University of Würzburg
Institute of Computer Science
Research Report Series

A Policy-Based Vertical Handover System

Rastin Pries, Dirk Staehle,
David Hock, Matthias Hirth

Report No. 471 May 2010

University of Wuerzburg, Germany
Institute of Computer Science
Chair of Communication Networks
Am Hubland, D-97074 Würzburg, Germany
phone: (+49) 931-3186646, fax: (+49) 931-3186632
{pries|dstaehle|david.hock|matthias.hrith}@informatik.uni-wuerzburg.de

A Policy-Based Vertical Handover System

Rastin Pries, Dirk Staehle,
David Hock, Matthias Hirth
University of Wuerzburg, Germany
Institute of Computer Science
Chair of Communication Networks
Am Hubland, D-97074 Würzburg, Germany
phone: (+49) 931-3186646, fax: (+49) 931-3186632
{pries|dstaehle|david.hock|matthias.hrith}@informatik.uni-wuerzburg.de

Abstract

The integration of different wireless transmission technologies provides several opportunities to perform load control and to optimize the Quality of Experience (QoE) of the end user. However, several problems occur when integrating these technologies. Each technology has its strengths and weaknesses in certain areas and several different approaches have to be applied to measure the performance.

The contribution of this work is a proposal of a combined WLAN-UMTS network. We introduce three different policies on which we base the vertical handover decision, the load in the cell, Quality of Service (QoS) constraints, and user mobility. Simulation results illustrate how the policies are applied.

1 Introduction

The immense growth of wireless transmission technologies in combination with the evolution of mobile equipments with multiple network interfaces leads us to the discussion of how the technologies can be efficiently combined to allow the user to have access anywhere, anytime, and from any network. This combination is however rather difficult because the wireless transmission technologies are designed for different purposes and vary in QoS support, latency, and bandwidth.

3GPP and 3GPP2 have standardized the interconnection requirements between 3G cellular and WLAN to provide mobility support for users moving between these systems [1, 2]. In order to provide seamless mobility, one of the main issues is the Vertical Handover (VHO) support. The VHO can be split into three phases, detection policies, handover decision, and handover execution [3–5]. Currently, the decision which network to use is either based on the signal strength or can be selected by the user. Due to the fact that the UMTS coverage is quite high, especially in urban areas, and the billing system is flat rate, this simple decision metric is not sufficient. However, a handover might be useful if the user is requesting a large amount of bandwidth or if the UMTS network load is high. This leads us to the question: When should a mobile be served by which technology?

In this report, all three phases of the vertical handover are studied in order to provide a sufficient mobility management. First, we describe how and where to gather information and which information is required to offer a seamless service for the end user. Second, we show how to decide and when to perform a vertical handover, and third, we show the results of our vertical handover protocol. All three phases are implemented in the OPNET Modeler simulation environment [6] and we evaluate their applicability in a combined UMTS-WLAN scenario at the end of this report.

This work is organized as follows. Section 2 gives an overview of policy-based vertical handover systems and shows possible network architectures. The third section shows the vertical handover process and describes the three vertical handover phases in detail. In Section 4, the feasibility of these policies is evaluated through simulation. Finally, conclusions are drawn in Section 5.

2 Background and Related Work

The idea of a vertical handover which is not based on the signal quality only, but on a variety of parameters, has been studied since 10 years. Most papers propose a handover framework which is based on several criteria but do not implement the framework in a simulation or in a real testbed environment.

2.1 Idea of a Policy-Based Vertical Handover System

According to Kassar et al. [7] the policy-based vertical handover systems can be divided into the following five different categories:

- Decision function-based strategies (DF) [8, 9]
- User-centric strategies (UC) [10, 11]
- Multiple attribute decision strategies (MAD) [12]
- Fuzzy logic and neutral networks based strategies (FL/NN) [13]
- Context-aware strategies (CA) [5, 14]

The first paper using a DF to perform the vertical handover was published by Wang et al. [8] in 1999. The model is based on the available bandwidth, power consumption, and cost of the network. Zhu et al. [9] optimize the vertical handover decision strategy by taking the user satisfaction into account. This is similar to the UC strategies [10, 11]. Calvagna and Di Modica [10] do not focus on load balancing from the operators point of view but on the user satisfaction by also taking the costs of a vertical handover into account. Ormond et al. [11] also focus on user-centric strategies and try to find the best network for non real-time data transfer.

