Efficient Multi-hop Communication in Beyond 3G Mobile Radio Networks

Ole Klein, Michael Einhaus, Alexander Federlin, and Erik Weiss
Chair of Communication Networks, RWTH Aachen University, Faculty 6, Germany
ole.klein@comnets.rwth-aachen.de

***Abstract*— Based on simulation results in this paper we evaluate the merits of applying the Frame Descriptor Table (FDT) concept in a frame based MAC protocol working in a multi-hop scenario. The FDT concept is a promising means to mitigate the need for resources necessary to transmit control information in future mobile radio systems. Moreover it can be used to establish TDMA channels applying a MAC protocol employing a frame based reservation scheme. When examining multi-hop solutions for frame based MAC protocols it becomes obvious that the reduction of overhead is even more important than in a single-hop scenario. A drawback of the multi-hop MAC-protocol is the fact that control signaling is needed for each hop. This results in an increasing overhead with an increasing number of hops. With the help of FDTs this overhead can be kept small. When thinking of a multi-hop solution which establishes fixed or even partly fixed connections for the relaying of data, implementing the concept of FDT in such MAC-protocols is getting even more interesting. The simulations done in the course of this work show the positive effects of applying the FDT concept in multi-hop scenarios. The simulation results presented show the benefits in terms of increased throughput and reduced delay.**

***Index Terms*— Analysis, Simulation, Overhead reduction, MAC protocol, WINNER, Quality of Service, Multi-hop, Beyond 3G, IEEE 802.11e, IEEE 802.16a, HiperLAN/2**

I. Introduction

A new B3G radio access system is under development within the EU FP6 project WINNER (Wireless World Initiative New Radio) [2]. The system will provide ubiquitous access with significantly improved performance compared to today's systems. Thus, peak data rates up to 1 Gbps in the short range assuming low mobility and up to 100 Mbps for wide area supporting medium to high or even very high mobility are predicted. This will permit usage of a wide range of services in different scenarios. To achieve these objectives the support of efficient multi-hop communication is essential [14]. Thus the new air interface requires most importantly the implementation of a new and more efficient MAC protocol which is capable of multi-hop.

The reservation of the resource "radio channel" prior to the initiation of transmission is a prerequisite for the support of Quality of Service (QoS).

This can be done in different ways. Two promising approaches are the reservation of the medium on a per-frame basis as applied in many QoS supporting MAC protocols e.g. 802.11e [5],[6], 802.16a [7], HiperLAN/2 [8] and the establishment of TDMA channels as utilized in W-CHAMB [4]. The FDT concept [1], [10] effectively combines the merits of both approaches by enabling the establishment of fixed TDMA channels in a frame based protocol and moreover improves the multi-hop performance by reducing the control information signaling. A simulative performance evaluation has been made in order to predict the behavior of a system realizing resource reservation by using the FDT concept in a multi-hop scenario.

The remainder of this paper is organized as follows: section II presents a MAC protocol, the characteristics of which can easily be mapped onto existing frame-based protocols. The main characteristics will also be part of the WINNER and most future MAC protocols with a frame structure as basis of the resource allocation. Based on this MAC protocol the general concept of FDT is explained. section III describes the potentials of applying the FDT concept in a multi-hop scenario. The simulation environment and scenario used for assessment of the concept is presented in section IV before the simulation results are discussed in section V. A summary of the results and findings given in section VI concludes the paper.

