Performance Evaluation of A Mobile Internet Architecture with IEEE 802.11a WLAN and GPRS/UMTS

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***Abstract*— The last decade was dominated by the development of new radio access technologies. The development has been driven by the great success of the second generation mobile communication. Although the third generation (3G) mobile system will start soon, many existing and emerging access technologies will coexist for a long time. Network operators are now very interested in merging the various access technologies to provide an ubiquitous wireless access system. This paper presents a simulation tool to investigate and plan the next generation mobile internet architecture deploying WLAN and GPRS/UMTS technologies. A simulation tool with the hybrid system of IEEE 802.11a and GPRS is developed using prototypical protocol implementations based on a Specification and Description Language (SDL) specification. Traffic performance is evaluated in detail by means of stochastical simulations. The impact of the vertical handover on the system performance can be seen from the simulation results.**

***Keywords*— IEEE 802.11, GPRS, Vertical Handover, Simulator Technique**

I. Introduction

Nowadays the ability to communicate on the move is becoming common and less luxurious, especially for business people the communication is becoming more of a necessity. Currently, WLAN-based systems are emerging as a new means of public wireless access. This increases the need for solutions to integrate the existing public wireless access systems, cellular networks, and potential new access systems.

Third Generation Partnership Project (3GPP) was intentionally formed to specify a common set of 3G cellular system specifications on behalf of the European, U.S., Japanese, and Korean telecommunication standardisation organizations. 3GPP has produced the global specifications for the Universal Mobile Telecommunication System (UMTS). Although 2G technology can meet the needs of voice communications of the typical cellular subscribers, its data communication capabilities are very limited.

The third-generation (3G, UMTS) cellular systems promise a competitive data rate, up to 300kb/s initially and increasing up to 2 Mb/s, as the same as that of always-on connectivity of wired technology.

Since 2.5G cellular data technology like GPRS/EGPRS is insufficient to meet market needs for data communications, and 3G cellular data is not yet fully deployed and accepted by the customers, mobile network operators are turning to wireless local area network (WLAN) technologies. To increase the acceptance and usage of the 2.5G data communication technology and to prepare the subscriber for UMTS it is commonly believed that operators must provide a seamless roaming between cellular and WLAN access network.

Wireless local area networks (WLANs) like IEEE 802.11a that work in the 5 GHz band and support transmission rates up to 54 Mb/s will be widely used for the wireless internet access [1] at hotspots like hotels, airports or fairs.

Although the coverage is very limited due to the high attenuation, wireless data services are becoming increasingly popular but are, however not ubiquitous. Consequently it is natural to use high bandwidth data networks such as IEEEE 802.11 whenever they are available and to switch to an overlay service such as GPRS network with low bandwidth when the coverage of WLAN is not available. To achieve a large coverage for mobile internet it is necessary to combine WLANs with cellular systems like GPRS. This paper presents an overview about different integration architectures. In section II a short description of WLANs and data cellular network is given. Section III presents in detail the WLAN handover mechanism and the scanning procedure followed by section IV dealing with enabling IP mobility. In section V the simulation tool developed at the chair of communication networks is presented in detail, followed by the first simulation results presenting the performance of an integrated architecture in section VI. The paper is concluded with a discussion in the last section.

II. WLAN and Cellular Data Networks

Cellular data networks provide up to 100~200kb/s that is a relatively low data rate, but with a very large coverage area. On the other hand WLANs like HiperLan/2 or IEEE 802.11 support a physical data up to 54 Mb/s. Further IEEE Working groups are even going toward much higher data rates; e.g. the 802.11n working group aintends to habe a data rate up to 1Gbit/s. WLAN coverage is now only available at hotspot areas, the coverage may increase in the future but no complete coverage is expected.

Combining both systems means merging the strengths of both systems, high data rate at places with high user density and basic provisioning with cellular systems with large coverage even in rural areas. The key enabler is seen as the mobility support, user and respective terminals must be allowed to move all around with a standard service support.

This paper evaluates a mobile internet architecture deploying WLAN IEEE 802.11a und GPRS/UMTS technologies see Fig. 1. In this architecture WLAN islands (Hotspots) are located within the coverage of GPRS/UMTS. A user leaving the WLAN area can maintain its connection by performing a vertical handover (VHO) to the GPRS/UMTS system (cp. Fig. 1). Several intersystem architectures have been proposed with different levels of interaction, starting form a combined billing up to providing certain services across the system borders [5].