Stevens-Navarro et al. [12] compare different handover decision algorithms according to bandwidth, delay, jitter, and bit error rate. The best performance is shown for the Grey Relational Analysis (GRA), where the network is selected which has the highest similarity to the ideal network. Guo et al. [13] takes, similar to the different handover decision algorithms of

Stevens-Navarro et al., also multiple-criteria for the handover decision into account. A combination of the prediction function of neural networks and the multi-criteria decision function of fuzzy logic is used to decide the handover. Three criteria are chosen for the handover decision, namely bandwidth, velocity, and number of users.

The handover strategies of Wei et al. [14] and Kassar et al. [5] are based on context information. These can be classified into information available on the mobile device and information available in the network. All information is transmitted to a central point. This architecture enables an intelligent handover decision which is important in future, heterogeneous wireless networks.

Our handover decision is based on three policies, the load in the network, QoS constraints, and velocity of the user. Similar to the context-aware strategies, all required information for the policies are stored at a central point, the Serving GPRS Support Node (SGSN) which is also responsible for initiating the vertical handover. Before describing the three policies in detail, we provide an overview of possible network architectures.

2.2 Network Architecture

There are three possibilities of how to integrate WLAN and UMTS: loose coupling, tight coupling, and very tight coupling. The current approach of mobile network operators to offer the networks separately without coupling and without the possibility of using a vertical handover is not be regarded as an integration.

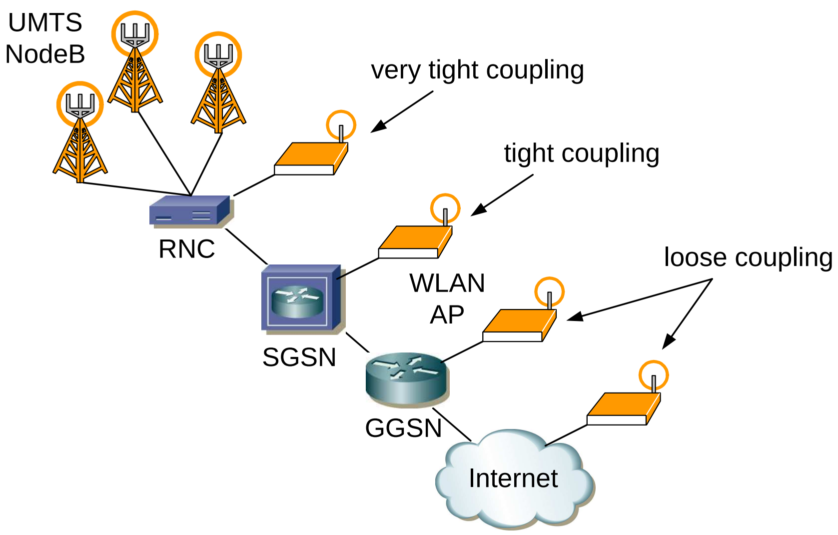


Figure 1: Different network coupling architectures.

2.2.1 Loose coupling

Loose coupling means that the WLAN Access Point (AP) is connected to the Gateway GPRS Support Node (GGSN) or the Internet as shown in Fig. 1. The problem with this architecture is that switching the access networks means changing the IP address because the IP packets have to be sent to the new location. However, changing the address means that the existing session will be disrupted. Therefore, a vertical handover approach like Mobile IP is needed. Furthermore, authentication, accounting, and mobility management mechanism for WLAN have to be realized. Thus, loose coupling is a good choice when using a private WLAN because mechanism like authentication or accounting are done separately at the wired Internet link. Although, if absolutely necessary in case of a WLAN Internet service provider, an overlay network like proposed in the IEEE 802.21 [15] standard can handle this. The huge advantage of loose coupling is that the UMTS architecture can remain unaffected and in the far future it will be easier for the network service provider to exchange the UMTS network with a new technology because only one interface for the new network has to be integrated.

