Paper

Seamless roaming between UMTS and IEEE 802.11 networks

Paweł Matusz, Przemysław Machań, and Józef Woźniak

Abstract—Mobile Internet access is currently available mainly using 2G/3G cellular telecommunication networks and wireless local area networks. WLANs are perceived as a local complement to slower, but widely available cellular networks, such as existing GSM/GPRS or future UMTS networks. To benefit from the advantages offered by both radio access networks, a mobile user should be able to seamlessly roam between them without the need to terminate already established Internet connections. The goal of this paper is to present an overview of the profitability of performing vertical handovers between UMTS and IEEE 802.11b using Mobile IP. Several simulations have been carried out using NS-2, which prove that handovers from IEEE 802.11b to UMTS can, under certain circumstances, be profitable not only when there is no more IEEE 802.11b coverage. Simulation results show that a mobile user should be able to roam between these networks depending on the current available channel bandwidth and quality, generated traffic type and number of users in both of them.

Keywords*— *UMTS, IEEE 802.11b, handover, roaming, Mobile IP.

1. Introduction

Both universal mobile telecommunication system (UMTS) and wireless local area network (WLAN) technologies enable fast Internet access. While UMTS is generally still in the phase of development with only a few existing installations, WLANs are already widely deployed. Devices supporting the IEEE 802.11a and IEEE 802.11b [10] standards are being manufactured by many companies and are widely available. Hot spots are installed at most large airports and in other public places such as hotels, train stations, and restaurants. Users of PDAs or notebooks with IEEE 802.11 network interface cards can easily access the Internet in such places, benefiting from the relatively high bandwidth of WLANs (11 Mbit/s in case of IEEE 802.11b and 54 Mbit/s in case of IEEE 802.11a).

On the other hand, the coverage offered by WLANs is quite limited. Those who need to have access to the Internet from almost everywhere must use a cellular network such as GSM/GPRS or UMTS. GPRS offers very low bit rates (theoretically up to 170 kbit/s, practically about 50 kbit/s [6]), which is often not satisfactory. 3G networks, such as UMTS, offer higher bit rates, theoretically up to 2 Mbit or even over 10 Mbit using HSDPA and 20 Mbit additionally using MIMO. Practically, for slow moving mobile users (pedestrians) the available bit rate should be about 384 kbit/s, although higher bit rates can be achieved depending on some conditions, such as good radio conditions or below-average cell load [9].

To enable switching between two different radio access networks, mobile users should have a terminal equipped with two network interface cards or a dual network interface card, e.g., supporting IEEE 802.11b and UMTS [1]. The terminal should be able to seamlessly switch (roam) between both networks without the user noticing it. Such a mechanism can be provided by Mobile IP [5]. In general, when available, the mobile terminal should connect to the Internet via WLAN to benefit from a higher bit rate and when it leaves the area covered by WLAN, it should automatically switch to UMTS. This is an obvious solution when the user roams between areas with WLAN coverage, while constantly being in the range of UMTS.

But, under certain circumstances, the efficiency of Internet access using WLAN could become much worse than using UMTS. Congestions may occur at the radio interface (multiple terminals trying to access the same access point at the same time), in the LAN connecting all APs with an Internet gateway or on the link connecting the gateway to the Internet (for example an often used 2 Mbit DSL connection). It would then be profitable for a terminal to switch from WLAN to UMTS, despite the still available WLAN coverage.

There has already been some research done in the field of using Mobile IP to switch between IEEE 802.11 and 2G/2.5G (GSM/GPRS) networks. Some of the conclusions, such as TCP-related issues, apply to UMTS [11]. But, mainly due to higher available data rates, lower packet delays and usage of WCDMA in UMTS [9] there are many issues that have never been discussed before.

In this paper handovers between UMTS and IEEE 802.11b using Mobile IP are analysed and discussed. The goal is to determine whether switching from IEEE 802.11b to UMTS can be profitable when there is both IEEE 802.11b and UMTS coverage. In the proposed scenario, a mobile user, equipped with a dual network interface card, accesses the Internet from a place with overlapping IEEE 802.11b and UMTS coverage. The mobile terminal may seamlessly switch between the two available radio access networks using Mobile IP. The profitability of performing such handovers is analysed, depending both on radio and network conditions – number of WLAN users, volume and type of traffic generated by those users, available UMTS channel bandwidth, and channel BLER. It is proven that, in case of UMTS, handovers between IEEE 802.11b and UMTS can be profitable.

