Challenges for Quality of Service in Next Generation Mobile Networks

Adrian Duda, Cormac J. Sreenan
Department of Computer Science
University College Cork (UCC), Ireland
E.mail: {a.duda, cjs}@cs.ucc.ie

Abstract

Next generation mobile networks, commonly referred to as 4G, are envisaged as a multitude of heterogeneous systems interacting through a horizontal IP-centric architecture. This paper presents an overview of the issues arising in such hybrid systems and international research work, with particular emphasis on quality of service (QoS) and vertical handoff. An outline of our research is presented, that is, optimising the handover process in proportion to both delay and throughput, by measuring QoS parameters and link characteristics at appropriate places in the networks, and drawing out decisions upon the profitability/necessity of a vertical handoff.

1. Introduction

The rollout of 3rd generation wireless networks has been delayed for a number of reasons. Some of these reasons are: the complexity of the 3G standards and building the networks and user equipment, the high cost of spectrum, delay of user equipment availability, lack of a "killer" application to drive its use, no worldwide standard, and its infrastructure is not based purely on IP, but instead relies on the circuit switched infrastructure inherited from 2nd generation wireless. For all of the above reasons and the current market condition in the telecommunications industry, wide spread deployment of 3G is still a ways off. This had led numerous people in the industry to question whether 3G will happen at all, and has led the drive towards 4th generation (4G) networks. 4th generation is intended to provide higher bandwidth, higher capacity, lower cost per bit, offer IP based services, and allow multiple access technologies. The paper is structured as follows: section 2 presents different views about what 4G will consist of. In section 3, key challenges for 4G are presented. Section 4 offers a brief description of the new business model envisaged to come 'hand in hand' with 4G. In the context of interaction among quality of service, security and mobility, Section 5 presents specific issues related to vertical handover, and international research work in the field. Section 6 presents an overview of the research carried out at UCC, concerning the vertical handover decision problem. Conclusions are presented in Section 7.

2. Next Generation Wireless Networks

Researchers and industry leaders are trying to contribute their ideas to the deployment of the yet-undefined 4G wireless world that is estimated to be operational around 2010. Four

European mobile equipment markers, Alcatel, Ericsson, Nokia and Siemens, have founded the Wireless World Research Forum (WWRF) which has the goal to "secure momentum, strategic orientation, and impact for the research on wireless communications beyond 3G" [7]. At the sixth WP8F conference held in Tokyo, it was agreed that mobile telecommunications systems will be combined with other systems such as wireless LAN, and achieve a data transmission speed up to 100Mbit/sec by 2010.

Although 4G is currently undefined there are many current opinions that outline the vision of the new wireless technologies. Walter Konh Suser of Siemens states [7] that "the transition to 4G will not be a change in interface technology as with UMTS but it promises to integrate different modes of wireless communications – from indoor networks such as wireless LANs and Bluetooth, to cellular signals, to radio and TV broadcasting, to satellite communications. The idea is to have a seamless merger so that mobile users can roam freely between standards". Alistair Urie of Alcatel states [7] that "we need to stop thinking about this network-centric, very defined world". And Nokia's Taipio Hedman states [7] that "4G is a misleading and confusing term which should not be talked about until 3G has come thoroughly into place".

Table 1 lists the key parameters of 4G compared to 3G. These parameters are likely to change though between now and when 4G is deployed:

Key parameters	**4G**	**3G**
Frequency Band	2-8 GHz	1.8-2.5 GHz
Data Rate	20 to 100 Mbps	384 kbps to 2Mbps
Bandwidth	5-20 MHz	5-20 MHz
Access	MC-CDMA or OFDM	W-CDMA
Switching	Packet	Circuit/Packet
Mobile top speeds	200 km/h	200 km/h

Table 1: Key Parameters for 4G vs. 3G

3. Key Challenges for 4G

A layered structure for 4G is proposed. The five layers are the distributed, cellular, hot spot, personal network and fixed layer. The supported mobility and covered cell size increase from the fixed layer to the distributed layer. Interworking will be required between different access systems in terms of intra-system and inter-system handover as well as seamless services of mobility, security and quality of service.