Because of handling the vertical handover on the network layer with solutions based on Mobile IP or a similar mechanism, a vertical handover in a loose coupling architecture is slower than in a tight coupling architecture.

2.2.2 Tight coupling

When the WLAN Access Points are connected directly to the SGSN this is called tight coupling. The WLAN is integrated into the UMTS network and all UMTS features like authentication, billing, and mobility management are done by the UMTS network. This way, the SGSN must be able to detect and handle directly connected WLAN Access Points which means that additional changes have to be performed. The WLAN Access Point has to support the functionality of a Radio Network Controller (RNC), for example it has to establish IP-tunnels to the SGSN to deliver the packets coming over WLAN.

2.2.3 Very tight coupling

As in the tight coupling architecture, the WLAN Access Points are integrated into the UMTS network. The difference between the two architectures is the point of integration. In a very tight coupling architecture the WLAN Access Point is connected to the RNC and has to provide the functionality of a NodeB, while in the above discussed tight coupling architecture, the WLAN Access Points are connected to the SGSN and has to provide the functionality of an RNC. The disadvantage of this architecture is that incoming IP packets from the Mobile Equipment (ME) have to be encapsulated in smaller packet data units to be transported to the RNC. This can be avoided by using a tight coupling architecture.

Loose Coupling as well as tight or very tight coupling requires extensions of the ME regarding sending or receiving network information and executing the handover. We decided to use a tight coupling approach because this avoids the need of Mobile IP and packet fragmentation.

3 A Policy-Based Vertical Handover System

The complete vertical handover can be split into three phases as shown in Fig. 2. During the first phase, all handover relevant data is gathered. This information is either taken from measurements at the NodeB's or WLAN Access Points or transmitted from the ME. From this information, the load in the cells and the QoS levels can be calculated. In our case, the second part of the vertical handover process, the handover decision, is performed by the SGSN. Thus, the information gathered by the NodeB's and WLAN Access Points is transmitted to the SGSN. Based on the QoS constraints, the cell load, and position and mobility information, the SGSN decides when a vertical handover is required and which ME is chosen for the handover. The last part of the handover process is the execution of the vertical handover itself which is initiated by the SGSN. In [16] we introduced a protocol for a seamless handover between UMTS and WLAN.

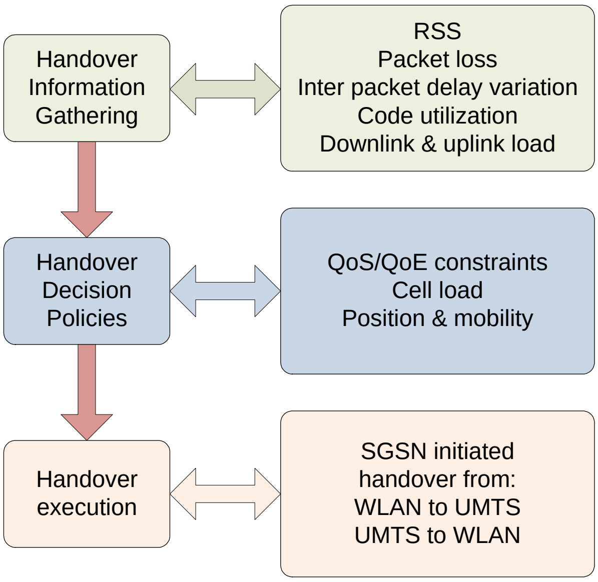


Figure 2: Vertical handover process.

