Location Assisted Fast Vertical Handover for UMTS/WLAN Overlay Networks

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Abstract. UMTS/WLAN integration offers considerable benefits for the users as well as for the mobile network. As soon as coverage is available, a mobile user should be able to switch seamlessly from the ubiquitous low bandwidth UMTS to a high bandwidth WLAN. This will improve his quality of service, but this also increases capacity in the cellular network. To be able to change between radio access technologies, an inter-RAT handover protocol is needed. If this handover protocol is not fast enough, the vehicular user will penetrate deep into the cell, underutilizing the available bandwidth with a lower overall performance as a result. In this paper we introduce a new vertical handover protocol which uses location information from the vehicle to predict where and when the handover should occur, thus optimizing user throughput and network performance. We consider its deployment on three UMTS/WLAN integration scenarios.

1 Introduction

Beyond 3G systems are considered to be heterogeneous networks with multiple of radio access technologies (RATs) as well as reconfigurable user terminals in order to allow mobile users to enjoy seamless wireless services irrespective of their location, speed or time of day. Users will be able to choose its access technology according to his or her own needs. This concept of "Always Best Connected" (ABC) [1] is shared by the ETSI 3rd Generation Partnership Program (3GPP) and it has therefore laid the basis for a UMTS/WLAN interworking specification. While Wireless Local Area Networks can offer high bandwidth, cellular networks provide a (nearly) full coverage. It is obviously advantageous for the mobile user to connect to the WLAN network as soon as coverage and capacity are available. The user terminal will therefore regularly scan the corresponding frequency bands and try to detect beacons of UMTS or WLAN cells. If signal strength is adequate, a handover to the other network technology is attempted. The handover of connections between different networks with

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different radio access technologies is also called vertical handover, but these inter-RAT handover procedures have not yet been defined by the 3GPP, except for GSM-UMTS/UMTS-GSM handover. Most of papers in the literature discuss the aspects related to the common management of radio resources and authentication, authorization and accounting (AAA) among heterogeneous networks from an architectural point of view, describing constraints, potential advantages and drawbacks of various integration levels [2]. However, fast mobility management for vehicular users in heterogeneous networks is in a very early stage and still requires many research efforts [3] [4] [5]. Some research suggest Mobile IP [6] or and end-to-end mobility scheme like SIP [7] for heterogeneous networks. Mobile IP is a well known IP network layer mobility management scheme, in which packets from and to the mobile host are tunneled through a home agent at its home network so that the corresponding node that communicates with this mobile host is unaware of the mobility of the mobile host. Unfortunately, Mobile IP suffers from high delay and packet loss and is therefore not suited for fast moving mobile users. End-to-end based mobility management protocols can handle mobility without additional support from the network elements. The drawback of this end-to-end approach is that, especially in the case of fast moving users requiring fast handover, this protocol suffers from delay as both parties can be geographically spread. Additionally, this mobility scheme is only valid for applications that are SIP-aware.

In this paper we propose a proactive inter-RAT vertical mobility management protocol for all IP UMTS/WLAN interworking access networks called APACHE (A ProACtive Handover Enhancing protocol). It uses location information from the mobile user, for example acquired by a GPS system, and tries to proactively determine to which WLAN access point or UMTS base station the mobile user will switch and when this handover should occur. Our goal is to optimize the use of the available bandwidth for the user, keeping handover delay as low as possible and avoiding packet loss. In the next section we discuss possible UMTS/WLAN interworking architectural scenarios that allow inter-RAT mobility. Section 3 discusses the requirements for a location assisted proactive handover approach and introduces the APACHE protocol. The implementation of APACHE on the different interworking scenarios is also investigated. Following this section, we compare the performance of the APACHE protocol with a hard and a forwarding based handover scheme. We finish this paper with some conclusions.

2 UMTS/WLAN inter-RAT handover

In a UMTS/WLAN overlay network, one has typically large UMTS cells that provide nearly ubiquitous coverage, while in areas with high user density and high bandwidth demand, small WLAN cells will be deployed (e.g. in a town center). Vehicular users will have the choice of handing over from the low bandwidth UMTS cell to the higher bandwidth WLAN cell. Inside the WLAN access network, the UE is addressable by a local IP address assigned by a Dynamic Host Configuration Protocol (DHCP) server (figure 1). In the UMTS network a fixed external IP address will be assigned by the GGSN and makes the UE addressable to any host in the internet. The

Packet Data Gateway (PDG) in the WLAN access network binds the local address of the UE with its external address and performs network address translation on any packet from or to the UE in the WLAN. We assume the local AAA server interacts with the AAA server in the subscriber's home UMTS network.