II. II. General Description

A. MAC protocol

The underlying MAC protocol performs the resource allocation on a per frame basis. The available radio resources, i.e. the medium to be used for communication, are supposed to be fixed in the frequency domain and therefore only allocable in the time domain from frame to frame (Time Division Multiple Access (TDMA)) [3]. The adaptation of the concept to a system based on a combination of TDMA with Frequency Division Multiple Access (FDMA) [3] or even Code Division Multiple Access (CDMA) [3] is straightforward. The medium access is controlled by a master terminal. The logical relation of a data exchange between master and slave and vice versa is called a connection. There can be more than one connection established between the master and one slave. A frame is composed of a broadcast phase, a downlink (DL) phase, an uplink (UL) phase, and a phase for random access (see Fig. 1). During the broadcast phase the controlling master terminal sends out at least a Broadcast Channel (BCH) and a table of contents inside the Frame Channel (FCH). Inside the BCH information about the controlling terminal, the length of the FCH, and other information irrelevant in this scope are transferred. The FCH consists of Information Elements (IE) each describing one connection of the following UL and DL phases. The IEs specify for each connection among other things the transmission direction (DL/UL), the starting point of transmission in the frame, the transmission duration and the sender as well as the receiver. During the DL and UL phases user data and additional control information are sent from the master terminal to the slave terminals and vice versa.

A specific part of the UL phase is reserved for contention based random access in the Random Channel (RCH). The slotted RCH is primarily used for association of the slave terminals to the master terminal. The number of slots available is announced by the master inside the BCH. As mentioned before the concept of FDTs is able to work on different frame layouts and similar protocol behaviors as well. This is just an exemplary design of a MAC protocol which can benefit from the FDT concept presented in the following section.

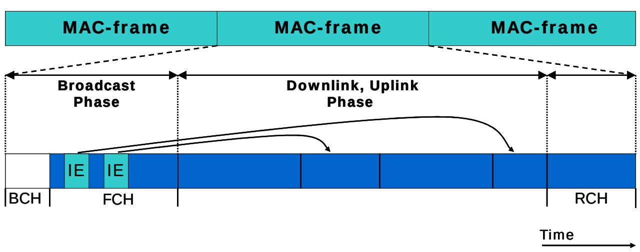

Fig. 1. Basic MAC Frame structure

B. *Frame Descriptor Table*

There are several ways to employ the concept of FDTs (see [1]). Based on the MAC protocol presented in the section before, in the following the general concept is outlined.

First of all we introduce the Frame Descriptor (FD). It contains IEs which describe the frame layout, i.e. the contents of the UL and DL phase. It differs from an FCH in that it is not transmitted every frame, but only in certain intervals. Additionally each FD transmitted has a unique ID. Each slave terminal maintains an FDT where all announced FDs are stored indexed by their ID. With the help of the ID an FD can be referred to by the master in one of the following frames. The slaves can look up the content of the FD by consulting their FDT with the help of the ID. If there is a certain periodicity in the communication needs of a particular service (e.g. VoIP) the master terminal can easily adapt to these needs by referring to two or more FDs in an alternating fashion.

The main advantage of this concept is the resulting decrease in overhead. The description of the frame layout is coded and can be simply communicated to the slaves by transmitting a number. In the following we assume the ID of the FD used during a certain frame is included in its BCH. To ease the understanding of the FDT concept we give two specific examples of its application:

The plainest case of the use of an FD is the description of a static frame completely with the help of an FD. In that case the FCH is substituted by specifying the identifier of an FD. The referenced FD has to be communicated to the slave terminals beforehand. This possibility of applying the FDT concept and the way to announce the FD to the slave terminals is illustrated in Fig. 2.

Inside the BCH a field is reserved for announcing the ID of the FD which describes the current frame. If the value in this field is 0 (see Fig. 2a)), no FD but an FCH describing the current frame is expected. For the purpose of introducing a new FDi the master terminal sets the identifier in the BCH to 0. The following FCH then contains the description of the current frame, as well as the new FD with ID equal i (see Fig. 2a) which is to be stored in the FDT in each slave terminal. Each time the master wants to reuse this FD it announces the ID (i) in the BCH as illustrated in Fig. 2b and Fig. 2c.