The situation when the terminal leaves the range of the IEEE 802.11b access point is not analysed, because in such a case the only possibility is to switch to UMTS, regardless of available conditions. Such analysis has already been done for GPRS and in general applies to UMTS.

2. Mobile IP handover overview

Handover describes a mechanism when a user moves through the coverage of different wireless cells. A handover between wireless cells of the same type is referred to as horizontal handover, while a handover between cells of different type is known as vertical handover [4]. Because IP protocols were designed for stationary systems, some extensions have been proposed to introduce mobility support.

The main problem of a handover is that an IP address uniquely identifies both the end point and host locations. Because the mobile host can change its localization, there is a need to update the host's IP address and route packets to the mobile host's new subnetwork. Because of this, all active connections using the mobile host's previous IP address, e.g., TCP connections, would be broken.

There are some solutions to the mobility problem in IP networks, e.g., IETF Mobile (MIP) IPv4 [5], IETF Mobile IPv6 [7], Cellular IP [8] and HAWAII [13, 14]. Because of hierarchical network division into domains the mobility can be divided into Inter-domain mobility and Intra-domain mobility. Inter-domain mobility (also called Macro mobility) is related to a movement from one domain to another. A domain is defined as a large wireless network under a single authority. On the other hand Intra-domain mobility (also called Micro mobility) refers to user's movement within a particular domain.

Almost all solutions that address Micro mobility (e.g., Cellular IP and HAWAII) assume that Mobile IP is only used for Macro mobility. Because IPv6 is not often used in today's networks, Mobile IPv4 is perceived as a appropriate current solution. The protocol aims at continuous TCP connections even though the IP address changes when the handover occurs. The mobile host is assigned a Home Address that identifies the host in its home network. To solve the problem of IP addressing, Mobile IP introduces a temporary Care-of-Address (CoA) in a foreign network. Two new functions are added to the network infrastructure: a Home Agent (HA) and Foreign Agent (FA). After the mobile host moves to the new IP domain it obtains a Care-of-Address from a Foreign Agent (Foreign Agent Care-of-Address) or through some external means (Co-located Care-of-Address) such as DHCP. In the next step the mobile host registers the new address with its Home Agent. From now on, the Home Agent tunnels all packets for the mobile host through the Foreign Agent.

An important issue concerning handover performance is movement detection. Mobile IP supports three movement detection schemes: Lazy Cell Switching, Prefix Matching, and Eager Cell Switching [10]. In the Lazy Cell Switching scenario the mobile host waits until the lifetime of its registration expires and then tries to reregister again or to discover a new Foreign Agent to register with. If Agent Advertisement messages are not received, then the station attempts to solicit an advertisement using an Agent Solicitation message. In the Prefix Matching scheme the mobile host uses the "prefix extension" to determine whether a newly received Agent Advertisement is from the same subnet. If the prefix is different, the mobile host knows it is connected to a new subnet and registers. Eager Cell Switching is based on the mobile host receiving beacons from multiple FAs simultaneously. Once the current FA is no longer available (e.g., because the mobile has moved) then it selects a new one form this list.

There are additional movement issues concerning vertical handover. When the mobile is registered with the FA at the higher level (with higher cells) and moves into the cell coverage of the lower level (downwards handover) Mobile IP advertisements can be continuously received. In that case Eager Cell Switching cannot be used because the mobile is connected to the previous Foreign Agent.

3. Simulation setup

To simulate handovers between IEEE 802.11b and UMTS a detailed and realistic simulation environment was created using Network Simulator 2 (NS2) [12]. In addition to the already available components such as mobility management and IEEE 802.11 MAC, support for UMTS radio access has been implemented. This support takes into account all significant features of WCDMA and the UMTS radio protocol stack.

The simulated network architecture is presented in Fig. 1. It consists of two radio access networks, the UMTS and IEEE 802.11b access networks, connected via Internet.

The IEEE 802.11b radio access network consists of a single access point (AP), connected to a 100 Mbit Ethernet LAN, which is in turn connected to the Internet through a gateway, using a 2 Mbit/s link (e.g., DSL). Other APs can be connected to the same LAN (and the same gateway, which is not simulated), forming a wireless radio access network. Moreover, the particular number of mobile terminals are simulated, all associated with the same AP.

