be informed whether the user is willing to share a ride again, based on the information extracted at the end of the itinerary.

As far as the cost of the itinerary is concerned, the user also specifies its weight. This means that the user is in position to state the level of expenses he can afford, or this is of no importance for him. The cost of the itinerary is calculated when a service request is made (this procedure is analyzed in 5.3.2).

Table 5-1: User Profile Parameters

Parameters	**Notation**
1.Age	AG
2. Gender	GEN
3. Educational Level	EL
4. Family State	FS
5. Work	WOR
6. Smoking	SM
7. Language	LAN
8. Nationality	NT
9. Source	SR
10. Destination	DEST
11. Commuter Cost	CC
12. Evaluation	EST
12.1 Driving Skills	DS
12.2 Social Behavior	SB
12.3 Repeat Match	RM

In order for the system to be aware of the gas expenses, in the beginning of the itinerary the driver sets the number of the kilometers, as well as whether the itinerary includes tolls or not. Last but not least, the driver's driving competence and social behavior is evaluated by the passengers when the itinerary is completed. The value of these parameters is calculated as the mean of all passengers' evaluations.

A summary of the parameters associated with the User Profile Aspects component and their notations, is provided in Table 5-1.

5.3.2. Service Aspects

This component stores information about the service delivered to users. In particular, it is responsible for keeping records of the information regarding the service requests, the service requests that were satisfied and the users that were involved in the realization of the car pooling service. This means that when a user makes a car pooling service request, this request is received and decoded by the Service Aspects component, through identifying the critical information within the request (user id, departure point, destination point) and then passing this information to the User Profile Aspects component, in order to make the initial scanning of the user profiles and propose the potential matches.

The aforementioned critical information is reflected on a list of parameters, summarized in Table 5-2.

Table 5-2: Service Parameters

Driver Parameters	Matching Parameters	Passenger Parameters
Driver departure point	Itinerary	Passenger departure point
Driver departure time	Itinerary's cost	Passenger departure time
Driver destination point	Pick-up point	Passenger destination point

A parameter that has to do with the itinerary is the passenger's starting point. The respective parameter for the driver is the driver's starting point, which is dependent on the itinerary he will follow to reach his destination. In other words, a matching takes place when *passenger's departure and destination point* are convenient for the *driver's itinerary* and *departure and destination point*. For instance, co-workers or people working in the same area of the city may agree on a car pooling service on a daily basis [39]. Moreover, *itinerary's cost* is agreed between users, so as they are both aware of the amount of money the passenger is going to compensate the driver. The cost is calculated taking into account the number of kilometers, as well as the fees spent on tolls, through a specific formula. The result of the formula represents the amount of money that the passenger will provide the driver and depends on the distance of the itinerary, and also the number and the cost of the tolls [33].

This formula can be defined as follows:

$$\sum cost = \frac{(0.25 \cdot Km + 2 \cdot n)}{N} \qquad (26)$$

where km is the itinerary's distance (expressed in km), N is the number of the passengers and n expresses the times that tolls shall be paid throughout the itinerary. The cost of the tolls is set to 2€, yet it may change and the formula may be formed accordingly.

Finally, it is important to be punctual and agree on how long the driver will wait for a passenger. The usual waiting time is 2 to 3 minutes [12].

5.3.3. Optimization Method: Decision Making and Implementation

This component receives the potential matches from the User Profile Aspects and the Service Aspects components. Its main responsibility is to make a decision amongst those matches, through an optimization process, which aims at maximizing the value of an objective function (OF) [40], whose variables are the profile and service parameters (see also Table 5-1, Table 5-2 and [41]. The OF value is calculated for every user based on the parameters and their respective weights. The driver for which the OF is maximized is the driver that best fits to the user requesting the service, and therefore the one that will be chosen among all candidates.

Let x be the user, with X denoting the set of users ($x \in X$). Accordingly, let d be the driver, where D is the set of drivers ($d \in D$). Each parameter (among the ones previously mentioned) is denoted as par , where PAR is the set of parameters ($par \in PAR$). In this respect, $W(x, par)$ is the weight for each parameter (par) for the user x and $par(d)$ is the value of the parameter that corresponds to the specific driver. The OF for the system is formed as followed:

$$OF_{System} = Max\left\{\sum_{d} K(x,d)\cdot \sum_{par} W(x, par)\cdot par(d)\right\} par > 0, par = 1,...N \qquad (27)$$

As can be observed, the OF_{System} consists of the sum of the OFs of each driver (OF_d) and the factor $K(x,d)$. The TM-CPS target is to identify the maximum amongst the OF values that correspond to each of the drivers. The OF_d is given by the following formula:

$$OF_d = \sum_{par} W(x, par)\cdot par(d) \qquad (28)$$

Also, it holds that K is a binary parameter which shows whether a driver is chosen by user or not. Specifically:

$$K(x,d) = \begin{cases} 0, & \text{if user x does not choose driver d} \\ 1, & \text{if user x chooses driver d} \end{cases} \qquad (29)$$

This formula denotes that every user x may select only one driver d for each itinerary.

The above described procedure applies also to the reverse procedure, when a driver is seeking for a passenger, in order to use car pooling service. The scenarios that follow in section 5.4, present this procedure and therefore the way OF works in order to find the best match for each user.

5.3.4. Feedback – Evaluation

As already mentioned, when registering on the platform, the user provides the system with their personal data and preferences. Yet, a change of user’s preferences or personal data is possible, therefore the system will have to be able to update the according parameters and adapt to user’s new preferences and needs. Of course, a user may update his profile by himself. For instance, in case he changes area of residence or area of work, he can update this information by himself. On the other hand, changes in user’s profile or preferences may be inferred through the *evaluation procedure* within the system. This procedure is done by the passengers concerning the drivers and vice versa, at the end of every ride. It provides the users (both the driver and the passenger) with the option to fill in a brief questionnaire, evaluating the driver/ passenger. The questions aim to extract the user's opinion on his co-passenger's social behavior, the driving competence and skills and whether he is willing to share the same ride with this driver or not.

Specifically, there are three categories of overall evaluation (*overall evaluation on user parameter*) which a user can choose from: positive, neutral or negative. Also, the user may specify whether he is *willing to share a ride again with the same user* of the system. In this way the system may create, and each time update, a *"+" list* for positively evaluated users and a "–" *list* for negatively evaluated users. *Driving style*, *driving competence* and *social behavior* are some evaluation parameters which help the system to update the user profile, in order to create more successful matches in the future. In addition, each user can explain their evaluation through comments, giving e.g. details on the punctuality or reliability of the other member. Each user may have access to the evaluation user profile of a user, in which all received evaluations are collected. By viewing this profile, other users can view evaluations and profit from the experiences of other users [9]. It is important to make comments easily understandable and factual for other users, as other users may read evaluations. The purpose of the comments is to allow other members to hear of certain experiences and of course not to insult other users *[9]*. The update parameters are summarized in Table 5-3.