The 3G to 4G transition is towards a predominance of automated and autonomously initiated machine-to-machine interactions. 4G must be dynamic and adaptable with built-in intelligence. Key challenges will be personalisation, seamless access, quality of service, intelligent billing [11].

3.1 Personalisation

In summary the following requirements characterize a "personalization architecture": support of personal context - user profiling, context awareness; seamless service provisioning - advanced signaling and session control, AAA (authentication, authorization, accounting); open third party access (e.g., web services); adaptability (on all levels) -

content, communication (protocols), service logic; reconfigurable terminals - new strategies for pervasive/ubiquitous computing; programmable open platforms.

3.2 Seamless Access

Seamless access in 4G will go much beyond the roaming as we know it today and will be a much more sophisticated affair. Seamless Access in 4G will mean connectivity to the end-user across a wide range of access technologies and access networks with minimal input from the user.

The following requirements characterize "seamless access": seamless network integration based on IP; terminal mobility, personal mobility, service mobility, session mobility; new 4G wireless technologies should be IP-centric; dynamic resource allocation at all network/system levels; adaptability/programmability of network components; secure but simple service agreements; SIM-card like universal authentication.

3.3 Quality of Service

4G service quality will be the collective effect of the performance of all system elements in combination with the user expectations, which determines the degree of satisfaction of the 4G customer. The operator’s perspective is characterized by the customer service requirements, the customer perception of QoS, the offered QoS, and the QoS actually delivered. QoS modeling and QoS signaling would be crucial factors for a future 4G system that integrates heterogeneous network types.

3.4 Intelligent Billing

User related requirements include: QoS dependent charging; billing support to diverse access; support to real time billing information; support to interworking of prepaid systems; support to “per-call” service situations.

Operator related requirements include: billing support to IP traffic; flexibility of costs calculations (time, volume, QoS dependent, access dependent); distribution of revenue by value chain operators; customer relationship management; reliability of billing operations; instant fraud detection and cut-off.

4. New Business Model

So far, users could only subscribe to one provider and have access to the services offered by that provider. Each provider is responsible for the management of its own network and for the delivery of the supported service (vertical structure). When the service developer is an entity other than the network provider, the fruition of the service itself is restricted to the users whose network providers’ technology meets the service requirements. Moreover, when the communication requires inter-working of networks based on different technologies, a limited support is guaranteed as concerns particular applications, whilst no support at all is provided in some circumstances.

A more flexible architecture is therefore needed in order to support a multi-service environment; this in its turn will increase accessibility and penetration of services and applications themselves, thus fostering competitiveness and paving the way for a new business model in which network and service providers will separately play their role [7]. In the *horizontal architecture* of next-generation communications, IP acts as adapter of the different network technologies as well as glue between service-application layer and network layer.

5. Vertical Handoff

A vertical handover occurs when moving between access networks of different technologies. In the context of 4G networks as a combination of heterogeneous systems, vertical handovers will play a vital role.

There are some important differences between the horizontal and vertical handoffs. First, there is a distinction between *up* and *down* in vertical handoffs: an *upward vertical handoff* is a handoff to an overlay with a larger cell size and lower bandwidth/ area, and a *downward vertical handoff* is a handoff to an overlay with a smaller cell size and higher bandwidth/area. Downward vertical handoffs are less time-critical, because a mobile can always stay connected to the upper overlay during handoff. Second, in a heterogeneous network, the choice of the "best" network can be challenging; for example, an in-building RF network with a weak signal may yield better performance than a wide-area data network with a strong signal. Finally, there may also be financial differences that do not arise in a single network; some networks charge per minute or byte.