The inter-RAT mobility management procedures are different depending on the

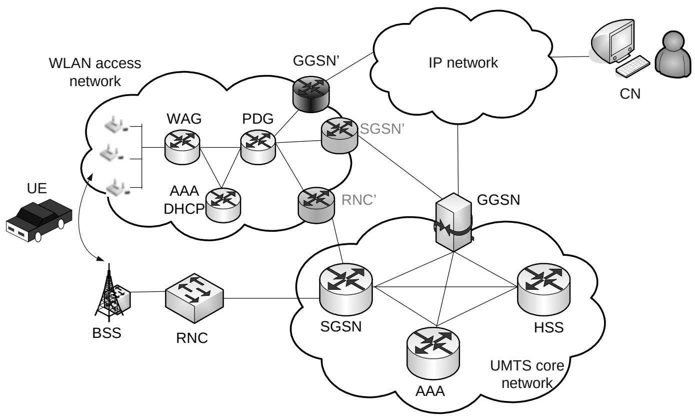


Fig. 1. Three degrees of UMTS/WLAN coupling

degree of coupling between both access networks. The WLAN and UMTS interworking architecture is standardized in 3GPP with the following alternatives [8][9] (although other variants are possible).

- **Very tight coupling**

Basically, in the very tight coupling approach the WLAN access network is considered as a generic UMTS RAN, connected to the UTRAN core network. Interworking is realized via the Iu interface between the UTRAN core network's SGSN and a RNC emulator in the WLAN access network (RNC'). In this case the management of user's mobility between the two access network technologies is performed through basic UMTS intra-SGSN handover specifications. This approach offers the lowest handover delay, but poses high hardware and software requirements on the RNC emulator that may be technologically or economically unfeasible.

- **Tight coupling**

In this case we have a WLAN connected to the UMTS core network via an SGSN emulator (SGSN') through the Gn interface. The WLAN coverage area appears like another routing area to the UMTS core network, but governed by a different SGSN. Mobility from UMTS to WLAN or from WLAN to UMTS will result in inter-SGSN routing area update procedure. All following packets from the internet will arrive at the GGSN and will be tunneled from GGSN to SGSN' over the core network and from SGSN' to the UE. The vertical handover delay is higher than the very tight coupling approach due to packet forwarding and PDP context transfer from SGSN to SGSN'/PDG and vice versa.

- **Loose coupling**

In the loose coupling approach, the WLAN access network is not directly connected to the UTRAN core network, but with a SGSN/GGSN emulator (GGSN') to the internet via the Gi interface. Packets, that were not delivered to the UE, need to be forwarded from the SGSN (GGSN'/PDG) to the GGSN' (GGSN) in case of UMTS to WLAN (or WLAN to UMTS) handover. All following packets from the internet will arrive at the GGSN and will be tunneled from the GGSN to the GGSN' via a dedicated tunnel over the internet and from the GGSN' to the UE. This internet tunnel will also be used for signaling traffic towards the GGSN in the UMTS core network. In this case no existing handover specifications are applicable and are yet to be defined. Note that in these interworking scenarios, mobility across WLAN and UMTS should not result in a change of external IP address for the mobile user. The mobile user will always be reachable through his external IP address assigned by the UMTS core network. The core network's GGSN is considered as the gateway to the internet and thus also to any corresponding internet host (CN). This way we avoid the need for an external mobility management system like Mobile IP or SIP. The correct access network location of the user is always maintained by the Home Subscriber Server (HSS) in the UMTS core network.

3 Location assisted proactive vertical handover

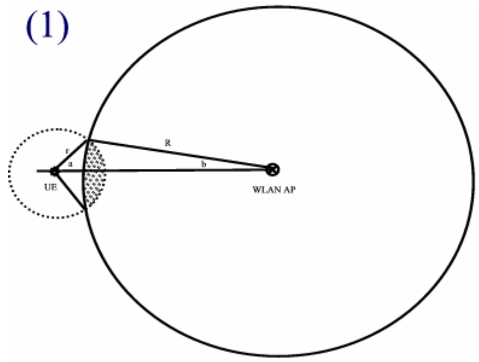
3.1 Introduction

To achieve seamless mobility management, a small handover delay is critical. In the APACHE protocol we use location information of the mobile user to determine to which next base station or access point the subscriber will connect and to set up the routing path proactively. The authors of [5] use a database of offline discrete power measurements, and use pattern matching to determine the location of the mobile user based on his online power measurement reports. However, we will show that a reasonable accurate location determination is needed to be able to outperform the existing forwarding based vertical handover protocol. This is however impossible without external location determination systems. Given the low cost of GPS devices nowadays, we predict that future vehicles will have default an accurate GPS system on board. We use this information in our proactive handover protocol.