The UMTS architecture adheres to UMTS Release 4 specifications. The simulated UMTS terrestrial radio access network (UTRAN) consists of a single radio access network (RAN) controlled by a radio network controller (RNC). One Node-B (working in FDD mode) connected to the RNC via a 155 Mbit/s (STM-1) ATM link is simulated. A number of mobile terminals can be simulated, all located in the same cell and therefore using the same Node-B. The RNC is connected to a serving GPRS support node (SGSN) in the UMTS core network (CN) via a 655 Mbit/s (STM-4) ATM link. The SGSN is connected via a 655 Mbit/s ATM link to a gateway GPRS support node (GGSN) that connects the CN to the Internet via a 2 Mbit/s link. Only a part of the packet switched (PS) domain is simulated. Other network elements in the CN (such as the whole circuit switched (CS) domain, HLR, VLR, etc.) are neglected, because they do not affect the simulation. AAL2 is used for transport between RNC and Node-B and AAL5 between RNC, SGSN and GGSN.

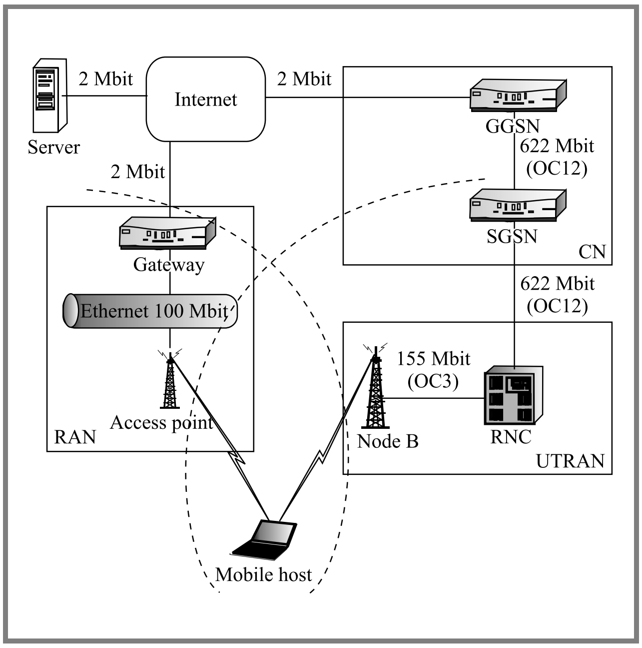

Fig. 1. Simulated network architecture.

Mobility management is performed by the Mobile IP mechanism, as described in [1, 2] and [5]. The Home Agent (HA) is located somewhere on the Internet (where the mobile host obtained its address) and Foreign Agents (FA) are located in the WLAN's gateway and in the SGSN. When a mobile terminal is using the FA, all traffic must first be sent from the server to the HA where it is encapsulated and then transferred to the FA, which performs decapsulation and routes it to the terminal. TCP acknowledgements generated by the terminal are routed directly to the server, without having to pass through the HA.

A scenario with overlapping UMTS and WLAN coverage, which is the most common scenario in urban environments, is considered. It is assumed that the mobile terminal is equipped with either two wireless interface cards, or a dual UMTS/IEEE 802.11b interface card. Both interfaces operate independently, i.e., UMTS and IEEE 802.11b connections can be active at the same time. This facilitates seamless handovers, because there is no time wasted for a new connection setup (assuming overlapping network coverage). During a handover from WLAN to UMTS, the terminal is authenticated and authorized in the UMTS network and a dedicated channel (DCH) is allocated while data transfer is performed by the IEEE 802.11b interface. If DCH with satisfactory QoS parameters (generally throughput and bit error rate) is allocated and the handover is assumed profitable, the actual handover takes place. During a handover from UMTS to WLAN, the terminal is first registered, authenticated and authorized by the AP in the WLAN while the data is still transferred using UMTS. After successful registration, the handover (when assumed profitable) takes place and UMTS channels are released. Such a scenario is simulated, because traffic delivery delays caused by the actual handovers are not additionally prolonged by authentication, authorization, and resource allocation mechanisms. User billing, authentication, radio network ownership (the same or different owners of both the UMTS and WLAN networks) and similar problems do not directly affect the simulation and are out of scope of this paper.