Handover between the different network tiers can lead to a very different quality of service available to the mobile terminal, for example handover from a wireless LAN (2Mbit/s) to GSM (9.6kbit/s) [20]. Two different approaches can be taken to support the change of bandwidth. Firstly the applications used on the terminal can be written to support the varying quality of service [5]. This has the disadvantage that 'standard' applications cannot be used on the mobile terminals. The second approach uses support for standard applications within the network using network proxies or packet filters [20].

5.1 International Research Work Overview

The primary technical objectives in the design of a seamless vertical handoff system are the balance among handoff latency, power consumption, and wasted bandwidth [3, 6].

A special inter-technology roaming protocol layer can be inserted between the application and the transport protocol layer [16]. This has been done in projects such as On The Move [31] and Mobile TCP/IP [24]. There is another category of approaches that offers modifications above the TCP/IP stack: X-interface mobility project [25]. Mobility gateway can be used to provide mobility in the transport level. Examples are Indirect TCP [26] and MSOCKS [27]. In the network layer, most widespread approach is the IETF Mobile IP. Network layer implementations have been done in projects like Monarch [28], MosquitoNet[29], Daedalus/Barwan [30].

In the area of vertical handovers, three main research directions have been identified:

- interworking between access networks
- minimizing handover delay
- keeping QoS parameters values during/after handover as close as possible to their values before the handover

5.1.1 Interworking between access networks

Three possibilities have been identified so far: no-coupling, loose coupling, tight coupling (at SGSN/GGSN level) [5, 12, 16].

5.1.2 Minimizing handover delay

Some of the topics here include: hierarchical function delegation [3]; extensions to Hierarchical MobileIP [2]; link layer triggering [3, 5, 9]; Extended SIP mobility [1].

5.1.3 Maintaining the QoS parameters values as close as possible to those before handover

This is a crucial problem when moving between different access technologies. And especially the problem comes up when moving from a high rate network (WLAN) to a lower bandwidth one (GSM). In this case the rates that were previously available can no longer be supported, and a deprecation of QoS parameters is likely to happen.

Some areas of interest are: network load balancing scheme/estimates [19]; QoS conditionalized handoff for MIPv6 [8]; context transfer [4, 5]; planned handover [5].

5.2 Inter-system Handover Algorithms

In [17] the vertical handoff characteristics in a multiple vertical environment are analysed, showing the relation between the handoff delay and throughput reduction coefficient to the throughput perceived by the mobile user during the handover transition period. An evaluation of vertical handoff profitability is made, but without considering the QoS related aspects. They conclude that it is preferable to persist in WLAN as long as the data rate is higher than in GPRS/EDGE, and that this principle is true with any two systems having different data rates.

A comparison of handover procedures in IEEE 802.11, GPRS and CDPD is made in [18].

In the next generation networks the advanced operators may permit the mobile users to define their personal set of mobility parameters for tailored policies when to trigger vertical handoff [17]. In [19], a policy-enabled handoff system is described that allows users to express policies on what is the ‘best’ wireless system at any moment, and make trade-offs among network characteristics and dynamics such as cost, performance and power consumption.

Since the data rate supported by different tiers of the network architecture will vary, loss free handover can be achieved if applications sense the change in service level and adapt their QoS demand accordingly. Experiments on handover performance from slower to faster networks have shown that relatively fast handovers can be achieved with only a small amount of buffering and re-transmission required for loss free handover. From fast to slower networks, either significant amount of buffering and re-transmissions are required or data loss will be experienced [20].

In [4] it is proposed an algorithm for 3G/WLAN intersystem handover, with decision in the mobile node, that employs a Central Radio Resource Management (CRRM) that keeps load information about WLAN cells collected from the access points. CRRM is a policy manager for the access to the cell and radio access bearers (RAB). An interwoking function is also employed, which sends/receives/translates RAB parameters (context) between WLAN and UTRAN. Inter Access Point Protocol (IAPP) is also used.

In [21] it is presented a handover algorithm and associated signalling protocols for heterogeneous mobile environments. The derived handover protocols are based on GPRS and UMTS. The emphasis is on handover execution, and much less on handover decision phase. MCHO (mobile controlled handover) is adopted.