Table 5-3: System Update – Evaluation Parameters and their potential values

System Update – Evaluation Parameters	**Potential Values**
Overall evaluation on user	positive, neutral, negative
Willingness to share a ride again	positive, neutral, negative
Driving style	calm, convulsive, environment friendly and gas saving
Driving competence	good, efficient, dangerous
Social behavior	pleasant, friendly, annoying, rude

5.4. Results

This section contains indicative results that derive from the utilization of the TM-CPS to a simulated transportation infrastructure environment. Some indicative, realistic everyday scenarios are presented, which can lead to comprehensive results and thus showcase the efficiency of the proposed scheme. The scenarios have been constructed using information and being influenced by [2], [5], [9]-[16], [27], [31], [33].

Three scenarios will be presented. The scenarios are user-driven, in that they are differentiated based on user preferences. In this respect, the first one presents the typical paradigm of a car pooling service request. The second one serves as an example for the case when a user values extremely high a certain parameter (the cost, in our case). Finally, the third scenario presents a case when a user has no particular preferences, i.e. values the parameters approximately the same.

5.4.1. Scenario 1: Regular car pooling service request

We consider user Mary, who has already registered on the TM-CPS and therefore disposes a unique identity in the system. Her starting point is SP-A and her destination point is DP-A, an itinerary of 18 kilometers (km). At the same time, three (3) drivers make a car pooling system request, making the system aware that they are going to follow the itinerary SP-A to DP-A. In summary, the itinerary has the following characteristics:

- Starting Point: SP-A,
- Destination Point: DP-A,
- Kilometers: 18 Km.

Mary is supposed to have already filled her personal profile, stating the weights of parameters and also depicting her personal preferences on the driver or passenger (in case she is the driver). Table 5-4 presents the parameters and their respective weights (viewed from both), the passenger and the driver side. In the sequel, following the procedure discussed, the TM-CPS is responsible for deciding upon the best possible match. Specifically, taking into consideration the data provided by Table 5-4, Table 5-5 is formed in order to provide reference to the parameters and their respective weights for each of the three suggested candidate drivers, in order to showcase their differences.

Table 5-4: Scenario 1 - Parameters and their respective weights

Parameter	Weight
Age	*0,09*
13 – 17	0,1
18 – 24	0,25
25 – 34	0,4
35 – 44	0,16
45 – 54	0,05
55 – 64	0,02
65 – 70	0,02
Gender	*0,02*
Male	0,5
Female	0,5
Educational Level	*0,07*
Higher	0,6
Medium	0,2
Low	0,2
Marital Status	*0,05*
Married	0,3
Single	0,7
Occupation	*0,07*
Employed	0,4
Unemployed	0,05
Housewife	0,05
Student/ Pupil	0,5
Smoking	*0,25*
Yes	0,1
No	0,9
Language	*0,02*
English	0,3
French	0,3
Greek	0,3
Other	0,1

Nationality	*0,05*
English	0,8
Other	0,2
Evaluation	
Driving Competence	0,25
Good	0,5
Medium	0,35
Low	0,15
Social Behavior	0,08
Good	0,8
Medium	0,1
Low	0,1
Itinerary Cost	0,05
Economic	0.6
Non-economic	0.4
Repeat Match	
(NMB) No Match Before	
Yes	
No	

For every candidate driver, there is a respective OF value, based on the parameters and their weights, as presented in 5.3.3 and formula (28). Specifically,

$$OF_{George} = \sum_{par} W(x, par) \cdot par(d) =$$
$$0{,}09 \cdot 0{,}16 + 0{,}02 \cdot 0{,}5 + 0{,}07 \cdot 0{,}2 + 0{,}05 \cdot 0{,}3 + 0{,}07 \cdot 0{,}4 +$$
$$0{,}25 \cdot 0{,}9 + 0{,}02 \cdot 0{,}3 + 0{,}05 \cdot 0{,}8 + 0{,}05 \cdot 0{,}4 + 0{,}25 \cdot 0{,}5 + 0{,}08 \cdot 0{,}8$$
$$= 0{,}5614$$

Similarly,

$$OF_{Kate} = \sum_{par} W(x, par) \cdot par(d) =$$
$$0{,}09 \cdot 0{,}4 + 0{,}02 \cdot 0{,}5 + 0{,}07 \cdot 0{,}6 + 0{,}05 \cdot 0{,}7 + 0{,}07 \cdot 0{,}5 +$$
$$0{,}25 \cdot 0{,}1 + 0{,}02 \cdot 0{,}3 + 0{,}05 \cdot 0{,}8 + 0{,}05 \cdot 0{,}6 + 0{,}25 \cdot 0{,}5 + 0{,}08 \cdot 0{,}8$$
$$= 0{,}448$$

and

$$\mathrm{OF}_{\mathrm{Nicolas}} = \sum_{par} W(x, par) \cdot par(d) =$$
$$0{,}09 \cdot 0{,}4 + 0{,}02 \cdot 0{,}5 + 0{,}07 \cdot 0{,}6 + 0{,}05 \cdot 0{,}7 + 0{,}07 \cdot 0{,}5 +$$
$$0{,}25 \cdot 0{,}1 + 0{,}02 \cdot 0{,}3 + 0{,}05 \cdot 0{,}8 + 0{,}05 \cdot 0{,}6 + 0{,}35 \cdot 0{,}5 + 0{,}08 \cdot 0{,}8$$
$$= 0{,}4105$$

Replacing the respective factors to formula (27) and taking into account formula (29), we construct the following formula:

$$OF = Max\left\{\sum_{d} K(x,d) \cdot \sum_{par} W(x, par) \cdot par(d)\right\}$$
$$= Max\{1 \cdot 0{,}5614 + 0 \cdot 0{,}448 + 0 \cdot 0{,}4105\}$$
$$= 0{,}5614$$

Table 5-5: Scenario 1 - Candidate Drivers' Parameters and their Values

Parameters	**George**	**Kate**	**Nicolas**
Age	44 years old (0,16)	26 years old (0,4)	34 years old (0,4)
Gender	Male (0,5)	Female (0,5)	Male (0,5)
Educational Level	Medium (0,2)	Higher (0,6)	Higher (0,6)
Marital Status	Married (0,3)	Single (0,7)	Single (0,7)
Occupation	Employed (0,4)	Student (0,5)	Employed (0,5)
Smoker	No (0,9)	Yes (0,1)	Yes (0,1)
Language	English (0,3)	English (0,3)	English (0,3)
Nationality	English (0,8)	English (0,8)	English (0,8)
Departure	SP-A	SP-A	SP-A
Destination	DP-A	DP-A	DP-A
Itinerary Cost	Non - Economic (0,4)	Economic (0,6)	Economic (0,6)
Evaluation			
1. Driving Competence	Good (0,5)	Good (0,5)	Medium (0,35)
2. Social Behavior	Good (0,8)	Good (0,8)	Good (0,8)
3. Repeat Match	NMB	NMB	Yes

Figure 5-3 depicts the weights of the parameters with regards to Mary's preferences.