In some cases a connection only needs few resources

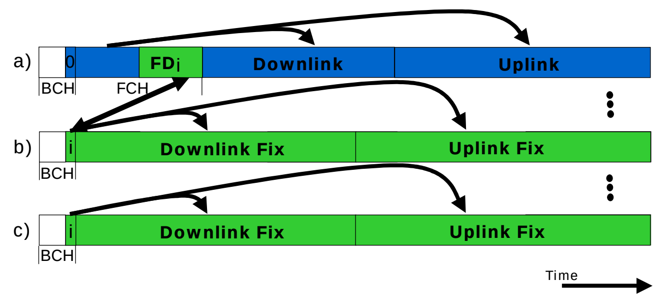

Fig. 2. FD describing a Static Frame

infrequently. Reservation of resources for a prolonged period of time would therefore be very inefficient. To easily accommodate such needs without having to change the layout of the frame and having to transmit a new FD, a dynamic portion is included in the frame. As shown in Fig. 3b, the FD describes the fixed portions of the UL and DL. This information only has to be transmitted once (cp. Fig. 3a). In the subsequent frames this description is referred to by the ID of the FD given in the BCH. In addition to these fixed portions, there are dynamic portions of UL and DL which are described within the FCH. As can be seen from Fig. 3b and Fig. 3c the content of the dynamic parts of the frame are changing while the fixed parts correspond to the description of the FDi.

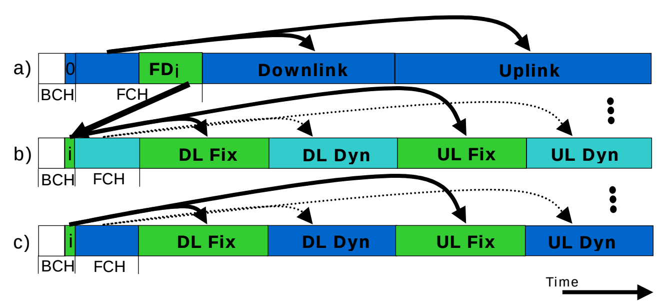

Fig. 3. Description of Fixed and Dynamic Portions

III. FDT IN MULTI-HOP

As explained in the section before the concept of FDTs allows for a reduction of overhead by decreasing the amount of signaling. When examining multi-hop solutions for frame based MAC protocols [13], [14] it becomes obvious that this reduction will get even more important. A drawback of the multi-hop MAC protocol is the fact that control signaling is needed for each hop. This results in an increasing overhead with an increasing number of hops. With the help of the FDTs this overhead can be kept small. Considering a multi-hop solution which establishes fixed or even partly fixed connections for the relaying of data, implementing the concept of FDT in such MAC protocols is even more interesting.

In a typical multi-hop scenario there is a master serving several slaves. At least one of the slaves, the relay, on his part acts as a master for several remote slaves. The traffic used by the remote slaves can be multiplexed onto one single connection from the relay to the master and vice versa. This connection has a more or less fixed resource requirement. Instead of describing this long standing and slowly changing connection every frame, it can be described using an FD. This provides an easy means to ensure a minimum bandwidth allotted to the relay as well as saving overhead and thus enabling the allocation of more resources to the slaves attached to the master directly. There is an additional advantage of the fixed allocation of resources on the UL connection. Usually a station has to send a resource request which has to be processed by the master. At the earliest in the next frame resources can be allocated. This step can be omitted using this method of establishing a fixed TDMA channel.

IV. Simulation Environment & Scenario

A. Simulation Environment

The simulation results presented in the next section have been obtained with the help of the modular simulation environment WNS (Wireless Network Simulator) [12], developed at ComNets [11]. The tool allows carrying out performance evaluations by means of event driven stochastic simulations. The WNS is a library supporting the user in creating new modules. In addition it offers a small tool called WNS-core which enables the use and interaction of multiple modules each implementing services which can be used by other modules. Therefore each of the participating modules supplies an interface to the services it offers. The WNS-core loads the modules and acts as a service broker negotiating between service provider and service user. The different modules interact with the help of an "Interface"-library. For example the module RISE (Radio Interference Simulation Engine) implements the characteristics of the radio channel. For this work the module PRIME (Protocol of next generation Radio Interface for a Modular Environment) was utilized on top of the RISE which provides a realistic channel model for 5 GHz including motion and fading.