In [22] the advantages and drawbacks of different inter-system handover algorithms for integrated terrestrial/satellite-UMTS environment are described. The backward MAHO (mobile assisted handover) with signalling diversity is adopted in the paper, as it is considered to be the optimum strategy in minimizing the signalling load and delays, and allowing a relatively simple MT.

In [16] it is shown how fuzzy logic and neural networks class of algorithms can be used to control inter-technology handoff procedure. WLAN and GPRS are used as a case study example. To facilitate features such as power saving by powering down unused interface cards, the proposed algorithm allows for several levels of alert (stable/unstable/poor WLAN), which would enable the system to prepare for an upcoming handoff. The handoff metrics that have been used in handover decision were RSS (radio signal strength), beacon packets, SNR (signal-to-noise ratio), BER (bit error rate), packet error rates, hysteresis margin.

Ericsson's approach to handover between WCDMA and GSM can be found in [32]. They focus on the handover mechanism, but they do not give details about the handover decision problem. The idea of steering traffic between GSM and WCDMA based on load sharing is described in [33].

In [34] it is proposed an architecture for integrating UMTS and 802.11 WLAN. The terminal model, power up, addressing scheme, resource reservation, mobility and inter-system handover procedures are described.

6. Our Research

As mentioned before, it is envisaged an interaction between quality of service, mobility and security components. Moreover, the three research topics that have been identified regarding vertical handovers (interworking between access systems/ minimizing handover delay/ keeping the session quality at good parameters during and after handover) have to be dealt with in parallel. A solution to one of these problems might have an impact on the other two. The way access systems are interconnected causes different handover delays, which, in turn, has effect on the QoS during the handover.

The research carried out at UCC is aimed at optimising the handover process in proportion to both delay and throughput, by measuring QoS parameters and link characteristics at appropriate places in the networks, and drawing out decisions upon the profitability/necessity of a vertical handoff.

The research comprises two areas:

- Drawing out decisions upon the profitability of a vertical handoff
- Measuring QoS and link characteristics

6.1 Drawing Out Decisions Upon the Profitability of a Vertical Handoff

In a network of homogeneous base stations, the choice of 'best' base station is usually obvious: the mobile chooses the base station with the highest signal strength after incorporating some threshold and hysteresis. When dealing with different wireless technologies, the overlay networks may have widely varying characteristics, and the criteria for starting a vertical handover may be not only based on the link characteristics (the signal strength perceived by the user), but also on other factors such as the network load, or the type of data being transmitted. In 802.11 networks for instance, an increased load (number of users) leads to a decrease in throughput due to the functioning of the MAC layer.

- [13] GSM is a connection-oriented and circuit-switched network; therefore the delay jitter is small. Some connections (for example voice) are not well supported if the jitter is too high even if the latency is low.

- The DAB (regional area) network suffers from high latency and therefore cannot be used for interactive or real-time data. It could be used for large downloads or web browsing.
- When the HIPERLAN network is not busy, latency is low and delays are short. Therefore, it is the ideal network for all connections. However, when the network is loaded, bursty traffic is still well supported but voice connections would be more efficient if transported by GSM [13].

In IP networks it is difficult to determine the traffic type of packets, but information from the IP header, such as the host addresses and port numbers, could be used to roughly categorize traffic.