3.2 APACHE protocol

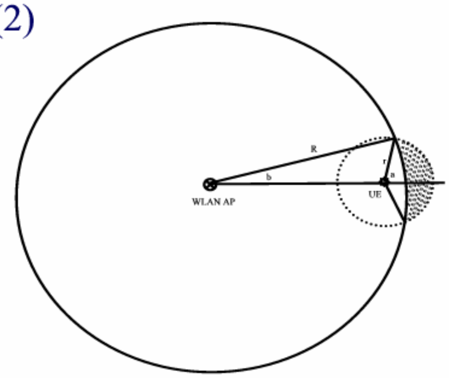
In mobile overlay networks it is important to choose the network with the best performance for the customer as soon it comes into range. If the access network with higher bandwidth or QoS is not detected fast and the handover delay is large, then the mobile user will have penetrated deeply in the coverage area of the cell before it can take advantage of the additional available resources. This is especially the case for fast moving vehicular users. The APACHE handover protocol uses a prediction algorithm to decide when to switch from one access technology to the other. As already mentioned, we assume that the mobile user transmits on a regular basis its GPS coordinates to the network at which it is currently connected. These GPS coordinates have typically a fixed accuracy and precision depending on the manufacturer, e.g. an accuracy of 10m for a precision of 95%. This means that there is a probability of 95% that the user is located in an area with radius 10m around the calculated GPS coordinates. Given the hardware constraints regarding the frequency at which these coordinates are updated (in the order of seconds), we use an extrapolation technique to determine the next position of the mobile user. In the UMTS system, the UE reports on a regular basis its power managements, including the time at which a base station beacon has been received. The frequency of these updates is much higher than the location updates from the GPS system, e.g. in the order of milliseconds. Because the time between those beacons is as good as fixed, we extrapolate the next coordinates of the location of the UE starting from the last GPS coordinates taking into account the number of beacons the UE has received, the speed of the vehicle and the direction in which the vehicle is driving based on his previous GPS coordinates. In this way we can estimate the user's following position without having to wait for new GPS coordinates, provided that the vehicle's movements are not random. Note that according to the IEEE 802.11 standard specification, the user is not required to give feed back on its beacon measurements to the WLAN network.

(1)



$$prob = \frac{0.95}{\pi}\left(a - \frac{1}{2}\sin 2a - \frac{1}{2}\left(\frac{R}{r}\right)^2(\sin 2b - 2b)\right)$$

(2)



$$prob = \frac{0.95}{\pi}\left(a - \frac{1}{2}\sin 2a - \frac{1}{2}\left(\frac{R}{r}\right)^2(2b - \sin 2b)\right)$$

Fig. 2. Calculating the probability that a GPS equipped user has crossed the handover barrier when entering or exiting the WLAN cell respectively.

However, the IEEE 802.11k study group proposes a new standard for radio resource management and aims to provide key client feedback to WLAN access points. Here we assume that the UE also provides beacon measurement reports in the WLAN as in the UMTS access network. Once the estimated location of the mobile user is determined for the next expected measurement report, the probability that the user will have crossed the handover barrier is calculated. Figure 2 gives these probabilities (1) for UMTS to WLAN and (2) for WLAN to UMTS handover. These probabilities are equal to the relation of the shaded area to the surface of the GPS accuracy circle, multiplied by the GPS precision (here 95%). If this probability is higher than a threshold value eta, then the handover process will be initiated by the APACHE protocol. The handover barrier itself, must be predetermined by measurements in the field and can be stored in a database system, for example for each road entering and exiting the WLAN coverage area.