B. Scenario

The multi-hop scenario used for the analysis of the concept is shown in Fig. 4. It consists of an AP representing the master, UTs representing the slaves and one Fixed Relay Node (FRN). The FRN acts as a slave from the AP point of view and as a master from the associated Remote User Terminals (RUT) point of view. There are 10 UTs attached directly to the AP. Attached to the FRN are another 10 RUTs, with the same load as the ones in the AP cell. On the first hop between AP and FRN all data targeted from the AP to the RUTs and vice versa are multiplexed onto a single bidirectional connection. The FRN processes its MAC frame alternately with the AP MAC frame. Each frame has a length of 2ms. I.e. the frame interval for AP and FRN is 4ms each.

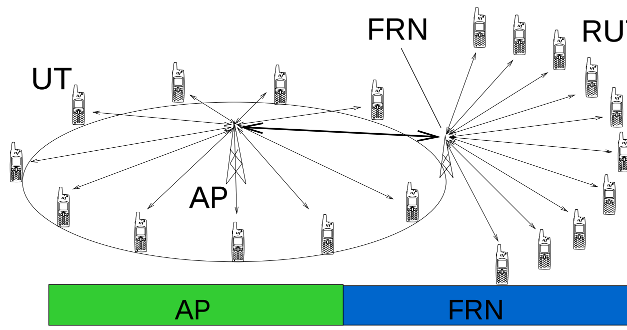

Fig. 4. Frame-by-frame multi-hop scenario

V. Simulation Results

In this section the results obtained by simulation with the extended PRIME simulator are presented. Since the main objective of these simulations is to compare the effects caused by the use of FDTs, the absolute throughput values are not important. Therefore in all results given the traffic load is scaled to the percentage of the PHY mode. The amount of the frame available and used for transmission of user data is given as percentage of the whole frame. Since the delay cannot be displayed independently of the PHY modus, the delays are all given using a PHY mode of 9 Mbps.

All the simulation results presented in the following were obtained assuming an ideal channel. This means no packets were lost due to interference or other causes. The load generator creates packets of size 48 byte and follows a Poisson distribution. The length of the MAC queue for packets coming from higher layers in each terminal is limited to 1000 packets. All parameters of the MAC and PHY are chosen as specified in [8] and [9]. As a compromise between flexibility and overhead the interval for changing the FD is set to 5 frames for the simulations executed in the course of this work.

In order to show the merits of the FDT concept, the system throughput and delay of the scenario given in section IV.B was measured in an identical setting without (see section A) and with (see section B) application of the FDT concept.

A. Without FDT

In the first simulation a round robin scheduling over all connections is performed without using FDTs. The resulting throughput vs. the traffic load is shown in Fig. 5 and Fig. 6.

Fig. 5 shows the throughput of the whole system versus increasing load on the local links. As can be seen, the throughput of the system is actually reduced with higher load. This can be explained by the fact that with low load on the local links the main throughput is generated by the highly loaded connection from the AP to the FRN. The relay connection is heavily overloaded and packets are discarded. If the load on the local UTs is increased, it is spread across more connections. Scheduling more connections in one frame increases the overhead. Thus the overall throughput of the system is reduced.