As part of the research, it is intended to study and determine some 'good rules' (algorithms) about deciding upon the appropriateness of a vertical handover – whether to remain in the present overlay, or handoff to another (upward/downward), (pre-emptively) shutting down the previous interface or having multiple interfaces to different technologies active at the same time. The decisions will be based on measurements in the network combined with the QoS perceived by the user. A thorough analysis of the parameters needed in order to be able to make accurate handover decisions in different situations is needed. An investigation will also be made concerning the appropriateness of keeping the state of the network somewhere – in a centralized/distributed manner in order to minimize the message overhead (some kind of a sub/network manager). It is envisaged that QoS utility functions should be designed in order to have a palpable measure of the present QoS conditions, and the aim would be to maximize this utility function. The cost should also be taken into consideration, along with SLAs (service level agreements). For instance, is it acceptable that user pay less much and drop down to a poorer quality of service (in case of a handoff)? In case yes, he may be handed over to a 'poorer' network, and saving the space for users who have tighter SLAs. Another question that arises for instance is whether a utility function should be defined per flow, or per class? (the latter doesn't take into consideration the user's point of view, but is more scalable).

Knowledge of human perception in the handover decision problem will be exploited: cross-modal interaction (a user's perception of audio quality in a multimedia clip is affected by the video quality and vice-versa), content dependency (e.g. cross modal interaction is strongest when the face of the talker is visible), synchronization, task dependency (e.g. a person chatting to a relative in a videoconference may only require visual confirmation that the person is on the other end, whereas someone negotiating a business transaction may require video quality which is good enough to pick up on subtle facial clues; another factor is whether or not the task is passive or active). Details about these can be found in [23].

When deciding upon the necessity of a vertical handover, one more thing intended to be taken into consideration is the new business model that will be in place, i.e. networks and service providers playing their role separately. If a user requests a service, they do not have to stick to a single operator managing the network they have made contract with, but they can choose the service to come from multiple service providers. For example, when the quality of the service degrades, the user could remain in the same overlay, but change only the source the service comes from (a closer service provider maybe) so that the perceived quality be better. It will be investigated in which ways such a business model that is envisaged to come up 'hand in hand' with the fourth generation might influence the vertical handover.

When having done the algorithms to decide upon the appropriateness of a vertical handoff, there will have also to be determined the QoS and link parameters that are given as input for the algorithms and that hence have to be online monitored. Here comes the second step in the research: doing the active measurements.

6.2 Measuring QoS

6.2.1 What to measure?

Investigation will be made concerning which of the technology-based QoS parameters (i.e. delay, jitter, system/application level data rate, transaction rate, etc), QoS user-based parameters (i.e. picture detail, picture color accuracy, video rate, video smoothness, audio quality, etc) and link characteristics (radio signal strength, signal to noise ratio, etc) are the most relevant in the context of a vertical handoff. Handover metrics are closely related to the type of algorithm that will be employed to make handover decisions.

6.2.2 Where to measure?

This is a major issue in order to obtain accurate results concerning QoS characteristics at a certain moment. In [10] for instance, the challenging problem of efficiently monitoring bandwidth utilization and path latencies in an IP data network is addressed. In this paper the network is seen as a graph and the measurement location problem is reduced to a 'vertex cover formulation' - that is, to monitor all links in the graph, what is needed is to select a minimum subset of nodes such that if placing a measurement agent in those nodes, then all the links are covered. The implications of measuring the QoS characteristics at access points for instance, or at SGSNs, etc need to be further investigated.

6.2.3 How to measure?

There has been a flurry of both research and industrial activity in the area of developing novel tools and infrastructures for measuring network bandwidth and latency parameters. Examples include SNMP and RMON measurement probes, Cisco's NetFlow tools, the IPMaps and Network Distance Maps efforts for measuring end-to-end network latencies, the 'pathchar' for estimating Internet link characteristics.

In [14] a measurement model is proposed in which a single, predefined point in the network is responsible for actively gathering bandwidth and latency information from network elements. There are presented ways to minimize the monitoring communication overhead in IP networks. The main idea there is to combine global polling with local event driven reporting. These algorithms have been designed in the context of wired Internet. They seem promising, and as part of the research it will be investigated whether they can be adapted to make measurements in a wireless environment.

Measurement based admission control algorithms [15] have been proposed as an alternative to parameter-based admission control, whose admission decisions are mainly based on traffic parameter estimates from measurements obtained from an existing traffic. These have been generally applied so far to IntServ traffic. In the research it will be analysed whether these can be extended for DiffServ domains, when measuring aggregates, and whether we can benefit from them within a wireless environment.