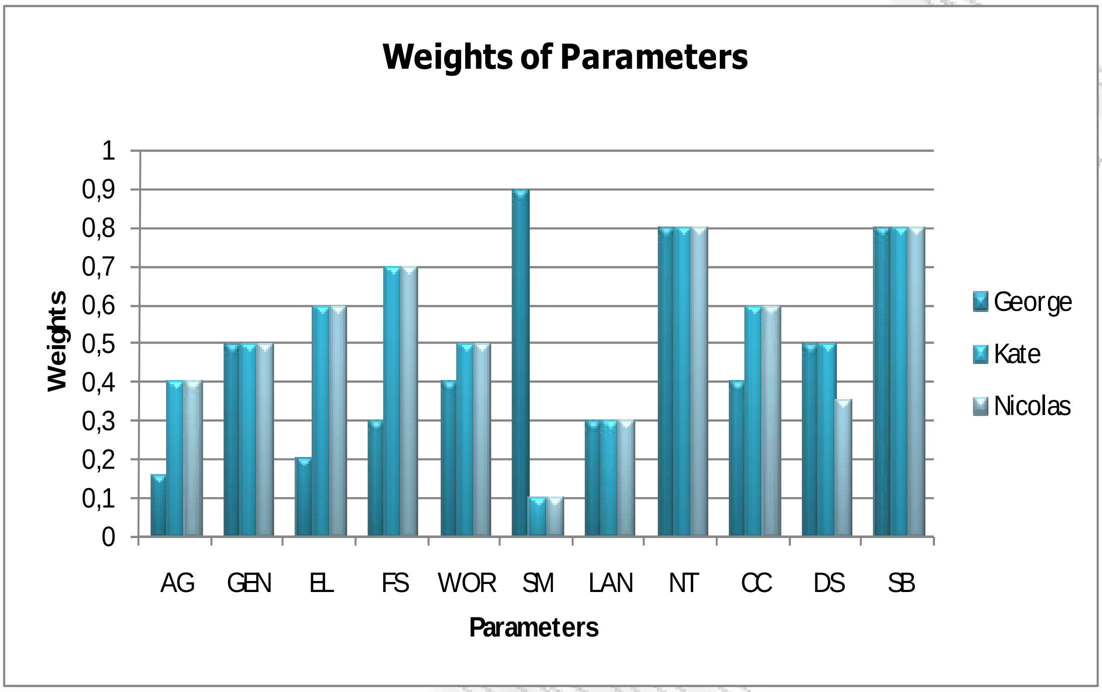

Figure 5-3: Scenario 1 - Parameters weights in combination with passenger's preferences

Based on the results, what can be concluded is that the TM-CPS will decide in favor of Mary and George, as George's OF value is the highest, among the three candidate drivers. It may also be observed that despite the fact that Kate and Nicolas comply with Mary's preferences as far as age, educational level and marital status are concerned, driver George is selected as more appropriate, as Mary thinks of driving competence and smoking as more important factors to make the match.

Figure 5-4 graphically presents the OF values of the 3 candidate drivers.

Furthermore, let it be noted that using formula (26) presented in section 5.3.3, we can calculate the cost of the itinerary, which in this case is ***2.25€***.

When the selection of the users that will share the ride has been finalized, they contact each other by telephone, e-mail or SMS in order to set the details of the itinerary, namely the time of the pick-up, the pick-up point, the destination point, the maximum time of waiting at the pick-up point and the cost of the itinerary.

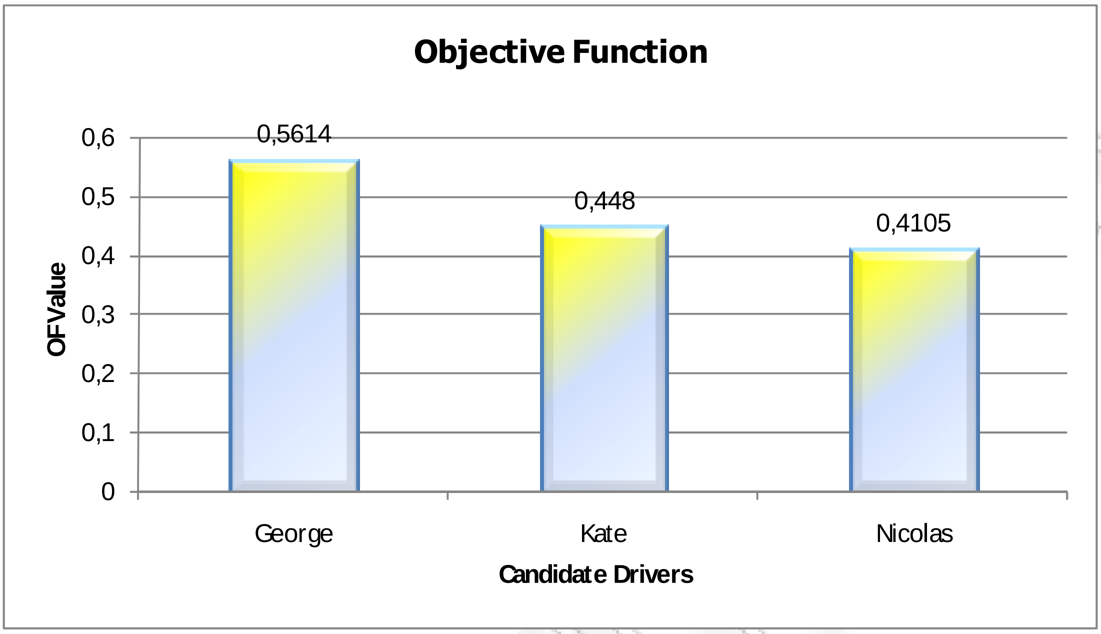

Figure 5-4: Scenario 1 - Objective function value for each candidate user

Of course, candidate drivers and passengers have the right to reject a potential match, as they will be able to view their candidate's match profile. In case one of the users rejects a match, then the solution proposed is the second optimum choice.

5.4.2. Scenario 2: Cost – driven scenario

In this case, user Thomas (a driver now) wishes to drive an itinerary of 463km, having as starting point the SP-K and destination point the DP-L. This means that the itinerary is an interurban itinerary and it definitely involves tolls. Driver Thomas specifies the day and time of departure, the possible stops he is going to make during the itinerary and the number of tolls he is going to pay:

- Starting Point: SP-K,
- Destination Point: DP-L,
- Kilometers: 463 Km,
- Number of tolls: 5.