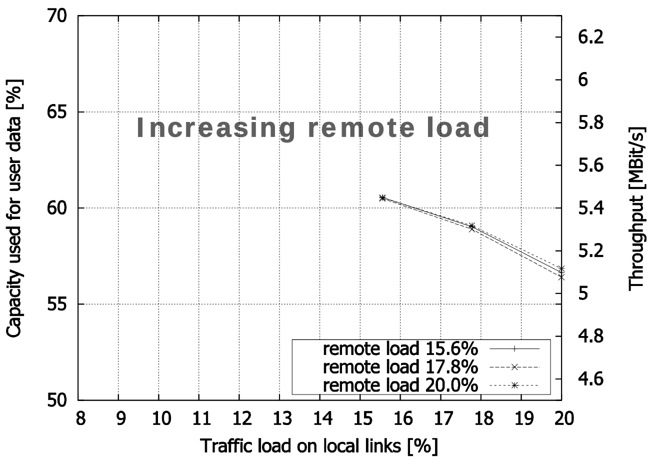

Fig. 5. Throughput without FDT - rising load on local connections

The fact that the connection from the AP to the FRN is in overload becomes clear from Fig. 6. Here the same data is displayed but this time the throughput is plotted vs. the load of the relay connection. The char parameter is the load on the local UTs. As can be seen, the throughput of the system does not change when increasing the load on the relay connection. It is already overloaded. This becomes apparent as well when examining Fig. 7 in which the end-to-end DL delay of the connection from the AP to the RUT is shown. As can be seen, the delay of the two-hop connection solely depends on the load generated by the local UTs. The delay is in the order of magnitude of one second. This is another proof of the overload condition of this link.

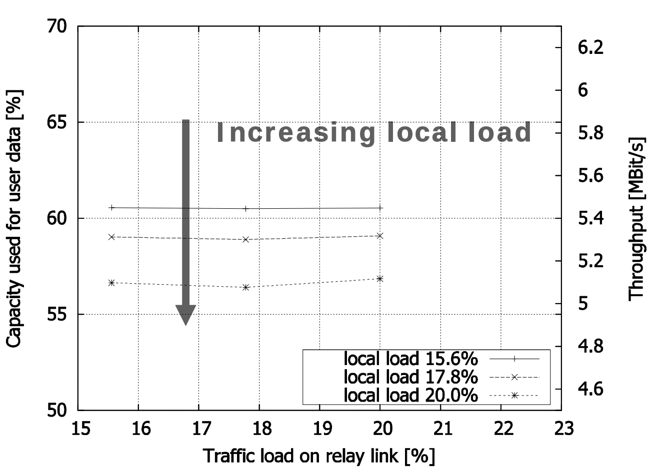

Fig. 6. Throughput without FDT - rising load on relay connection

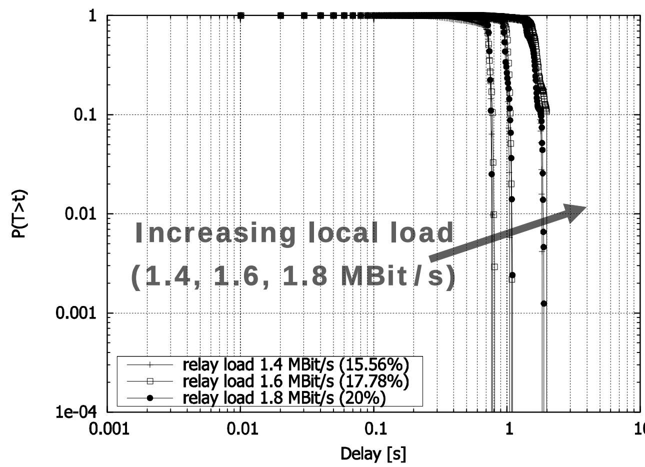

Fig. 7. Downlink end-to-end delay without FDT

B. *With FDT*

The situation described above is clearly a very unbalanced one. Because of the round robin scheduling the one connection serving the FRN is not able to request as many resources as would be necessary. An FDT can be used to establish a channel of fixed capacity between the AP and the FRN. This ensures the connection serving the FRN obtain a certain amount of resources which does not depend on the load imposed by the local UTs and moreover reduces the amount of signaling during the broadcast phase.

This has been done in the following simulation. Half of the frame has been reserved for the transmission of data described by an FDT. This section of the frame is used for transmissions to and from the FRN. The throughput of the relay connection and the local connections are shown in Fig. 8 and Fig. 9.

As above, the throughput of the whole system is plotted vs. the load on the local connections in Fig. 8. This time, the connections from the AP to the local UTs and vice versa are overloaded earlier. There is now only half a frame for them to be scheduled in. The other half is reserved for the connection to and from the FRN. As can be seen the total throughput is increased from around 60% without FDT to around 65% with the use of FDT.