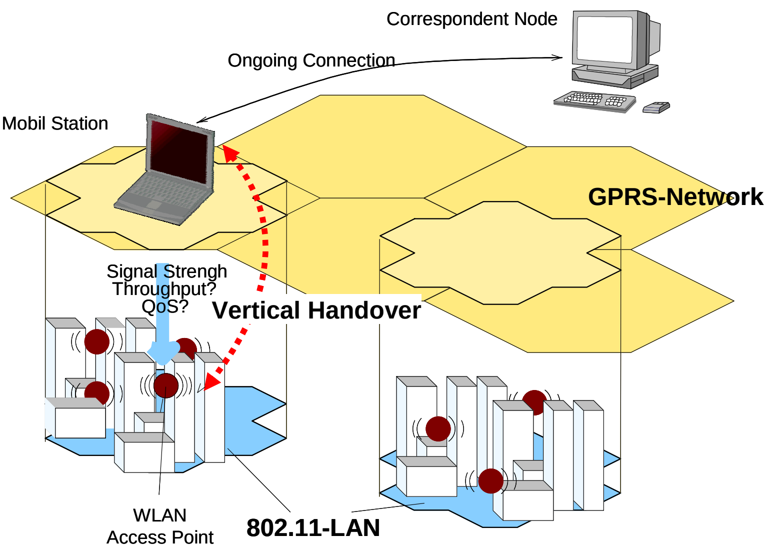

Fig. 1. An architecture with WLAN and GPRS/UMTS

III. WLAN IEEE 802.11 HANDOVER

IEEE 802.11 is a widely deployed and very popular WLAN standard thanks to its simple but robust medium access control (MAC). 802.11 bases on a distributed MAC using the carrier sense multiple access with collision avoidance (CSMA/CA). Each node is operating on one frequency at a time. 802.11 supports two main working modes, the infrastructure mode and the independent mode (ad hoc mode). Operating in infrastructure mode means all nodes are connected to one access point (AP); all nodes belonging to one service set are forming a basic service set (BSS) (Fig. 2). The second mode is called independent mode, the nodes are communicating as an ad hoc network without connection to the internet or an AP.

Usually when a WLAN-network is set up, the AP is placed to cover the necessary area (airport, fair). To minimize the interference between different BSSs to each adjacent AP a different frequency is given. In IEEE 802.11b only three independent frequencies are available whereas in IEEE 802.11a up to 19 frequencies can be used.

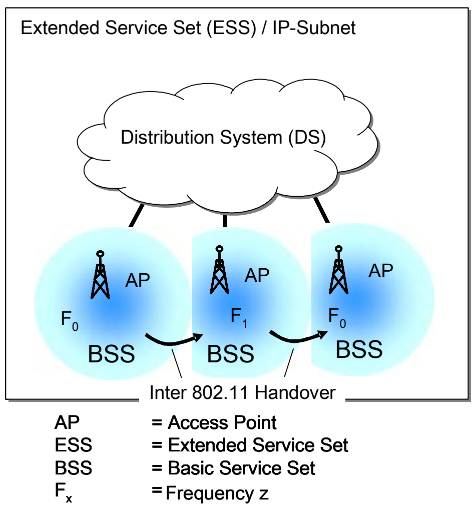

Fig. 2: IEEE 802.11 Intra-System Handover

A node that is part of a BSS and connected through an AP must search for a new AP when leaving its old cell. 802.11 proposes two different handover methods. The first one bases on a passive principle where the terminal changes onto a new frequency and waits for an AP signature, which is send in regular intervals. The signature is called beacon and contains the parameter describing the BSS. This procedure is done with all available frequencies. After all frequencies are scanned the node chose the AP with the beacon received as the strongest. Since there are up to 19 frequencies to scan and it takes one beacon interval to scan one frequency, the scanning duration is usually very high. Therefore a second handover mechanism has been standardized that bases on an active principle. A node switching to another frequency sends a request (Probe Request) initiating a receiving AP to reply with a *Probe Response* (similar to a beacon). This shortens the waiting time at each frequency and decreases the scanning time. When a new AP is found, the node continues with an open authentication. The next step is the association also exchanging two signals. After successful authentication and association the node is connect at the second ISO/OSI layer to the network. The described handover methods are also available when the node moves from GPRS to WLAN. If the node moves outside the extended service set (ESS) and accordingly outside the IP subnet[1], existing IP sessions must be discarded and must be reestablished. This is also valid when the node moves from one system to another system, a previous IP address can no longer be used and existing sessions are lost. This could be avoided by using well know IP mobility protocols like mobile IP (MIP) and hierarchical mobile IP (HMIP). Pure connection reestablishment on layer two does not ensure seamless mobility on the IP layer.