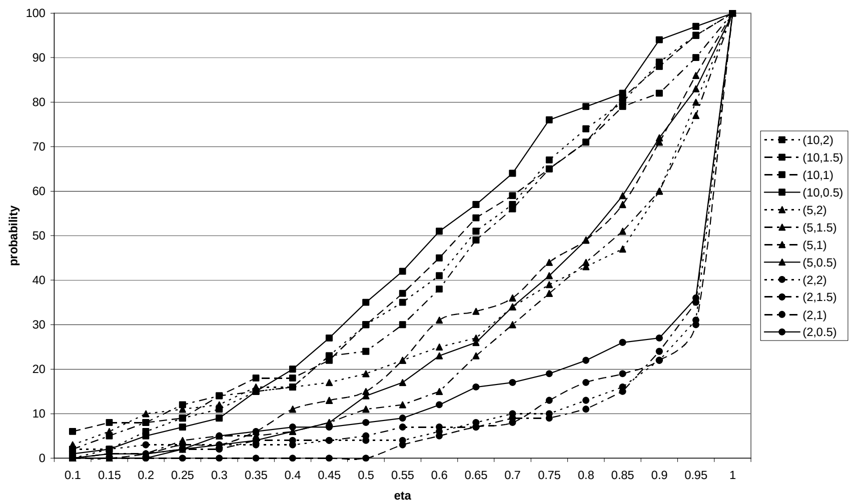


Fig. 3. Cumulative distribution of the optimum value of eta for different GPS accuracies and update periodicities

Figure 3 shows the cumulative distribution function for the optimum value of eta for a fixed mobile user speed of 20 m/s. The GPS accuracy goes from 10m to 2m and the GPS update periodicity from 0.5s to 2s. For lower GPS accuracies of e.g. 10m, a good value for eta is difficult to choose, because for every value of eta, there will be an equal probability that (non-proactive) handover happens sooner or later. If GPS accuracy is 5m and we choose a value for eta of 0.5 (in this case the shaded area in figure 2 is halve the GPS accuracy circle), then we can expect that only 20 % of the vehicles will make a handover sooner than we expected. The figure also shows that with our estimation technique variances in the GPS update periodicity do not have an important impact on the distribution of eta.

Figure 4 depicts the influence of the variance in the mobile user's speed on the estimations. The user moved with an average speed of 20m/s, the GPS updates had a periodicity of 1s up to 2s and the value of eta was in this case 0.5. For a constant speed (variance = 0 m/s), the APACHE estimation made the right decision in 70% of the cases. In 20 % of the cases, the handover occurred sooner and in 10% of the cases later. If more variance in the speed is introduced, then the number of correct handover decisions will decrease.

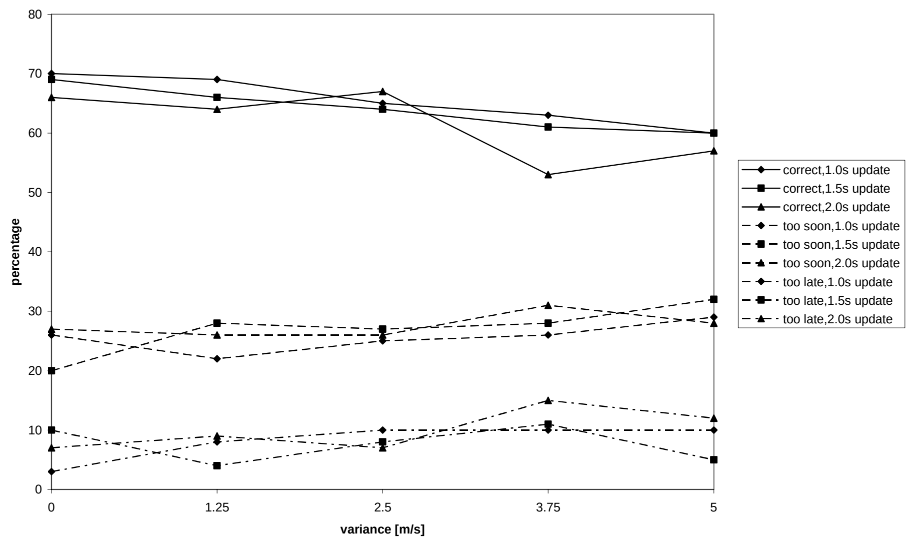


Fig. 5. Influence of the variance of the user's speed on the APACHE estimation algorithm

However, in this case the percentage of handovers that happened sooner than our estimations will increase more than the percentage of handovers that were later. These results have different meaning if handover occurs from UMTS to WLAN or from WLAN to UMTS in the APACHE handover protocol.