In such a long itinerary it seems rational that, more than any case, the cost is important to the users, as it is higher than any other itinerary. The weights of parameters for Thomas are presented in Table 5-6.

Table 5-6: Scenario 2 - Parameters and their respective weights

Parameter	Weight
Age	*0,1*
13 – 17	0,15
18 – 24	0,3
25 – 34	0,3
35 – 44	0,1
45 – 54	0,05
55 – 64	0,05
65 – 70	0,05
Gender	*0,02*
Male	0,5
Female	0,5
Educational Level	*0,09*
Higher	0,5
Medium	0,35
Low	0,15
Marital Status	*0,04*
Married	0,3
Single	0,7
Occupation	*0,08*
Employed	0,2
Unemployed	0,25
Housewife	0,05
Student/ Pupil	0,5
Smoking	*0,15*
Yes	0,8
No	0,2
Language	*0,02*
English	0,3
French	0,3
Greek	0,3
Other	0,1

Nationality	*0,05*
English	0,65
Other	0,35
Evaluation	
Driving Competence	0,0
Good	0,0
Medium	0,0
Low	0,0
Social Behavior	0,1
Good	0,8
Medium	0,1
Low	0,1
Itinerary Cost	0,35
Economic	0,1
Non-economic	0,9
Repeat Match	
(NMB) No Match Before	
Yes	
No	

As it may be observed, the driver thinks of the cost as a very important factor of the itinerary. Another point to underline is that in the evaluation part, the sub-parameter "Driving Competence" is not taken into consideration (it is equal to zero). This is because in this case the driver is the one that looks for a co-passenger and not vice versa. Therefore, it is of no importance whether the passenger is a competent driver or a driver at all, since he is not going to use such skills. There are three users of the system that wish to make the same itinerary as Thomas and seem to be close to the characteristics that the driver has applied for.

Table 5-7 presents the weights that correspond to the values of parameters for each candidate user, as formed according to Thomas' preferences and priorities, expressed in Table 5-6.

Table 5-7: Scenario 2 - The weights of the parameters for the candidate passengers

Parameters	Margaret	Amy	Jim
Age	23 years old (0,3)	53 years old (0,05)	31years old (0,03)
Gender	Female (0,5)	Female (0,5)	Male (0,5)
Educational Level	Higher (0.5)	Medium (0,35)	Higher (0,5)
Marital Status	Single (0,7)	Married (0,3)	Single (0,7)
Occupation	Student (0,5)	Housewife (0,05)	Employed (0,2)
Smoker	Yes (0,8)	No (0,2)	Yes (0,8)
Language	English (0,3)	English (0,3)	English (0.3)
Nationality	English (0,65)	English (0,65)	English (0,65)
Departure	SP-K	SP-K	SP-K
Destination	DP-L	DP-L	DP-L
Itinerary Cost	Economic (0,1)	Non-Economic (0,9)	Economic (0,1)
Evaluation			
1. Driving Competence	-	-	-
2. Social Behavior	Good (0,8)	Good (0,8)	Good (0,8)
3. Repeat Match	NMB	NMB	Yes

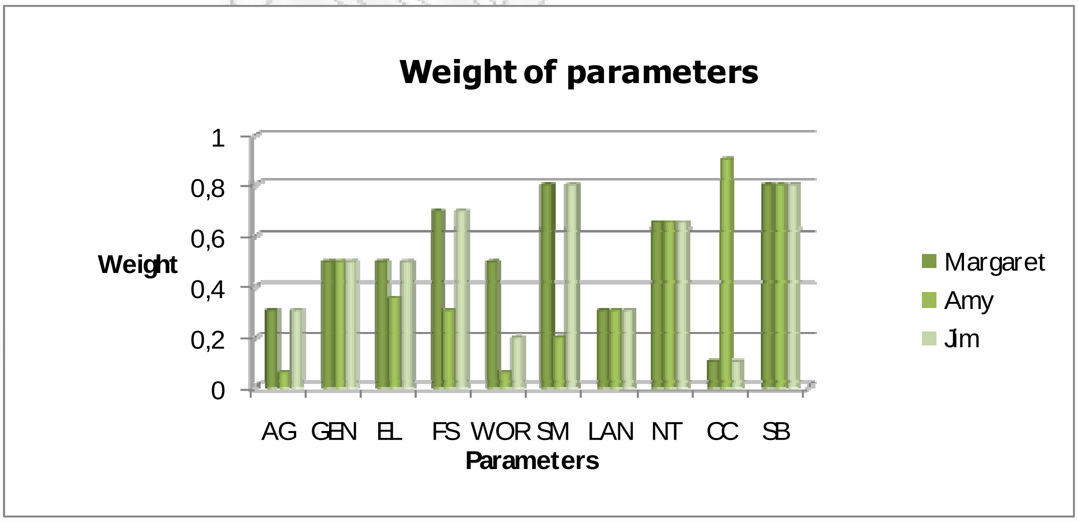

Figure 5-5: Scenario 2 - Parameters weights in combination with driver's preferences

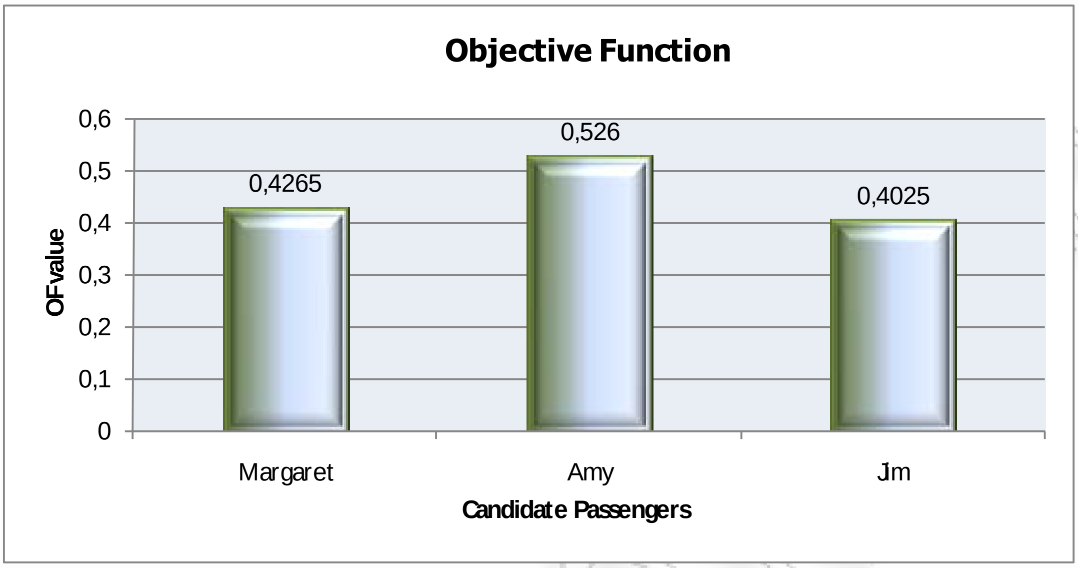

Figure 5-6: Scenario 2: Objective function value for each candidate user

Then, based on the parameters and their weights, we can calculate the OF's value for the three candidate passengers, using the formula (27), and following the example of the first scenario (in section 5.4.1).