Fig. 3 shows the handover delays from WLAN to UMTS and from UMTS to WLAN using our vertical handover protocol. Although the complete handover takes between 290 ms and 650 ms, a normal communication of the ME is possible during the connection establishment and the connection release phase. Only during the handover, the switching from one technology to the other, no communication is possible and this phase lasts only a few milliseconds.

The focus of this report is however the second phase of the handover process, the handover decision policies.

As already mentioned, the handover decision is typically based on the signal strength only. This is not a solid criterion in urban areas where we can consider the signal strength to be sufficient for all technologies. Hence, our main criterion for the handover decision is the load in the cells that we complement by considering the mobiles' QoS requirements, positioning information, and velocity. The entity which stores this information for every cell and user is the SGSN. Whenever the load is high in one cell or the users do not receive the expected quality, the SGSN initiates the handover.

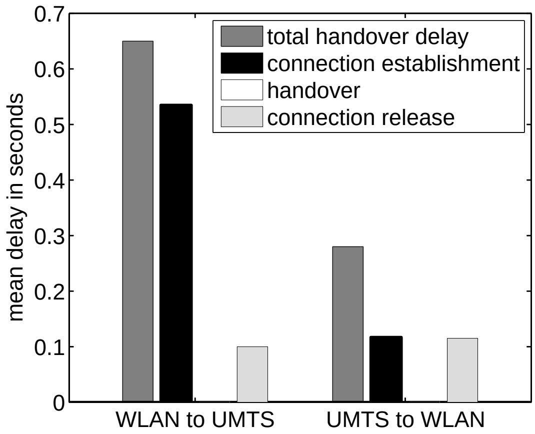


Figure 3: Vertical handover delays.

3.1 Position and Mobility

The position of a UMTS user can be retrieved with different methods like Observed Time Difference Of Arrival (OTDOA), Uplink - Time Difference Of Arrival (U-TDOA), and Assisted-GPS (A-GPS) which all provide sufficient accuracy for vertical handovers.

For the positioning in WLAN, a fingerprint mechanism can be used. With this mechanism, the location of the WLAN Access Points has to be known. The position of the user can then be estimated with the received SNR.

Besides the positioning information, the mobility of the ME is important for the handover decision. For a fast moving user, it does not make sense to handover the user to a WLAN cell with a small coverage area because of the short time the user remains in this cell. The speed of the user can also be retrieved with GPS. For the simulation scenario, we use a GPS-based system, which provides us both, positioning information as well as the velocity of the MEs.

3.2 Load Control

In order to support QoS traffic in a heterogeneous network, we have to compute the load in UMTS and WLAN. Furthermore, we want to balance the traffic load between the different cells and technologies. Therefore, we need to know how much load a single user produces or will produce in both network technologies.

3.2.1 UMTS Load Control

The UMTS cell capacity is limited by several factors which we use as an indicator for the load a user generates. We consider the following air interface radio resource metrics: uplink load, downlink load, and code utilization. In literature, many models are available for the characterization of the uplink and downlink air interface in UMTS, see e.g. [17–19]. We assume that the system is able to measure the most relevant parameters for the calculation of the radio resource metrics either at the NodeB or at the ME. The measurements are defined in [20]. Measurements which are performed in the MEs are reported to the RNC with measurement reports, which are either triggered by the radio resource management or sent periodically. In [21] we define the load metrics to determine the load on the downlink, on the uplink, and the code utilization. These metrics are used for the second policy, the load-based vertical handover.

3.2.2 WLAN Load Control

Due to the contention-based access of WLAN, it is rather difficult to estimate the network load. During the development of a mechanism to determine the load, we have seen that with the access parameters proposed in the IEEE 802.11 standard, neither QoS constraints can be supported, nor are the limited resources efficiently utilized. We proposed two different mechanisms, the Dynamic Contention Window Adaptation (DCWA) algorithm [22] and an adaptive frame bursting for non real-time traffic [23] to guarantee QoS for real-time traffic and to enhance the throughput of non real-time traffic. If the mechanisms are not sufficient to provide QoS guarantees, the SGSN is informed and a VHO of one or more MEs is initiated.