Verification of the proposed solution will be done by practical experiment and simulation. A testbed will be implemented in the research lab at UCC, as complementary to the access network built within the University of Limerick, part of the joined EI – funded REALM project .

7. Conclusions

This paper is in first place an overview of the issues regarding the next generation wireless networks, the so-called 4G networks, focusing on the quality of service and vertical handover aspects. Thanks to interworking between different networks, users can enjoy seamless coverage. International research work in this area has been presented. It has been noticed that there has not been paid much attention yet to the handover decision/selection problem, i.e. the ability of a system to select the access technology that is best capable of providing the requested service and quality. The very most of the ideas take into consideration criteria based only on signal quality, and not much on the other quality of service aspects. Secondly in this paper, the research being conducted at UCC has been presented. It has as the theme designing a set of algorithms in order to decide upon the appropriateness/profitability of a vertical handoff, so that the best suitable access network be selected at every moment for a certain service the end user has requested, maximizing the user's satisfaction in terms of quality perceived and cost.

Acknowledgments

This research is sponsored by Enterprise Ireland Innovation Partnerships concerning the grant project "Remote broadband wireless access networks" no. IP-01-055.

References:

[1] E. Wedlund, H. Schulzrinne, "Mobility support using SIP", ACM/IEEE International Conference on Wireless and Multimedia (WOWMOM), Aug. 1999, pp. 76-82

[2] T.Kato, R. Takechi, H. Ono, "A study on Mobile IPv6 based mobility management architecture", transmission, *FUJITSU Sci. Tech. J., 37, 1,* pp.65-71 (2001).

[3] V. Marques, R. Aguiar, A. C. Casado, "A simple QoS service provision framework for beyond 3rd generation scenarios*", ICT'2003, 10th International Conference on Telecommunications, pp. 1475-1481, Tahiti, French Polynesia*, Feb 2003.

[4] M. Ademola, "Intersystem handover for WLAN and WCDMA" – *MSc thesis*, University of Jyväskylä, Finland, 2002.

[5] G. Neureiter, L. Burness, A. Kassler, P. Khengar, "The BRAIN quality of service architecture for adaptable services with mobility support", *Proc.11th IEEE International Symposium on Personal, Indoor and Mobile Radio Communication.* London, United Kingdom, 18-21 September 2000.

[6] X.Fu, G. Schafer, "SeQoMo architecture: interactions of security, QoS and mobility components", *Technical Report TKN-02-008, Telecommunication Networks Group,* Technical University Berlin, April 2002.

[7] E. Rizzi, "Multimedia QoS management in next-generation networks", White Paper, 2002

[8] X. Fu, H. Karl, C. Kappler, "QoS-Conditionalized Handoff for Mobile IPv6", In *Proc. of the 2nd IFIP-TC6 Networking Conf. (Networking2002)*, pp. 721-730, Pisa, Italy, May 2002

[9] N. Montavont, T. Noel, "Handover management for mobile nodes in IPv6 networks", *IEEE Communications Magazine, vol. 40*, August 2002, pg. 38 – 43

[10] Y. Breitbart, C.Y. Chan, M. Garofalakis, R. Rastogi, A. Silberschatz, "Efficiently monitoring bandwidth and latency in IP networks", *Proceedings of IEEE INFOCOM*, 2001.

[11] "Visions of the Wireless World Beyond the Third Generation", *Proc. IEEE Int. Conf. on Telecommunications (ICT 2001)*, vol. 1, (Bucharest, Romania), pp. 9-14, June 2001.

[12] A. Kassler et. al., "BRAIN architecture specifications and models, BRAIN functionality and protocol specification*", Technical Report IST –1999 – 10050, D2.2/1.0*

[13] C. Lebre, R. Titmuss, P. Smyth, "Handover between heterogeneous IP networks for mobile multimedia services*", International Symposium On Service and Local Access,* Venice, Italy, 22-27 March 1998

[14] M. Dilman, D. Raz, "Efficient reactive monitoring", *Proceedings of IEEE INFOCOM*, Alaska, April 2001.