We first consider the UMTS to WLAN handover situation. Off course, if estimations were correct than a path to the next WLAN access point will be set up (handover preparation phase) and all new arriving packets will be directed towards that access point. If an inter-RAT handover occurs sooner than we had expected, the APACHE estimations are canceled and normal forwarding based handover is initiated. Upon arrival at the WLAN access point, a path to the GGSN will be set up and packets are forwarded from the old SGSN. If handover occurred later than we expected, the user will disconnect from the UMTS network and begins actively scanning for the appropriate WLAN access point until it comes into range. In the mean time, all packets will mount up in the buffer of the WLAN access network until the user makes the actual handover. Thus, no packets are lost, but some jitter is experienced by the user.

In the case of WLAN to UMTS handover and the handover happens sooner than we expected, again the APACHE estimation is canceled and the forwarding mechanism initiated. Because we are considering a UMTS/WLAN overlay network and handover to the UMTS network is always possible due to its omnipresence, handover that happens too soon has a different meaning in this context. In this case the user is unable to take full advantage of the coverage area of the WLAN because the APACHE protocol will order it to switch to the UMTS network before the WLAN cell edge is reached.

Figure 6 shows the different steps of the APACHE protocol for UMTS to WLAN and WLAN to UMTS handover.

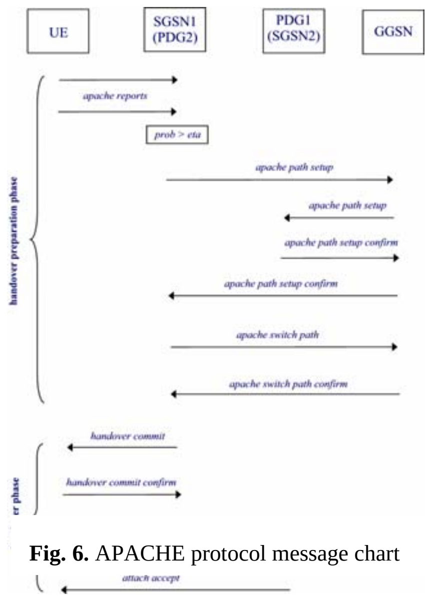


Fig. 6. APACHE protocol message chart

4 Implementation requirements

In the following sections we discuss the implementation of the APACHE protocol in the different scenarios of UMTS/WLAN interworking. We consider the UMTS to WLAN handover. APACHE procedures can be applied analogously to WLAN- UMTS handover.

- **Very tight coupling**

This architecture offers the lowest delay for the UMTS/WLAN inter-RAT handover. After the UE has associated with the WLAN access network, acquired a local IP address, executed AAA functions and has established the tunnel with its PDG, instead of forwarding further packets to the RNC of the last UMTS BSS, the SGSN now needs to redirect them to the RNC' of the WLAN. For UMTS to WLAN handover, APACHE offers only limited performance improvement as in this case only context transfer is avoided after handover if APACHE's estimations were correct. However in the WLAN to UMTS case, the forwarding of packets and the context transfer from the PDG to the SGSN is avoided.

- **Tight coupling**

If APACHE predictions were correct, the UE's contexts should already be available at the PDG and the SGSN' after the UE has made the handover. The tunnel between the GGSN and the SGSN' has already been setup by the APACHE protocol and packets, buffered at the PDG, can immediately be delivered to the mobile user. On the other hand, if the path has not yet been set up by APACHE, normal inter-SGSN handover procedures are performed between the UMTS SGSN and the WLAN SGSN'. In this case packets destined for the UE are forwarded from the old SGSN to the WLAN PDG and handover delay increases. Further packets arriving at the GGSN will be tunneled to the SGSN' over the UMTS core network and from the SGSN' to the UE.

- **Loose coupling**

In the loose coupling approach, the APACHE protocol will have proactively set up a tunnel between the GGSN of the UMTS core network to the WLAN GGSN' when the mobile user attaches to the WLAN access network. Again, packets buffered at the PDG can immediately be delivered to the UE. If the APACHE prediction algorithm was unsuccessful, this tunnel has to be set up and contexts need to be canceled at the previous SGSN after the UE has registered itself to the WLAN PDG, again increasing the handover delay.