3.3 Quality of Service Constraints

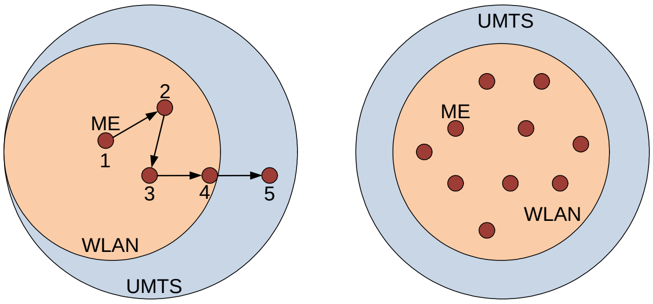
We consider the following QoS metrics for real-time connections: delay, jitter, and packet loss. Measuring the one-way delay is rather difficult because either a clock synchronization using GPS, or an alternative approach like Adaptive per Hop Differentiation (APHD) [24] is required. In our simulation environment, we consider a delay smaller than 150 ms as desirable, but still accept delays of up to 400 ms as recommended in the ITU-T G.114 [25] standard. The second parameter to determine the quality of real-time traffic is the jitter. For constant bit rate voice traffic, the jitter can be calculated as the standard deviation of the inter-packet delay. According to Hossfeld et al. [26], the threshold of the jitter should be set to 7.2 ms for the G.711 voice codec, because a large jitter results in a bad voice quality. Finally, the packet loss has to be lower than 1 or 3 percent, depending on the used voice and video codec. In a WLAN environment it is better to determine the number of retransmissions on the MAC layer instead of using the packet loss as we showed in [22]. As the WLAN MAC layer performs several retransmissions before dropping the packet, a reaction on packet loss would be too late.

4 Evaluation of Handover Strategies

In order to validate the three different handover policies, we implemented the complete framework in the OPNET Modeler simulation environment and set up the two scenarios shown in Fig. 4. Scenario 1 is used for the mobility-based handover and Scenario 2 for the load and QoS-based vertical handover.

4.1 Mobility-based VHO

In order to validate the first policy, the mobile equipment moves within the WLAN cell before it leaves the cell after Position 4 from Fig. 4(a) is reached. Fig. 5 shows the signal strength



(a) Scenario 1. (b) Scenario 2.

Figure 4: Simulation scenarios.

of the ME at the WLAN Access Point at the different positions. Although Position 2 is at the border of the WLAN cell, the signal strength is with over 45 dB still above the threshold of 30 dB. Shortly after Position 4 is reached, the signal strength drops below the threshold and the vertical handover to UMTS is initiated. This can be affirmed by the stop of the signal strength measured at the WLAN Access Point as well as the increase of the code utilization the user produces in the UMTS cell.

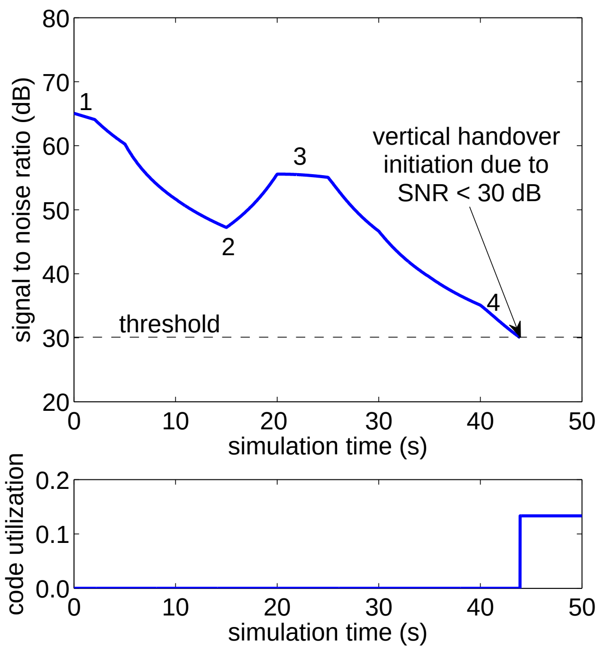


Figure 5: Mobility scenario.