[15] Y. Opoku, J.Park, T. Eshler, K.P.Flanagan, "Admission Control for IP quality of service", project presentation, The Bradely Dept. of Electrical & Computer Engineering , Virginia Tech, 2000

[16] M. Ylianttila, R. Pichna, J. Vallström, J. Mäkelä, "Handoff procedure for heterogeneous wireless networks", *Global Telecommunications Conference*, 1999.

[17] M. Ylianttila, J. Mäkelä, P. Mähönen, "Supporting resource allocation with vertical handoffs in multiple radio network environment", *IEEE Internation Symposium on Personal Indoor and Mobile Radio Communications*, 2002

[18] K. Pahlavan, P. Krishnamurty, A. Hatami, M. Ylianttila, J. Mäkelä, R. Pichna, J. Vallström, "Handoff in hybrid data networks", *IEEE Personal Communications*, April 2000

[19] H. Wang, R. Katz, J. Giese, "Policy-enabled handoffs across heterogeneous wireless networks", *WMCSA,* 1999
[20] L. Taylor, R. Titmus, C. Lebre, "The challenges of seamless handover in future mobile multimedia networks", *IEEE Personal Communications, Special Issue on "Advanced Mobile Communication Systems – Managing Complexity in a Competitive and Seamless Environment"*, 1999
[21] N. An, Y.F. Hu, R.E. Sheriff, J.G. Gardiner, "Development and Implementation of a handover algorithm in heterogeneous mobile environments", *ICCT2000*
[22] N. Efthymiou, Y.F. Hu, R.E. Sheriff, A. Properzi, "Inter-segment handover algorithms for an integrated terrestrial/sattelite-UMTS environment", *9th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC),* Boston, Massachusetts (USA), 8-11 September 1998.
[23] M.B. Myers, "Predicting and measuring quality of service for mobile multimedia", *3G Mobile Communication Technologies, Conference Publication No. 471, IEE* 2000.
[24] X. Qu, J. Xu Yu, R. Brent, "Implementation of a portable-IP system for Mobile TCP/IP", *ANU Computer Science Technical Report*, 1997
[25] T. Richardson, F. Bennett, G. Mapp, A. Hopper, "Teleporting in an X Windows System Environment*", IEEE Personal Communications, vol I, no. 3,* 1994
[26] A. Bakre, B.R. Badrinath, "Implementation and performance evaluation of Indirect TCP/IP", *IEEE Trans. Comp., vol. 46, no. 3*, 1997
[27] D. Maltz, P. Bhagwat, " MSOCKS: an architecture for transport layer mobility*", IEEE INFOCOM* 1998
[28] A. Hills, D. Johnson, "A wireless data network infrastructure at Carnegie Mellon University", *IEEE Personal Communications, 3(1)*, 1996
[29] M. Baker, X. Zhao, S. Chershire, J. Stone, "Supporting mobility in MosquitoNet", *Proc. of USENIX Technical Conference*, 1996
[30] S. Seshan, H. Balakrishnan, R. katz, "Handoffs in cellular wireless networks: the Daedalus implementation and experience", *Kluwer International Journal on Wireless Communication Systems*, 1996
[31] Meggers et al., "Roaming between GSM and wireless LAN", *ACTS Mobile Telecommunications Summit, Granada, Spain*, vol. 2, pp. 828-834, 1996
[32] G. Alsenmyr et al, "Handover between WCDMA and GSM", Ericsson Review no. 1, 2003
[33] R. Heickerö et al, "Ericsson seamless network", Ericsson Review, 02/2002
[34] M. Jaseemuddin, "An architecture for integrating UMTS and 802.11 WLAN networks", *IEEE Symposium on Computers and Communications - ISCC,* Turkey, 2003