During simulations, the mobile user downloads a file from a FTP server located on the Internet. This implies the need for the best available bandwidth, which directly affects download time. The user's terminal can perform a handover either when it leaves or enters the area covered by WLAN range, or when a network congestion occurs in WLAN. The average delay between the WLAN gateway (or the GGSN) and the server have been set to 25 ms, which is the average value of inter-Europe packet delay in February 2003 according to Internet traffic measurements performed by Stanford University [15].

4. IEEE 802.11b and UMTS configurations

To carry out simulation experiments one AP and a number of mobile terminals (MT) were configured. Every MT was associated with the AP. The medium access control (MAC) sublayer operated in distributed coordination function (DCF) mode. In that mode the medium access algorithm is fully distributed and every MT uses carrier sense multiple access with collision avoidance (CSMA/CA) algorithm to access the shared medium. The DCF function is the basic and obligatory mode

Optional request-to-send and clear-to-send (RTS/CTS) function was used for all frame lengths, to test the worst case scenario by generating additional control traffic. RTS/CTS handshake also alleviates the hidden node problem, that is, when two or more MTs associated with the same AP cannot hear each other.

In the simulated scenario every mobile station set up an FTP connection with the server located outside the current subnetwork. The node utilizes a 2 Mbit/s Internet connection to reach the FTP server. The change of network conditions has been simulated by increasing the number of mobile stations. When a mobile station experiences the lack of sufficient network resources or estimates that the UMTS network can offer better resources, it can decide to switch to UMTS.

The constant, one-way processing delay introduced by all UMTS network elements in CN and UTRAN and by user equipment (UE, the mobile terminal) is estimated as 60 ms, as specified in [3] and [9]. An additional delay is introduced by link buffering and signal propagation, but because of fast ATM links (STM-1 and STM-4) this delay is insignificant compared to the processing delay and delay introduced by the radio protocol stack, and the radio interface.

The configuration of the radio protocol stack in UTRAN partially determines the delays that occur on the radio interface between Node-B and UE. It is assumed that one dedicated transport channel (DCH) is allocated for the user in downlink and one in uplink to guarantee the required bandwidth. Such a guarantee cannot be made when using common or shared channels. In UMTS, dedicated channels with bandwidths up to about 2 Mbit/s can be allocated for a single user, but theoretically only in a fixed (indoors) environment. UMTS is required to support data rates of 144 kbit/s for mobile terminals moving with vehicular speeds and 384 kbit/s for terminals moving with pedestrian speeds (up to about 5 km/h). Because the simulation scenario may include user movement within the area covered by both networks, it is assumed that a 384 kbit/s DCH can be allocated most of the time. The available bit rate can change depending on the load of the cell and on radio conditions. This is why simulations have also been performed for downlink channels with bit rates lower than 384 kbit/s, although all have been done for a 32 kbit/s uplink channel. The uplink channel does not need to provide high bandwidth, because it conveys mainly TCP acknowledgements and RLC status messages.

Table 1
Radio protocol stack configuration

Parameters	Downlink	Uplink
Channel rate [kbit/s]	384	32
PDCP mode	No-header	
RLC mode	AM	
RLC block size [bits]	320	
Logical channel	DTCH	
Transport channel	DCH	
TTI [ms]	10	
Transport formats	0×320 1×320 2×320 3×320 4×320 8×320 12×320	0×320 1×320

Table 1 presents the radio protocol stack configuration used in simulations for both the uplink (32 kbit/s) and downlink (384 kbit/s) channels. Channels with other bandwidths differ only by the number of transport blocks defined in transport formats for those channels.

5. Simulation results

In UMTS, when using dedicated channels, the effective channel throughput depends only on the radio channel quality, described by the block error rate (BLER) parameter. This parameter represents the percentage of transport blocks which encounter bit errors on the radio link and therefore require retransmission. For BLER = 0% (no retransmissions) the effective channel utilization is about 95% because of the addition of UMTS radio protocol stack headers [1]. This figure can slightly change depending on the radio protocol stack configuration.

Figures 2, 3, and 4 depict results of simulations in a situation when the mobile host is connected to the Internet via UMTS. Average packet delay has been measured between the server and the mobile host as a function of packet length, allocated channel bandwidth, and channel BLER. Because the channel bandwidth, once assigned to a user, does not change, the actual packet delay is one of the variables that should be considered while making a handover decision.