4.2 Load-based VHO

Scenario 2 is used for the second handover policy, the load-based vertical handover. In the scenario, a new user connects to the UMTS network every 10 seconds using a radio access bearer of 384 kbps. The position of the user within the cell is thereby chosen randomly. Fig. 6 shows the increase of the load in the UMTS cell over time. When six users are active in the cell, the downlink load is still below 20 %. Although the uplink load is with 40 % twice as high as the downlink load, the threshold of 80 % load is by far not reached. The code utilization is however with 78 % just below the threshold and as soon as the seventh user enters the UMTS cell, the threshold is exceeded and the vertical handover is initiated by the SGSN. Therefore, the SGSN first determines which MEs are equipped with a WLAN interface. Afterwards, the user causing the highest load is identified and if more users have the same highest load, the SGSN chooses the ME which spent the longest time interval in the UMTS cell. After the ME is handed over to the WLAN cell, the load in the UMTS cell decreases below the threshold, cf. Fig. 6.

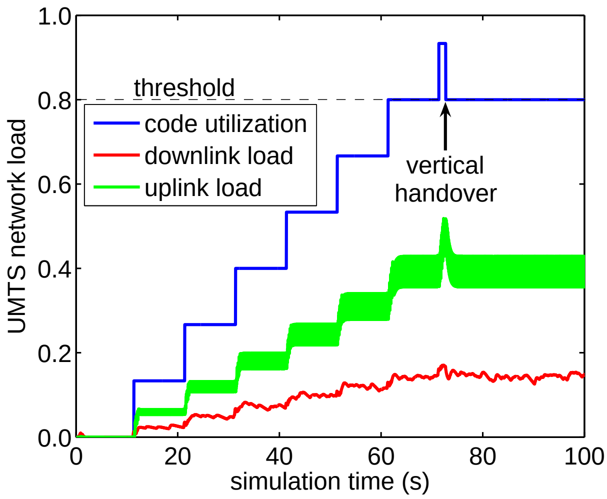


Figure 6: Vertical handover is initiated due to high code utilization.

4.3 QoS-based VHO

For evaluating the last handover policy, the QoS-based VHO, Scenario 2 is used again. This time, the MEs are connected to the WLAN cell. The simulation is initiated with one voice user whose number of retransmissions and jitter are measured. After 10 seconds, the first best effort user enters the WLAN cell, trying to utilize the complete bandwidth. Fig. 7 shows the progress of the the jitter and the number of retransmissions over time. As the voice user uses a constant bit rate voice stream, the jitter is calculated as the standard deviation of the inter-packet delay. For the number of retransmissions, the mean was measured over an interval of 100 ms and 1 s. As the mean of the 100 ms interval fluctuates too much over time, we decided to use the 1 s mean for this policy and set the threshold for the handover decision to 0.9. The delay is not shown as it was always far below the threshold.

After 32 seconds, the vertical handover is initiated based on the number of retransmissions and not due to the jitter. As soon as the third best effort user enters the WLAN cell, the jitter exceeds the threshold of 7 ms and the vertical handover of the voice user is initiated which can be seen by the missing curve after 32 seconds of simulation.