Figure 5-5 presents the values of the parameters for every candidate passenger, while Figure 5-6 presents the OF values for all three candidate passengers.

Out of the three candidates, Margaret and Jim have almost all parameters' values similar and very high. This means that they have high chances to match with Thomas. Thus, it would be sensible that the system would have to choose between one of the two passengers (Margaret or Jim) to travel with. Yet, since Thomas thinks that the cost is the most important factor, Amy will be chosen, as she is the user that has the same opinion with Thomas, that is a non-economic itinerary, and Thomas attributes a high importance to this parameter (providing a high value). This means that Thomas would like to travel through the most expensive and yet safer manner, which is through the National Highways.

Figure 5-6 shows in a graphical way the OF values of the 3 candidate drivers. Moreover, using formula (26) presented in section 5.3.3, we can calculate the cost of the itinerary, which in this case is ***62,87 €***.

This is a typical example showing that the weights can catalytically affect the results of the OF value calculation. However, the driver is in position to reject the candidate passenger with the highest OF value and choose the passenger that has resulted to the second highest OF value, as also previously mentioned.

5.4.2.1 Scenario 3: No particular preferences (similar parameter weights)

In this case a user makes a car pooling service request without having a specific preference on a certain parameter. In other words, the user attributes approximately the same weight in every parameter. This means that the user is not interested whether his co-passenger fits with his own personal preferences, e.g. whether he smokes, if he prefers an economic or non-economic itinerary, if he is employed, student or housewife, etc. As a result of this, the parameters' weights are similar. The following section presents the characteristics of this match request.

- Starting Point: SP-P,
- Destination Point: DP-Q,
- Kilometers: 120 Km,
- Number of tolls: 1.

The following table (Table 5-8) presents the weights of parameters, as defined by the user Angela, who makes the request. Going through Table 5-8 it can be concluded that Angela values the parameters in a similar manner, as she does not have any specific preference to the other user(s) preferences.

More specifically, according to Angela's preferences and priorities on the parameters, presented in Table 5-8, Table 5-9 is formed and presents the weights of parameters of the candidate passengers'.

After inferring the values of the parameters for the candidate drivers, the OF formula can be filled in, in order to provide the results and present the classification of the candidate drivers. Then, the OF is calculated for each driver, following the example given in 5.3.3.

Table 5-8: Scenario 3 - Parameters and their respective weights

Parameter	**Weight**
Age	*0,08*
13 – 17	0,05
18 – 24	0,15
25 – 34	0,27
35 – 44	0,2
45 – 54	0,18
55 – 64	0,1
65 – 70	0,05
Gender	*0,07*
Male	0,47
Female	0,53
Educational Level	*0,09*
Higher	0,3
Medium	0,4
Low	0,3
Marital Status	*0,09*
Married	0,4
Single	0,6
Occupation	*0,08*
Employed	0,2
Unemployed	0,25
Housewife	0,3
Student/ Pupil	0,25
Smoking	*0,10*
Yes	0,3
No	0,7
Language	*0,09*
English	0,25
French	0,25
Greek	0,25
Other	0,25

Nationality	*0,09*
English	0,55
Other	0,45
Evaluation	
Driving Competence	0,10
Good	0,6
Medium	0,35
Low	0,05
Social Behavior	0,12
Good	0,9
Medium	0,05
Low	0,05
Itinerary Cost	0,09
Economic	0,5
Non-economic	0,5
Repeat Match	
(NMB) No Match Before	
Yes	
No	

The three candidate drivers are totally different with each other, yet the value of the OF for each one of them is similar. This occurs due to the weights that the passenger has attributed the parameters, which results to having similar OF values.

The forthcoming figures depict the parameters' weights, as well as the OF values for each of the three candidate drivers and the cost of the itinerary. To this end, Figure 5-7 shows the weight of every parameter.

Seeing these parameters in groups of three (as the number of candidate drivers) it can be easily inferred that their values do not differ much, while in most cases they are quite close, or similar. Accordingly, Figure 5-8 shows the OF values that correspond to each user.

Therefore it is clear that Miguel is the most appropriate match for Angela, having small differences from Lilly. The cost of the itinerary is calculated by formula (26) and it is ***16***

€. Thus, Miguel is the driver that will be presented to Angela as the best available match for the itinerary she wishes to make.

Table 5-9: Scenario 3 - The weights of the parameters for the candidate passengers

Parameters	Lilly	Miguel	John
Age	38 years old (0,2)	25 years old (0,27)	45 years old (0,18)
Gender	Female (0,53)	Male (0,47)	Female (0,47)
Educational Level	Higher (0.3)	Higher (0,4)	Higher (0,4)
Marital Status	Married (0,4)	Single (0,6)	Married (0,4)
Occupation	Housewife (0,3)	Student (0,25)	Employed (0,2)
Smoker	No (0,7)	No (0,7)	Yes (0,3)
Language	English (0,25)	Spanish (0,25)	English (0.25)
Nationality	English (0,55)	Spanish (0,45)	English (0,55)
Departure	SP-P	SP-P	SP-P
Destination	DP-Q	DP-Q	DP-Q
Itinerary Cost	Non-Economic (0,5)	Economic (0,5)	Non-Economic (0,5)
Evaluation			
1. Driving Competence	Good (0,6)	Good (0,6)	Good (0,6)
2. Social Behavior	Good (0,9)	Good (0,9)	Good (0,9)
3. Repeat Match	NMB	NMB	Yes