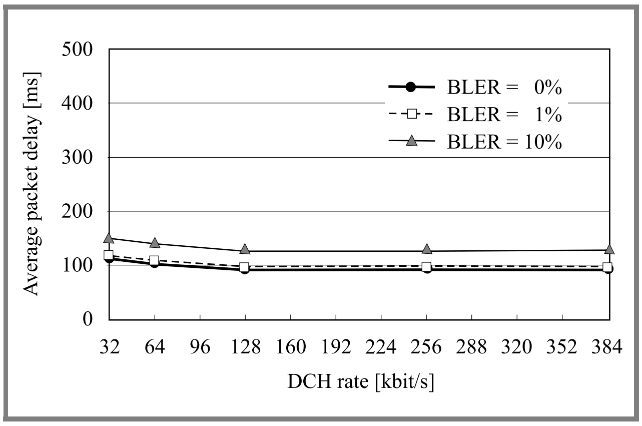

Fig. 2. 100-byte packet delay for UMTS.

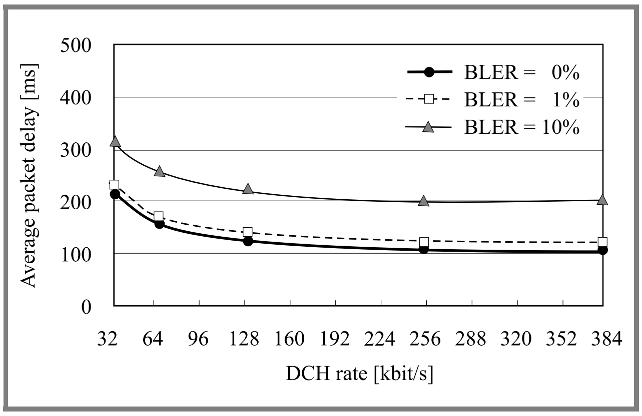

Fig. 3. 500-byte packet delay for UMTS.

As can be observed in Figs. 2, 3, and 4, the shorter the average packet size, the less the average delays that the packets encounter. This is caused by the fact that even for small channel bandwidths short packets can be sent in just a few TTIs and do not have to be spanned over several TTIs, as larger packets do. Additionally, shorter packets fits in the smaller number of transport blocks, so the probability of packet retransmission (as described by [3]) is less than for large packets. Applications requiring small packet delays should use short packets (at least when using dedicated channels with small throughput) to minimize the delays.

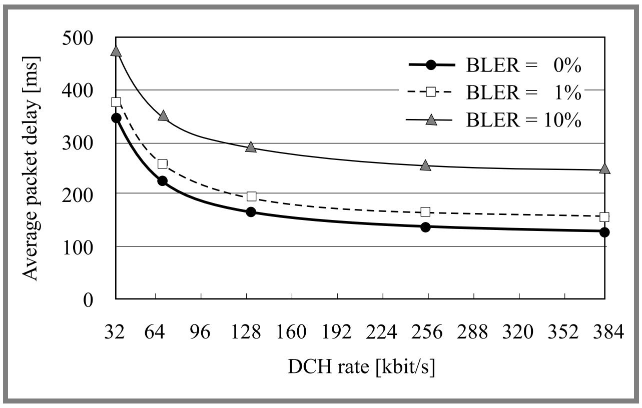

Fig. 4. 1000-byte packet delay for UMTS.

Throughput and packet delay experienced by a mobile station in WLAN are depicted in Figs. 5 and 6. According to the simulation scenario, in Fig. 1 the maximum throughput is limited by the bandwidth of the leased line connecting the WLAN to the Internet (2 Mbit/s). Generally, as the number of mobile hosts in the current subnetwork increases, the network conditions deteriorate. This is because of limited radio resources that must be shared by all stations.