IV. KEEPING THE SESSION WHILE MOVING

Session mobility is a step ahead pure roaming today common in GSM/GPRS. Existing IP data connections are secured, running applications can seamlessly be remain connected using IP mobility protocols.

A. Mobile IP

Mobile IP deals with the moving nodes and new IP addresses by mapping the newly created IP addresses to the original home IP address of the node. Each IP network needs an agent that provides the functionality of a home agent for terminals

[1] We assume that each IP subnet forms an own separate extended service set. Thus, when the ESS has changed the node knows that a new IP-address must be configured and consequently the home agent must be informed using a binding update message.

belonging permanently to this domain and supporting guest terminals as a foreign agent. A terminal at home could be reached simply by its IP address. If the terminal is attached as a guest to a foreign subnet with a different subnet IP, the node informs its home agent using a binding update (BU) message about its new location and about the new temporary foreign IP address. Thus the home agent can encapsulate and redirect packets targeted at the home IP address to the foreign IP address. Hence the node is still reachable via its home IP address and sessions set up to the home IP address are not interrupted while moving. Mobile IPv4 and Mobile IPv6 are basically similar, but Mobile IPv6 overcomes some drawbacks of Mobile IPv4. Both protocols are explained in detail in [6][7].

Furthermore extensions and enhancements [8][9] have been proposed introducing a hierarchy of agents to accelerate binding update signalling since the way to the home agent might be considerable long introducing high signalling latencies.

V. Application Scenarios

Several applications can benefit from the hybrid architecture proposed in this paper. The classical example is the email client that can skip to download a large file until a high rated WLAN is available. Streaming applications can benefit even more. During WLAN coverage a large part of the streaming data can be send in advance to the terminal. The only limiting factor is the terminal buffer. Since WLAN transmits date up to 100 times faster than cellular systems, the node is able to store during 10 seconds attached to a WLAN system data for approximately the next 15 minutes in advance. Another suited application might be a home office. While moving around, the subscriber works using a remote desktop connection, but the data is only temporarily buffered at his laptop and synchronisation with his home database is forced when WLAN connection is available. Whereas, during GPRS/UMTS connection only differential synchronisation is available.

VI. Coupling Architectures

Several different coupling architectures have been present in the past. In Fig. 3 five coupling points are presented. In [12] seven different integration ways are explained, although two are only business integrations ideas, like using the same bill for multiple systems but no real system integration.

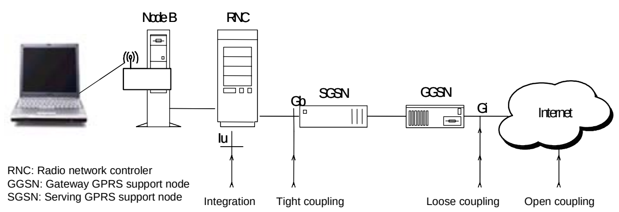

Fig. 3: Different Coupling Points

B. Open Coupling

In this scenario there is no real integration between two or more access technologies. The WLAN and GPRS networks are considered as two parallel independent systems sharing a single billing scheme between them. A common database and separate authentication procedures (i.e. SIM based authentication for GPRS and simple user name and password for WLAN)[16].

C. Loose Coupling

This approach provides interworking between WLAN and GPRS at the Gi interface. The WLAN network is coupled with the GPRS network in the operator's IP network. In contrast to tight coupling, the WLAN data traffic does not pass through the GPRS core network but goes directly to the operator's IP network (and/or Internet) i.e. this approach completely separates the data paths in 802.11 and 3G networks. The high speed 802.11 data traffic is never injected into the 3G core network so the 3G backbone network could be left untouched.

D. Tight Coupling

A tight coupling architecture is proposed in [7] and provides 3GPP system based access control and charging i.e. authentication, authorization, and accounting for subscribers in the WLAN to be based on the same AAA procedures utilized in the GPRS system; i.e. to allow the operator to extend access to its GPRS based services to subscribers in a WLAN environment (service continuity).

A very interesting tight coupling approach has been presented in [3]. The WLAN network is deployed as an alternative RAN and connects to the GPRS core network through the standard Gb interface (cp. Fig. 2). From the core network point of view, the WLAN is considered like any other GPRS routing area in the system

E. Integration

The integration scenario is similar compared to tight coupling regarding seamless handover. However in this case a WLAN can be viewed as a cell managed at the RNC (Radio Network Controller) level. This concept is not widespread because extensive large area network planning is uncommon for WLAN yet; i.e. interference levels are usually not considered because in today's scenarios geographical spreading of Access Points (AP) ensures lack of interference from neighbouring cells in particular in rural environments. However it should be noted that this method would be the ideal case from the end user perspective.