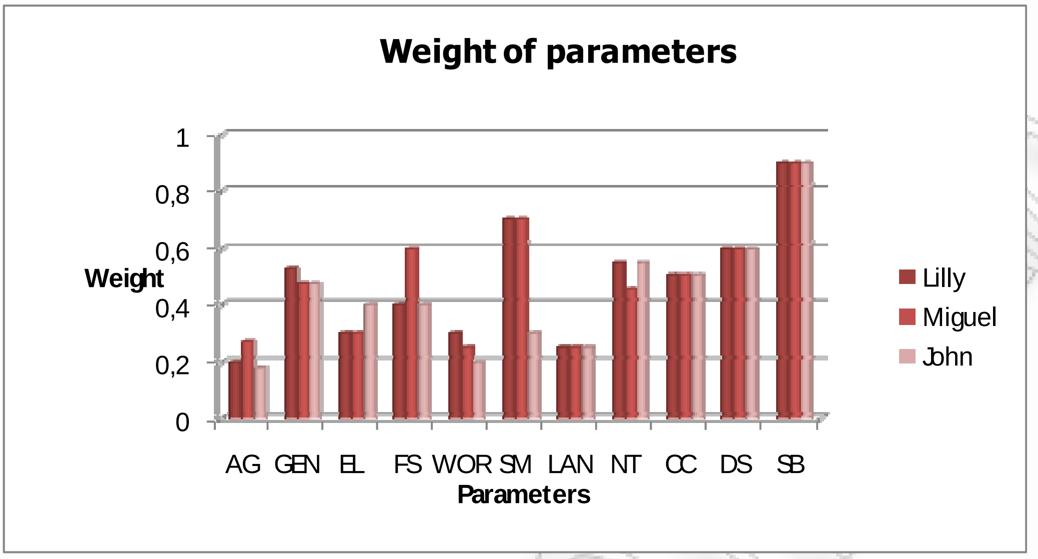

Figure 5-7: Scenario 3: - Parameters weights in combination with passenger's preferences

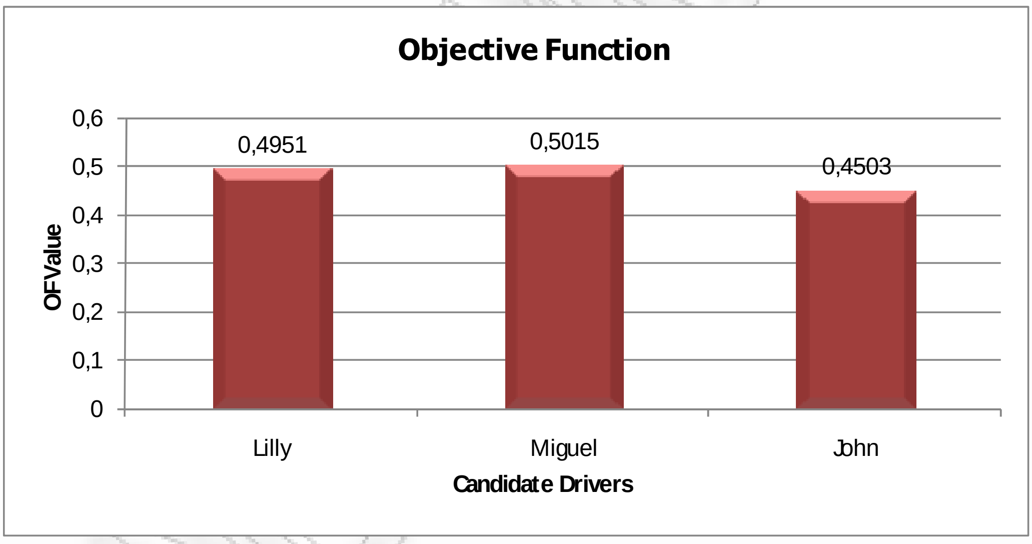

Figure 5-8: Scenario 3 - Objective function value for each candidate user

5.5. Conclusions and Future Work

The continuously increasing need for mobility has brought about significant changes in transportation infrastructures, usually associated with unpleasant traffic congestions. Those unpleasant phenomena raise the necessity for more efficient and safer mobility. A valid option to efficiently manage transportation is reflected on the concept of car pooling, which envisages that drivers and passengers can share an itinerary, increasing the number of passengers per vehicle, while decreasing the number of vehicles in the route (and thus reducing traffic). In this respect, the chapter has proposed a system, namely the "Transportation Management - Car Pooling System" (TM-CPS), which is capable of proposing optimal, reliable and secure community matches, based on profile and context information. Apart from the detailed description of the TM-CPS components, the chapter has also gone through extensive simulations, the results of which are more than encouraging in proving the TM-CPS's capability to be applied in real time transportation infrastructures.

In general, the TM-CPS represents a simple, while absolutely effective means to improve current transportation management schemes and their functionality and significantly reduce traffic congestions. At the same time, the TM-CPS contributes to the reduction of environmental pollution, as well as to the enhancement of social relations amongst users, since it takes into consideration users' personal preferences (such as occupation, educational level, marital status, etc). Furthermore, as the concept of car pooling is envisaged to attract significant attention in the near future, more and more organizations are expected to target the development and utilization of management systems, such as the TM-CPS.

A potential improvement to the proposed system could consist in a further analysis of cost factors that should be taken into account, with this denoting the design and development of advanced, composite objective functions that should be optimized when proposing matches. Furthermore, another aspect to be analyzed is the creation of user groups, by taking into account user history preferences (the parameter used in this system "Repeat Match", as well as personal characteristics of the user (area of residence, area of work, etc). In this way, the system will search on a first level within the group and if not finding a match, then it will proceed on the broader level of the system as a whole. A result of this procedure is to encourage social connections between people with common or similar interests and to make the itinerary more pleasant for passengers. Additionally, part of our future activities shall be devoted to the incorporation of, the TM-CPS in larger transportation management systems. This implies the exploitation of work on distributed, cognitive functionality in the transportation management domain, in terms of combining the concept of car pooling with other legacy and novel methods, such as vehicles redirections or traffic lights amendment, according to the management system's commands.

5.6. Chapter References

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6. SUMMARY – ONGOING CHALLENGES

This PhD thesis was engaged in the field of Quality of Service in Future Multimedia Systems, focusing on the Technoeconomic Analysis and User Profile Management in the Context of Services and Wireless B3G Networks. Particularly, the viability of Reconfigurable Networks was proved, after going through several different cases, and methodologies on learning user preferences, and therefore composing User Profile, were analysed, in order to improve overall functionality of the system. The results of all cases were thoroughly presented and discussed.

The First Chapter of the PhD thesis made an introduction to the main concepts that were discussed throughout the document. The structure of the PhD thesis was provided, so as to showcase the directions followed within the PhD thesis. Technoeconomic analysis took place, using the Net Present Value Tool (NPV Tool) in order to validate the cost efficiency of new technologies. Technoeconomic analysis took also into consideration Quality of Service that depicts user preferences. Should the system be dependable and perform according to user preferences, the service would become reliable, establishing its use by responding to user specialized needs. Furthermore, the connection between user preferences and Quality of Service is explored, by investigating User Profile parameters and by analysing different services, in order to improve system's functionality. The support by the State of the Art is also presented, in order the link of the current trends and the current work to be discussed. The Chapter concludes providing overview of B3G networks and making a short introduction for each chapter of the PhD thesis.