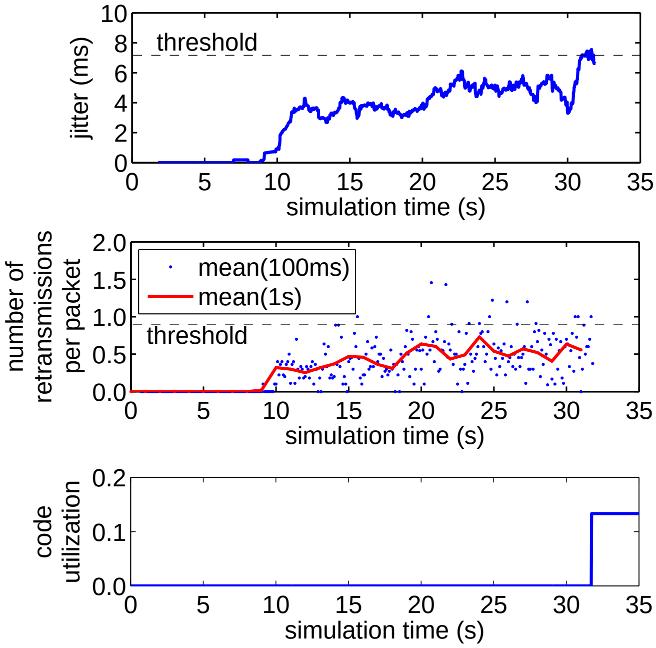


Figure 7: QoS-based VHO from WLAN to UMTS.

5 Conclusion

In this report, we introduced a policy-based vertical handover system. Without loss of generality, our studies remained on the two most common technologies: UMTS as a representative of the 3G cellular networks and WLAN based on the IEEE 802.11 standard as a widely used access technology. However, with a few network specific changes, it is possible to use this approach for any other IP based access network. In contrast to other works in this area, we implemented the complete handover process in a simulation environment, starting from transmitting the handover-related information to the SGSN, applying the three handover policies, and finally completing the handover using our own handover protocol. The simulation results show that the vertical handover is initiated whenever a threshold of one policy is exceeded which guarantees not only QoS for the user, but also decreases the blocking probability due to distributing the user to other cells/technologies when a threshold is exceeded. In future work, we want to improve the load-based VHO policy in order to be able to distribute the users over the cells, or if the load is low, to be able to switch some cells into standby mode to save energy.

References

[1] 3rd Generation Partnership Project., "3GPP TS 22.234 V8.1.0.; Technical Specification Group Services and System Aspects; Requirements on 3GPP system to Wireless Local Area Network (WLAN) interworking (Release 7)," June 2007. V8.1.0.

[2] 3rd Generation Partnership Project 2, "3GPP2 – WLAN Interworking," July 2004. V1.0.

[3] J. McNair and F. Zhu, "Vertical Handoffs in Fourth-Generation Multinetwork Environments," *IEEE Wireless Communications*, vol. 11, pp. 8–15, June 2004.

[4] E. Stevens-Navarro, Y. Lin, and V. W. Wong, "An MDP-Based Vertical Handoff Decision Algorithm for Heterogeneous Wireless Networks," *IEEE Transactions on Vehicular Technology*, vol. 57, pp. 1243–1254, March 2008.

[5] M. Kassar, B. Kervella, and G. Pujolle, "Architecture of an Intelligent Inter-system Handover Management Scheme," in *Future generation communication and networking (fgcn 2007)*, (Jeju, Korea), pp. 332–337, December 2007.

[6] OPNET Modeler, OPNET University Program: http://www.opnet.com/services/university/.

[7] M. Kassar, B. Kervella, and G. Pujolle, "An overview of vertical handover decision strategies in heterogeneous wireless networks," *Comput. Commun.*, vol. 31, pp. 2607–2620, June 2008.

[8] H. J. Wang, R. H. Katz, and J. Giese, "Policy-Enabled Handoffs Across Heterogeneous Wireless Networks," in *WMCSA*, (New Orleans, LA, USA), February 1999.

[9] F. Zhu and J. McNair, "Optimizations for Vertical Handoff Decision Algorithms," in *Wireless Communications and Networking Conference (WCNC)*, pp. 867–872, March 2004.

[10] A. Calvagna and G. D. Modica, "A user-centric analysis of vertical handovers," in *WMASH '04: Proceedings of the 2nd ACM international workshop on Wireless mobile applications and services on WLAN hotspots*, (Philadelphia, PA, USA), pp. 137–146, October 2004.