The most frequently discussed architectures at the moment are loose coupling and tight coupling [3]. The tightly coupled architecture integrates the WLAN backbone within the GPRS network. From the cellular point of the view the WLAN is seen as a certain routing area. VHO (Vertical handover) therefore appears as a routing area handover for the GPRS network. However all GPRS components must be able to deal with a huge amount of data traffic, since the WLAN traffic will be transported also through GPRS backbone. A closer description could be found in [3]. Operators may favour the loosely coupled architecture because of its easy deployment. The large benefit of the loosely coupled approach is that each system only needs minor changes on the deployed network components. These changes consider a common billing and authentication based on the cellular subscriber identification module (SIM) [4].

VII. Computer Simulation Technique

At the Chair of Communication Networks, Aachen University of Technology a simulation tool called SDL-based Generic Object-Oriented Simulation Environment (S-GOOSE©) has been built. This tool makes it possible to investigate intersystem aspects in a very detailed manner. Fig. 4 shows the overall principle, the simulation tool consists of several different protocol stacks, and each stack is separated into single independent libraries. In the past a simulation tool for each system has been developed in great detail to study the system performance and the influence of protocol enhance-

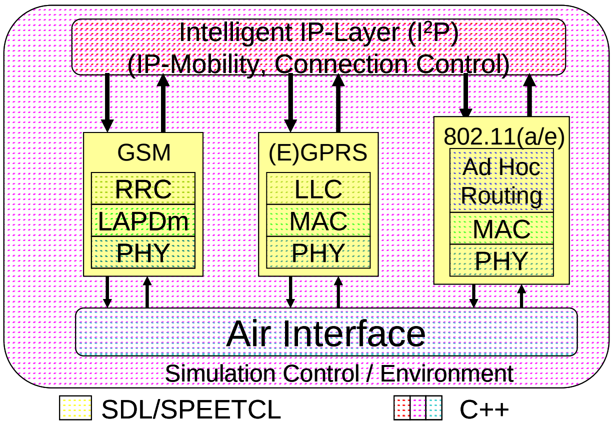

Fig. 4. Simulator Structure

ments and new proposals. These single system simulators are now merged to a multi-system simulator. All integrated systems use the same IP backbone and a combined interference engine. Abstracted traffic sources allow comparative investigations of the systems under the same load conditions.

The channel model involves a detailed interference calculation which is essential for the investigation of interference limited systems including the scenario topology, buildings, street maps and fading effects. This strategy gives the unique opportunity to investigate either the behaviour of a certain protocol layer within a particular system or the whole deployed system without a trade-off in accuracy. Hence the S-GOOSE can be used for intersystem cell and frequency planning or protocol investigation. Currently the simulator contains three different wireless systems, the GSM, GPRS and IEEE 802.11a/g/e (cp. Fig. 4).

VIII. Simulation Results

This section presents the simulation results gained, with the S-GOOSE© simulator. Traffic performance in the mobile internet architecture with IEEE 802.11a and GPRS is investigated using the described simulation tool. We show a simplified scenario containing a single GPRS cell. The investigated architecture was coupled using a tight coupled approach. The WLAN system has been connected to the SGSN, when WLAN coverage is available the SGSN switches the traffic and redirects the data stream to the WLAN network (tight coupled).

If it leaves the WLAN coverage, a terminal uses its GPRS interface and the SGSN switches the data stream back to the GPRS network. The GPRS cell serves as overlay network. To limit the simulation time we focus on a square area of 200m x 200m. The GPRS BTS and a IEEE 802.11 AP are place at the coordinates (100,100) and a second AP at (0,0) (cf. Fig. 5). The MS starts at (0,0) moves to the square border and returns to the cell centre. This movement pattern is done forming a circle around the BTS. The MS transmits in uplink direction and uses the passive scanning to find an appropriate AP. The vertical handover is initiated after the scanning failed five times. Establishing a GPRS connection took around 220 ms in the described scenario.