The Second Chapter of this thesis addressed the issue of the profitability of the investment on Composite and Reconfigurable Networks. Based on the Net Present Value tool, the factors that compose it were analysed. More specifically, Capital Expenditure (CAPEX), Operational Expenditure (OPEX), revenues, amortization and discount rate were analysed, in order to form the Net Present Value formula. More precisely, CAPEX refers to the initial investment for installing technology and the necessary infrastructure, the operational software, as well as the additional investments during the years for upgrading the system or supporting increased capacity. OPEX concerns the expenses to preserve and operate the system, to maintain/ acquire potential software licenses, as well as costs for system reconfiguration. Revenues (or benefits) concern the profit of the service from user/subscribers. Amortization (or depreciation) is the deduction of the capital expenses over a period of time (in this case the time horizon of the investment). The discount rate (or rate of return or company cost of capital), is defined by calculating the rate that the capital required for the investment could return if it were invested in an alternative project with similar risks. The computation of these factors acted as an input to form different cases and finally compare the results for both Composite Radio and Reconfigurable Networks. In all cases, as showcased in the Second Chapter, Reconfigurable Networks are not only viable as an investment, but also are going to yield more profit to the investors, even under very harsh circumstances.

The main target of the Third Chapter was to investigate Use Profile, regarding the parameters that compose it, influencing user preferences, in the context of a Mobile Service. To this end, the architecture of such a system was provided and analysed. The main components of this system are Profiles Management, Policies Derivation, Context Acquisition and Configuration Negotiation and Selection. Emphasis was given on Profiles Management, in order to model the User Profile for learning user preferences. In this sense, observable (Service, Quality of Service level, Location, Time Zone, User Role and User Feedback) and output (Utility Volume) parameters were introduced. Using these parameters, along with the appropriate methodology, the system is in position to learn and therefore provision user preferences. Two methodologies were discussed for recording and learning user preferences; Bayesian Rating and Bayesian Networks. The results of the application of both methodologies were presented, analysed and compared. Both methodologies were able to map user preferences with close approximation, being thus able to foresee user future preferences within the system.

The Fourth Chapter of this PhD thesis acted as an instance of an e-service application, in the User Profile management. More specifically, an e-learning service was investigated, aiming to identify the components of the system, focusing on learning user preferences. The components if this system are Domain Model (preserving the content), User Model (User Profile), User Monitoring and User Interface. The identified User Profile parameters for this type of service are distinguished in two categories, as in the previous chapter; target and observable parameters. Content Difficulty, Content Volume, Interactivity and Lesson Interface compose target parameters, while Lesson Duration, Test Duration and Performance compose evaluation parameters. Having this set of parameters, the Bayesian Networks methodology was used in order to record and learn user preferences. The results for different use cases of this application were presented and discussed thoroughly.

In the Fifth Chapter of the thesis another instance of User Profile management in e-services is discussed. This service is a Transportation Management service, also called Car Pooling. This system is composed of Service Aspects and User Profile Aspects, which act as the input of the system and Decision Making and Implementation process, which acts as the optimization procedure of the system. In order to find a match for a driver or a passenger, the system collects the appropriate information from the User Profile component, finding the most appropriate match for each user. The parameters identified for this specific service are Age, Gender, Educational Level, Family State, Work, Smoking, Language, Nationality, Source, Destination, Commuter Cost and Evaluation (consisting of Driving Skills, Social Behaviour and Repeat Match). The optimization procedure followed in this case was Objective Function (OF), through which the weights attributed to each parameter by each user were taken into account, showcasing the best match for the case. In this way, different case scenarios were presented to show the classification of each user, according to the weights (that map user preferences) in each case.

Recapitulating, the thesis presented o global view on the Quality of Service in New Services and Infrastructures. The technoeconomic analysis certified that Reconfigurable Networks are able both technically and economically to support the continuously evolved services and the need for personalisation to user specific needs. Furthermore, different methodologies to identify, measure, record, learn and further predict user preferences were presented, analysed and discussed in detail.

Thereof, the contribution of this thesis is multifaceted, as it presented:

- the technoeconomic analysis methodology, using the Net Present Value (NPV) tool. Net Present Value is one of the most popular tools for financial evaluation and is considered to be one of the most robust techniques for analyzing a variety of investment activities,

- the analysis that took place for Composite Radio Networks and Reconfigurable Networks. This work provided concrete proof that Reconfigurable Networks can provide significant business benefits for Network Operators, even under financially non-prosperous conditions,
- the structure of the architecture and the components that compose a mobile service system, as well as the parameters that compose the User Profile of a mobile system, in order to depict user preferences,
- the structure of the architecture and the components that compose an e-learning system, as well as the parameters that compose the User Profile of such a system, in order to represent user preferences,
- the structure of the architecture and the components that compose a transportation management – car pooling system, as well as the parameters that compose the User Profile of this system, in order to map user preferences,
- the methodologies followed to record and therefore learn user preferences, so as for the system to adapt to them. These methodologies are namely Bayesian Networks, Bayesian Rating and Objective Function.

The work presented in this PhD thesis serves actually as a basis for enhancing Quality of Service within a service or wireless network. This work may be extended in the following aspects:

- Further analysis of the parameters that influence Quality of Service in Services and Networks,
- The technoeconomic analysis made could be generalized in order to be applied for various technologies, for the validation of each investment's financial viability. A general formula may be created, which will apply on every new technology introduced, aspiring to replay the existing ones. In this way, apart from the technical and technological aspects, the economical aspects may be easily explored,
- The conformance and usability of the service may be investigated, so as to make the system more proactive regarding user preferences. Best practices and compliance (that appertain conformance) and documentation (that appertains

usability) are factors to be further analysed. This analysis will provide the designers more knowledge on user preferences and the users a more enhanced and personalised experience,

- The cost is another factor to be further researched. More precisely, the price of a service is very important and may be influenced by several factors and in various ways. This means that the cost will have to be carefully and globally analysed, in order to achieve accurate estimation and prediction on user preferences regarding cost,
- Investigation of the functionality, techniques and parameters, in order to enhance it, would also be a future aspect to explore. This could be done in the context of the different services available, in order to progress on the system's special characteristics.

Undoubtedly, the field of wireless communications and systems is very wide and continuously enhanced with new features and demands. This makes the abovementioned list of ongoing tasks growing continually, promising to fulfil users' needs in the best, most efficient, accurate and affordable way. In this sense, it is obvious that the progress and development within this scientific field is infinite. Thus, the realization of these goals is feasible, making this PhD thesis serving as a minimal contribution to the enhancement of this field. Therefore, the wish to add a minor, yet hopefully significant, page in the book of Quality of Service enhancement was an honour for me and a target for the past years.

Having the hope that this target of the completed PhD thesis was accomplished, it will accompany my thoughts and provide me the incentive to keep my research interests alive.