5 Results

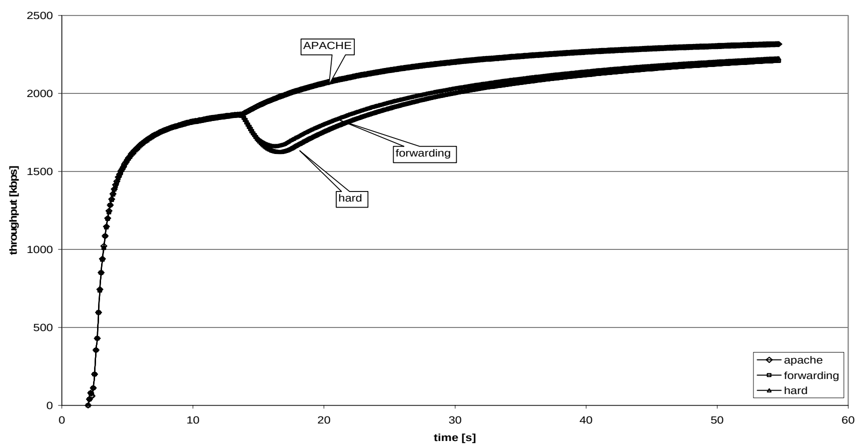


Fig. 7. TCP throughput comparison between APACHE, hard and forwarding handover protocol

In this section we show that our location assisted vertical handover approach (APACHE) is able to achieve a higher performance level than current solutions in terms of user experienced throughput. The APACHE protocol was implemented in the NS-2 [10] simulator. In figure 7 the mobile user is moving at a speed of 20 m/s and is downloading a file with an FTP application from a server in the internet. The user makes a handover from a 2 Mb/s UMTS cell to a 5 Mb/s WLAN cell. The TCP advertised receive window allows an average TCP throughput of around 2.4 Mb/s, although the user is unable to achieve such a throughput due to bandwidth restrictions in the UMTS cell, until he has arrived at the WLAN. It is important to mention that the WLAN network had a 10% faster link to the GGSN or SGNS in these simulations. We observe that the TCP throughput increases after the handover, but the APACHE handover protocol allows a much faster increase than the hard handover or forwarding handover protocol. In case of hard handover and forwarding based handover, packet loss and packet reordering respectively cause a TCP retransmission timeout and spurious retransmissions after handoff. This limits the user's observed throughput. The APACHE handover protocol on the other hand achieves a seamless handover when the prediction was correct. Note that if the WLAN cell would have had an equal or higher access network delay than the UMTS cell, then the TCP throughput of the forwarding based handover protocol would be the same as the

APACHE TCP throughput because the packets arrive in-order. This is however not always guaranteed, for example in the loose UMTS/WLAN coupling approach where the WLAN network is LAN or even gigabit LAN based with low link delay.

6 Conclusions

In this paper we introduce the APACHE handover protocol for vertical handover in UMTS/WLAN overlay networks. Using location information from the vehicular user we can achieve fast and seamless handover from a low to a high bandwidth radio access technology and vice versa. We have discussed its possible deployment in three UMTS/WLAN integration scenarios. The APACHE handover protocol approaches the speed of a hard vertical handover protocol without data loss such that a true seamless user experience is possible. However some overhead on the wireless link due to the location updates from the mobile user is required.

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References

1. Gustafsson, E.; Jonsson, A.: Always best connected. IEEE Wireless Communications, Vol. 10, 2003, pp.49-55
2. Salkintzis, A.K., Fors, C., Pazhyannur, R.: WLAN-GPRS integration for next-generation mobile data networks, IEEE Wireless Communications, Vol. 9 (5), 2002, pp. 112- 124
3. Varma, V.K., Ramesh, S., Wong, K.D., Barton, M., Hayward, G., Friedhoffer, J.A.: Mobility Management in Integrated UMTS/WLAN Networks, proceedings of ICC 2003, 2003, Vol. 2, pp. 1048 - 1053
4. Guo, C., Guo, Z., Zhang, Q., Zhu, W.: A seamless and proactive end-to-end mobility solution for roaming across heterogeneous wireless networks. IEEE Journal on Selected Areas in Communications, Vol. 22 (5), 2004, pp. 834 – 848
5. Siebert M., Schinnenburg M., Lott M., Goebbels S.: Location Aided Handover Support for Next Generation System Integration, proceedings of EW 2004, 2004, pp. 195-202
6. Johnson, D., Perkins, C., Arkko, J.: Mobility Support in IPv6, http://www.ietf.org/internet-drafts/draft-ietf-mobileipv6-24.txt, work in progress, 2003
7. Snoeren, A.C., Balakrishnan, H.: An end-to-end approach to host mobility, proceedings of MOBICON, 2000, pp.155-166
8. 3GPP TR 22.934 v6.2.0: Feasibility study on 3GPP system to Wireless Local Area Network (WLAN) interworking
9. 3GPP TR 23.234 v6.1.0: 3GPP system to WLAN interworking; System Description.
10. NS-2 simulator: www.isi.edu/nsnam/ns/