The IEEE 802.11 WLAN interface is scanning continuously. When the MS returns under the coverage of an AP it starts its association and authentication with the AP. Presented are the resulted throughput and packet delay distribution over the

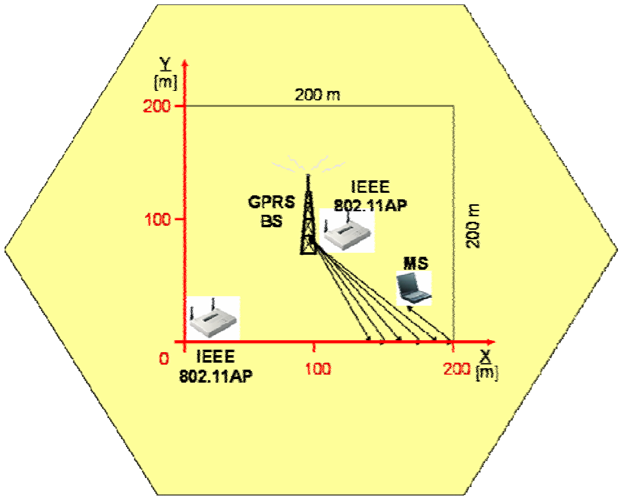

Fig. 5.Scenario Combining GPRS Cell and two WLAN Access Points

investigated area. The IEEE 802.11a WLAN interface has been configured to use BPSK ½ [1] as its coding scheme, thus the throughput at AP is limited to 3.4 Mb/s.

After switching to GPRS the throughput degrades rapidly, as shown in Fig. 6. The GPRS interface uses one PDCH and the coding scheme CS-2 which provides a net data rate up to 11.4 kbps. In the presented simulation a throughput of around 7 kb/s has been observed when connected via GPRS.

This result indicates that the VHO works to avoid the interruption of the connections during the change of the access technologies. When looking at the experienced delay the performance characteristic was quite similar to the throughput results. The WLAN network is able to deliver data packets much faster than the GPRS network

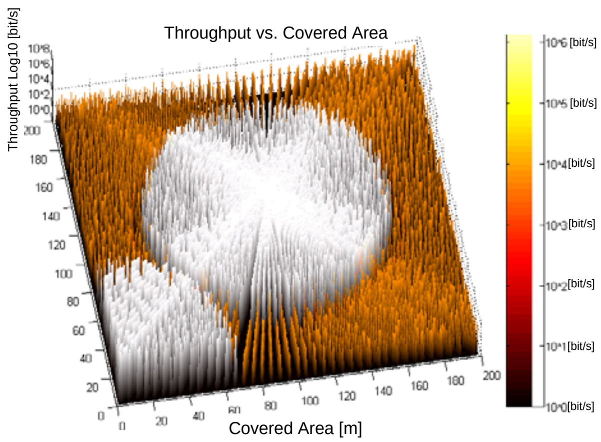

Fig. 6. Throughput Results of the mobile Internet architecture with IEEE 802.11a and GPRS

In this particular scenario only one mobile terminal has been simulated, thus no background traffic is considered. Therefore the packet latencies, presented in Fig. 7 are very small, the WLAN network delivers packets with a delay of around 184μs ($1,84*10^2$μs). When the node is connected through the GPRS system, the packet delay has been observed with up to around 100ms ($1*10^5$ μs). This is valid for the described parameters, and the delay can be decreased by using different coding schemes and more than one PDCH.

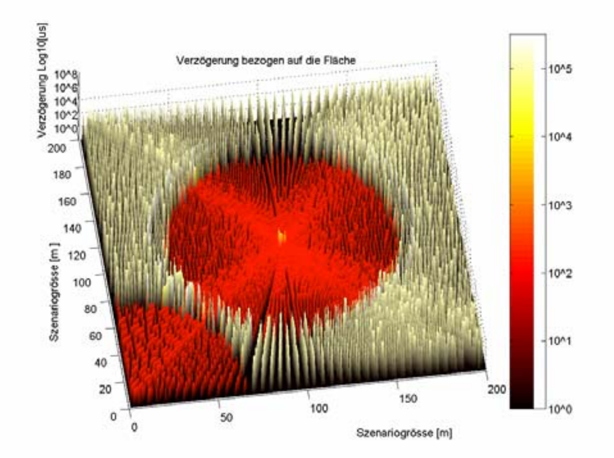

Fig. 7: Packet Latency Distribution of the mobile internet architecture with IEEE 802.11a and GPRS

IX. Discussion and Conclusion

The paper reviews different integration architectures, and presents a simulation tool that is unique for studying performance of hybrid systems. The developed tool as an intersystem simulation platform will be further developed to compare the different architectures and to add the UMTS protocol to the multi-system simulator S-GOOSE©. The paper presents the first simulation results showing the rapid service degradation when switching from WLAN to GPRS but the connection will not be disrupted. Intersystem handover cannot support QoS critical service with a data rate exceeding the cellular data network data rate. But intersystem handover might tremendously decrease the load in the GPRS network, since few seconds attached to the WLAN can replace minutes of a full connection via GPRS. And this result is also valid for UMTS. Therefore, for setting up or extending a GPRS/UMTS system the cell planning must consider the possible cooperation with WLAN hotspots..

Acknowledgements

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