7. APPENDIX A – ACRONYMS

Acronym	Explanation
3GPP	Third (3rd) Generation Partnership Project
B3G	Beyond the Third (3rd) Generation
BN	Bayesian Network
BR	Bayesian Rating
BSAP	Business Systems Architecture Process
BS	Base Station
CAPEX	Capital Expenditures
CPE	Customer Premises Equipment
CTMS	Cognitive Terminal Management System
DAB	Digital Audio Broadcasting
DP	Destination Point
DVB	Digital Video Broadcasting
HOV lanes	High-Occupancy Vehicle lanes
ICT	Information and Communication Technologies
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IT	Information Technology
LLC	Logical Layer Control
LSA	Latent Semantic Analysis
MAC	Medium Access Control
NMB	No Match Before

NOM	Network Operation and Maintenance
NO	Network Operator
NPV	Net Present Value
OF	Objective Function
OPEX	Operational Expenditures
QoS	Quality of Service
RAT	Radio Access Technology
TM-CPS	Transportation Management - Car Pooling System
UMTS	Universal Mobile Telecommunications System
UBM	Unified Business Model
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Access Network
WMAN	Wireless Metropolitan Access Network
WPAN	wireless personal area networks
WWRF	Wireless World Research Forum
UUU (U3)	1 UMTS element with 3 transceivers
UUW	1 UMTS element with 2 transceivers and 1 WiMax Base Stations
UWW	1 UMTS element with 1 transceiver and 2 WiMax Base Stations

8. APPENDIX B – LIST OF PUBLICATIONS (APRIL 2009)

Journal Publications	
1.	Y. Kritikou, P. Demestichas, E. Adamopoulou, K. Demestichas, M. Paradia. "User Profile Modeling in the Context of Web – Based Learning Management Systems". Journal of Network and Computer Applications, Volume 31, Issue 4, p.p. 603 – 627. Elsevier. 2008
2.	Y. Kritikou, G. Dimitrakopoulos, E. Dimitrellou and P. Demestichas. "A Management Scheme for Improving Transportation Efficiency and Contributing to the Enhancement of the Social Fabric". Telematics and Informatics Journal. Elsevier. Accepted for publication.
3.	Y. Kritikou, V. Stavroulaki, P. Demestichas, D. Bourse, A. Lee and J.M. Temerson. "Evaluation of the potentials of the business case of deploying reconfigurable segments in wireless B3G infrastructures". Wireless Personal Communications Journal. Springer. Accepted for publication.
Conference Publications	
1.	Y. Kritikou, P. Demestichas and F. Paraskeva. (2005). "Advanced Educational Systems for Adults Based on Contemporary Web Technologies and Learning Theories", in *Proc. Of the Greek Scientific Conference "Technology in Lifelong Learning"*, Lamia, Greece, April 2005.
2.	Y. Kritikou and P. Demestichas, "Network Adaptation in Support of E-Services", In *Proc. of the Fifteenth Wireless World Research Forum (WWRF)*, Paris, France, December 2005.
3.	15th IST Mobile & Wireless Communication Summit, Mykonos, Greece, 4th-8th June 2006. Participated as a member of University of Piraeus team presenting demos on DNPM (Dynamic Network Planning Management) and REMS (Reconfigurable Equipment Management System).
4.	Dimitrakopoulos, Y. Kritikou, P. Demestichas, K. Tsagkaris, A. Saatsakis, K. Moessner, M. Muck and D. Bourse, "Management Mechanisms for Supporting Cognition in the Wireless, B3G World". In *Proc. of the Eighteenth Wireless World Research Forum (WWRF)*, Elsinki, Finland, June 2007.
5.	Y. Kritikou, G. Dimitrakopoulos, E. Dimitrellou and P. Demestichas, "A Management System for Improving Traffic Efficiency in Transportation Infrastructures". In *Proc. of 1st International Symposium on Vehicular Computing Systems 2008 (ISVCS 2008)*, Dublin, Ireland, July 2008.

6.	Y. Kritikou, V. Stavroulaki and P. Demestichas, "A Theoretical Approach for Learning User Behaviour and Preferences as Part of the Management of Cognitive Wireless B3G Terminals". In Proc. of *11th International Symposium on Wireless Personal Multimedia Communications (WPMC2008),* Lapland, Finland, September 2008.
7.	V. Stavroulaki, Y. Kritikou and P. Demestichas, "Introducing Cognition in the Management of Equipment in the Future Wireless World". In *Proc. of 19th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications 2008 (PIMRC2008),* Cannes, France, September 2008.
8.	Y. Kritikou, V. Stavroulaki, E. Darra and P. Demestichas, "A Scheme for Learning User Preferences: Enabling Personalisation in Cognitive Wireless Systems". In *Proc. of 69th IEEE Vehicular Technology Conference: (VTC2009-Spring)*, Barcelona, Spain, April 2009.
9.	D. Petromanolakis, Y. Kritikou, V. Stavroulaki and P. Demestichas, "Context Learning and Configuration Selection for Cognitive Device Management". In *Proc. of 69th IEEE Vehicular Technology Conference: (VTC2009-Spring)*, Barcelona, Spain, April 2009.
10.	V. Stavroulaki, Y. Kritikou and E. Darra, "Acquiring and Learning User Information in the Context of Cognitive Device Management". In *Proc. of Joint Workshop on "Cognitive Wireless Networks and Systems - Cognitive Radio Networking", held in conjunction with IEEE International Conference on Communications (ICC 2009)*, Dresden, Germany, June 2009.
11.	Y. Kritikou, V.Stavroulaki and P. Demestichas, "Awareness of User Behaviour in Cognitive Device Management". In *Proc. of ICT Mobile Summit 2009*, Santander, Spain, June 2009.

Books	
1.	P. Demestichas, G. Efthymoglou, S. Retalis, Y. Kritikou, A. Papasalouros (2005), "Introduction to Computers and Internet" (in Greek) (Project conducted in cooperation with the Ministry of National Education and Religious Affairs and the General Secretary of Adults' Education, "Adults' Training in Acquiring Basic Abilities in New Technologies – HERON), 2005.
2.	Y. Kritikou, P. Demestichas, E. Adamopoulou and K. Demestichas, "User Modeling in the Context of Cognitive Service Delivery: Application to Learning Management Systems". In Book: "Innovations in E-Learning, Instruction, Technology, Assessment and Engineering Education". Pages: 411-416. Eds: Magued Iskander. Springer, December 2006.
3.	Y. Kritikou, P. Demestichas, G. Dimitrakopoulos, F. Paraskeva, M. Paradia, A. Kyriazis and N. Mitsis, "Management Architecture for the Provision of e-Services in Cognitive Environments". In Book: "Innovations in E-Learning, Instruction, Technology, Assessment and Engineering Education". Pages: 417-421. Eds: Magued Iskander. Springer, December 2006.
4.	P. Demestichas, G. Dimitrakopoulos and Y. Kritikou (editors), "Emerging Technologies to Support Reconfigurable Cognitive Wireless Networks", Book of Visions WWRF (Chapter 8), p.p. 349-365. WILEY, 2008.