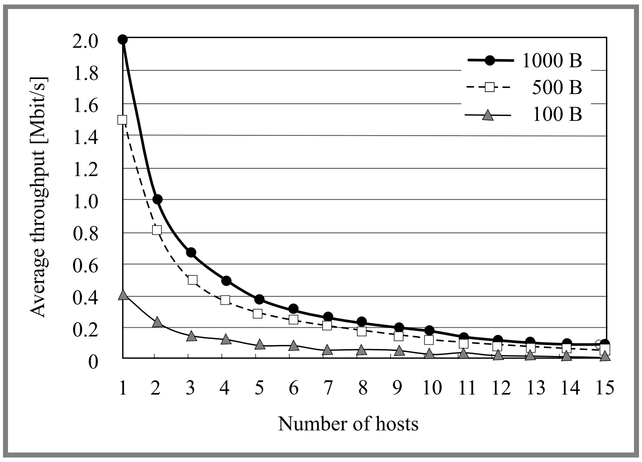

Fig. 5. Average throughput per station in WLAN.

Bandwidth utilized by the mobile host depends on the average size of transmitted packets. For shorter packets the MAC protocol overhead becomes substantial and average throughput deteriorates. This is mainly because of RTS/CTS handshake. When packets are short the data transmission time is small in comparison to the control frames exchange period.

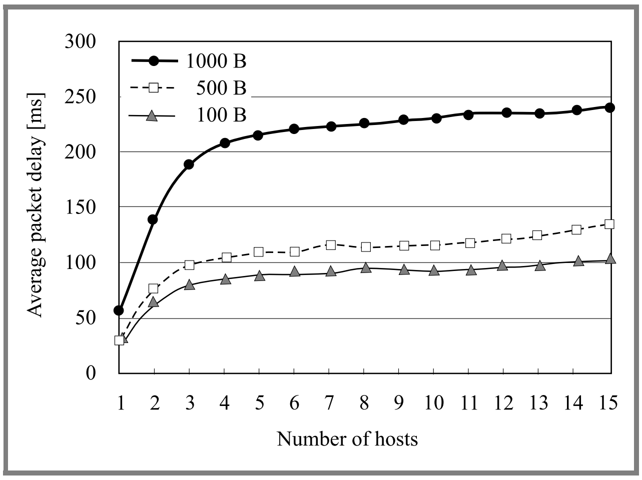

Fig. 6. Average packet delay in WLAN.

Average packet delay increases as network load increases and then saturates at a certain level. Packet delay is limited because the TCP protocol does not send more packets than can fit in the TCP window.

The handover itself does not cause any additional packet delay nor interrupts packet delivery – a route to the mobile host is always known by the Home Agent. This is because two independent network interface cards for UMTS and IEEE 802.11b are assumed to be used. Before performing the handover by the Mobile IP mechanism, the mobile host is already connected to both radio access networks and can access both Foreign Agents. These connections must be already established, because the mobile host has to have some knowledge about the available throughputs and delays in each network before making the handover decision. After the decision is made, the Mobile IPv4 handover mechanism [5] is invoked to switch controlling the Mobile Host from one Foreign Agent to another, in the other radio access network.

During the Mobile IP message exchange packets are sent continuously through one Foreign Agent and, after the Home Agent receives the new Registration Request, they immediately start being sent through the other Foreign Agent. The only delay in receiving packets may be caused by the difference in packet delays in both access networks and can be estimated at the time of making the handover decision (assuming that the average packet delays are known).

6. Conclusions

Mobile users can roam between UMTS and IEEE 802.11b not only when there is no WLAN coverage (which is the typical reason), but also when resources offered by UMTS are better than those offered by a reachable IEEE 802.11b network. It has been proven through simulations that, depending on experienced network conditions, handovers between IEEE 802.11b and UMTS can be profitable. A mobile user equipped with two network interface cards or a dual network interface card able to manage UMTS and IEEE 802.11b radio connections independently can benefit from the possibility of seamless roaming between the two available radio access networks. UMTS, unlike 2G systems, offers satisfactory channel throughput and QoS for most applications. Depending on QoS requirements of the generated traffic, a mobile user can choose to switch to a radio access network that offers the most suitable QoS conditions, e.g., guaranteed throughput or average packet delay.

Currently, work is being done to specify an optimal criterion that the mobile host can use to switch between available access networks. It should take into account network conditions, which can be hard to accurately measure or estimate. Simulation results presented in this paper may help by providing some reference values.

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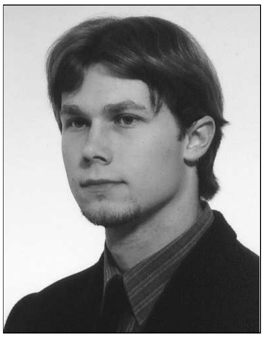

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