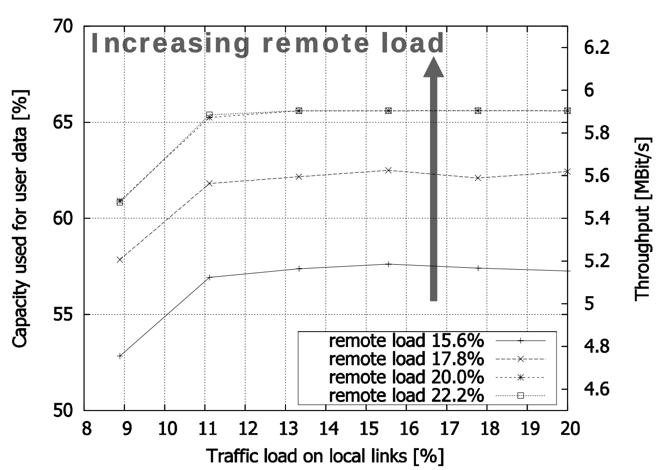

Fig. 8. Throughput with FDT - rising load on local connections

In Fig. 9 we can see that using FDTs has an immense impact on the system throughput when increasing the traffic load on the relay link. In contrast to the behavior without FDT (see Fig. 6) the system throughput increases up to a traffic load of about 20 % where the system starts to be saturated. This characteristic is independent of the load on the local links.

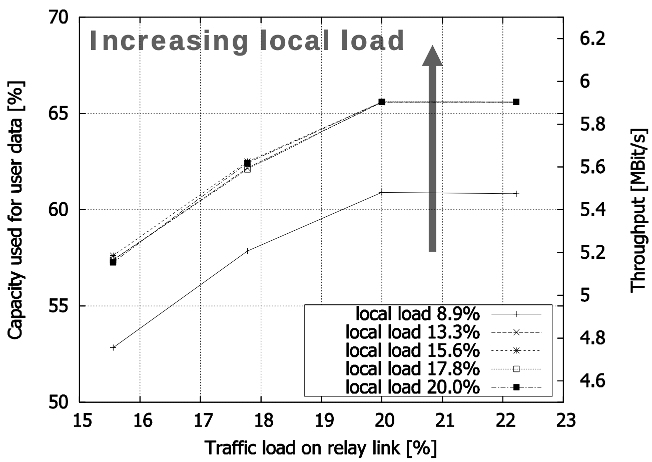

Fig. 9. Throughput with FDT - rising load on relay connection

The end to end delay of the relay connection in downlink direction is shown in Fig. 10. It becomes clear that the delay of the relay link does not depend on the load on the local connections anymore. It rises strictly with the load on the relay link. This is the expected behavior, since the same amount of resources are provided for the relay link, no matter how much load there is on the connections to local UTs. Moreover it can be seen that the delay compared to Fig. 7 could be reduced dramatically.

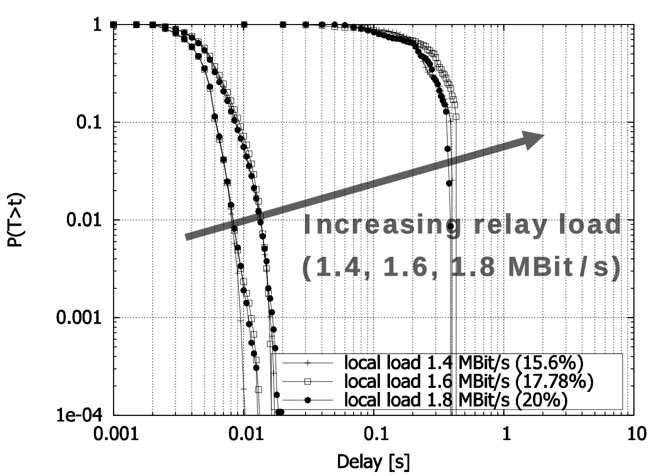

Fig. 10. Downlink end-to-end delay with FDT

VI. CONCLUSION

Within this paper the benefits of applying the FDT concept in particular in multi-hop scenarios are presented.