[11] O. Ormond, J. Murphy, and G.-M. Muntean, "Utility-based Intelligent Network Selection in Beyond 3G Systems," in *IEEE International Conference on Communications, 2006. ICC '06*, (Istanbul, Turkey), pp. 1831–1836, June 2006.

[12] E. Stevens-Navarro and V. W. Wong, "Comparison between Vertical Handoff Decision Algorithms for Heterogeneous Wireless Networks," in *IEEE Vehicular Technology Conference (VTC-Spring)*, May 2006.

[13] Q. Guo, J. Zhu, and X. Xu, “An adaptive multi-criteria vertical handoff decision algorithm for radio heterogeneous network,” in *IEEE International Conference on Communications, 2005. ICC 2005*, (Istanbul, Turkey), pp. 2769–2773, May 2005.

[14] Q. Wei, K. Farkas, C. Prehofer, P. Mendes, and B. Plattner, “Context-aware handover using active network technology,” *Comput. Netw.*, vol. 50, no. 15, pp. 2855–2872, 2006.

[15] IEEE 802.21/D8.0, Vivek G. Gupta, “IEEE 802.21 Standard and Metropolitan Area Networks: Media Independent Handover Services,” December 2007. Draft IEEE 802.21/D8.0.

[16] R. Pries, D. Staehle, P. Tran-Gia, and T. Gutbrod, “A Seamless Vertical Handover Approach,” in *Wireless and Mobility 2008, LNCS 5122*, (Barcelona, Spain), 2008.

[17] H. Holma and A. T. (Eds.), *WCDMA for UMTS.* John Wiley & Sons, Ltd., Feb 2001.

[18] J. Pérez-Romero, O. Sallent, R. Agusti, and M. A. Díaz-Guerra, *Radio Resource Management Strategies in UMTS.* John Wiley & Sons, Ltd, 2005.

[19] D. Staehle and A. Mäder, “An Analytic Model for Deriving the Node-B Transmit Power in Heterogeneous UMTS Networks,” in *IEEE VTC Spring*, (Milano, Italy), May 2004.

[20] 3GPP, “3GPP TS 25.215 V3.13.0 Physical layer - Measurements (FDD),” tech. rep., 3GPP, Mar 2005.

[21] R. Pries, A. Mäder, and D. Staehle, “UMTS Load Metrics for a Policy-Based Vertical Handover Framework,” Tech. Rep. 395, University of Würzburg, November 2006.

[22] R. Pries, S. Menth, D. Staehle, M. Menth, and P. Tran-Gia, “Dynamic Contention Window Adaptation (DCWA) in IEEE 802.11e Wireless Local Area Networks,” in *The Second International Conference on Communications and Electronics, HUT-ICCE*, (Hoi An, Vietnam), June 2008.

[23] R. Pries, D. Staehle, S. Menth, M. Menth, and P. Tran-Gia, “Impact of Best Effort Frame Bursting in IEEE 802.11 Networks,” in *IEEE VTC Spring 09*, (Barcelona, Spain), April 2009.

[24] B. Staehle, D. Staehle, R. Pries, M. Hirth, P. Dely, and A. J. Kassler, “Measuring One-Way Delay in Wireless Mesh Networks - An Experimental Investigation,” in *The 4th ACM International Workshop on Performance Monitoring, Measurement and Evaluation of Heterogeneous Wireless and Wired Networks (PM2HW2N)*, (Tenerife, Canary Island, Spain), October 2009.

[25] ITU-T Recommendation G.114, “One Way Transmission Time,” May 2000.

[26] T. Hoßfeld, D. Hock, K. Tutschku, P. Tran-Gia, and M. Fiedler, “Testing the IQX Hypothesis for Exponential Interdependency between QoS and QoE of Voice Codecs iLBC and G.711,” in *18th ITC Specialist Seminar on Quality of Experience*, (Karlskrona, Sweden), May 2008.