Multi-hop solutions for frame based MAC protocols have the drawback of implicating additional overhead introduced by control information to be signaled for each hop. With the help of the FDTs this overhead can be kept small.

The simulation results presented show an increased system throughput. A larger scenario with an increased number of relays would benefit even more from the application of the concept. The reduced end-to-end delays presented in addition reflect the advantages of having fixed TDMA channels for the connection between master and relay station which can be easily established when using FDTs.

Summarizing one can say that the concept of Frame Descriptor Tables is a promising way to enable efficient multi-hop communication in B3G mobile radio systems.

ACKNOWLEDGMENT

This work has been performed in the framework of the IST project IST-2003-507581 WINNER, which is partly funded by the European Union. The authors would like to acknowledge the contributions of their colleagues, although the views expressed are those of the authors and do not necessarily represent the project.

REFERENCES

[1] Klein, Ole and Einhaus, Michael and Federlin, Alexander: Reduction of Signaling Overhead in Beyond 3G MAC-Protocols using Frame Descriptor Tables. In Proceedings of 11th European Wireless Conference 2005, Vol.1, p.p. 260-265, Nicosia, Cyprus, 04/2005

[2] IST-2003-507581 “Wireless World Initiative New Radio Annex”

[3] Walke, B., Mobile Radio Networks, Chichester, Sussex, U.K.: Wiley & Sons Ltd., 2nd Ed., 2002.

[4] Xu, Bagnan: Self-organizing Wireless Broadband Multihop Networks with QoS Guarantee. Ph. D. Dissertation, Aachen University, p. 200, Lehrstuhl für Kommunikationsnetze, 07/2002, available under :http://www.comnets.rwth-aachen.de

[5] IEEE 802.11 WG, “Draft Amendment to STANDARD FOR Telecommunications and Information Exchange Between Systems - LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Medium Access Control (MAC) Quality of Service (QoS), IEEE 802.11e/ D8.0,” February 2004.

[6] Mangold, Stefan and Choi, S. and Hiertz, Guido and Klein, Ole and Walke, Bernhard: Analysis of IEEE 802.11 for QoS Support in Wireless LANs. In IEEE Wireless Communications, Vol.10, p.p. 2-12, 12/2003

[7] “Air Interface for Fixed Broadband Wireless Access Systems – Medium Access Control Modifications and Additional Physical Layer Specifications for 2-11 GHz”, IEEE P802.16a/D7-April, 2003

[8] Broadband Radio Access Networks (BRAN). HIPERLAN Type 2; Functional Specification; Data Link Control (DLC) Layer; Part1: Basic Data Transport Functions. DTS 0020004-1, ETSI, December 1999

[9] Broadband Radio Access Networks (BRAN). HIPERLAN Type 2; Physical (PHY) layer. Standard TS 101 475, ETSI, February 2001.

[10] Klein, Ole and Einhaus, Michael and Federlin, Alexander and Weiss, Erik: Analysis of Potential Savings in Signaling Overhead in Beyond 3G MAC Protocols by the use of Frame Descriptor Tables. In Proceedings of 12th European Wireless Conference 2006 , Athens, Greece, 04/2006

[11] Chair of Communication Networks, RWTH Aachen University, Kopernikusstraße 16, 52074 Aachen, Federal Republic of Germany, [Online]. Available: http://www.comnets.rwth-aachen.de

[12] Wireless Network Simulator. [Online]. Available: http://wns.comnets.rwth-aachen.de, 2005

[13] Esseling, Norbert and Walke, Bernhard and Pabst, Ralf: Performance Evaluation of a Fixed Relay Concept for Next Generation Wireless Systems. In Proceedings of PIMRC 2004, p. 9, pp. 9, Barcelona, Spain, 09/2004

[14] Schultz, D.C. and Pabst, R. and Irnich, T.: Multi-hop based Radio Network Deployment for efficient Broadband Radio Coverage. In Proc. WPMC, Vol.2, pp. 377-381, Yokosuka, Japan, 10/2003