Effects of Frame Descriptor Tables in Beyond 3G Systems

Ole Klein, Michael Einhaus, Alexander Federlin, and Erik Weiss

***Abstract* — In this paper we evaluate the potentials of the Frame Descriptor Table concept. Newly developed mobile radio interfaces beyond 3rd generation (B3G) present a new set of challenges in regard to medium access control protocols. Beside the requirement of supporting high Quality of Service B3G systems will need to achieve high spectral efficiency. Hence, new concepts have to be developed in order to enhance the efficiency of resource reservation. This work evaluates the performance of the promising concept of Frame Descriptor Tables (FDT) introduced in [1] regarding its impact on delay and throughput. Assuming a frame based reservation scheme, the concept helps to reduce signaling overhead by eliminating redundant description of frame layout across frames. This is done by caching the descriptions of frame layouts in mobile stations and referencing a certain description by transmitting an associated ID. This merges the concepts of frame based resource reservation and the reservation of TDMA channels in order to take advantage of the merits of both concepts. The simulations done in the course of this work show the resulting positive effects on signaling overhead. The results presented show a reduction of overhead and the feasibility and usefulness of establishing TDMA channels using a MAC protocol employing a frame based reservation.**

***Index Terms* — Analysis, Overhead reduction, MAC protocol, 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. The new air interface requires most importantly the implementation of a new and more efficient MAC protocol.

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 effectively combines the merits of both approaches.

A simulative performance evaluation has been made in order to predict the behavior of a system realizing resource reservation by using the FDT concept.

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. Using this MAC protocol which is also applied to achieve the simulation results, the general concept of FDT is explained. For further details of the concept refer to [1]. In section III the simulation environment and scenario used for assessment of the concept is presented before the simulation results are presented in section IV. A summary of the results and findings given in section V concludes the paper.

II. General Description

A. MAC protocol

To explain the FDT concept we assume a MAC protocol performing the resource allocation on a per frame basis.

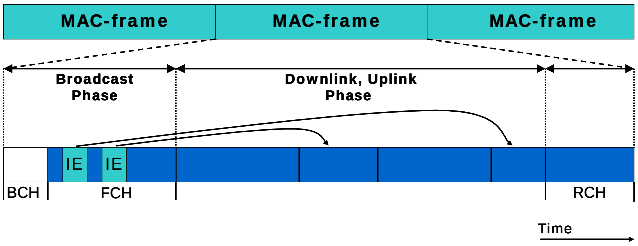

Fig. 1. Basic MAC Frame structure

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.

Manuscript received December 23, 2005.

Ole Klein is with Communication Networks, RWTH Aachen University, Faculty 6, Kopernikusstr.16, D-52074 Aachen, Germany (phone: +49 241 8028575; fax: +49 241 8022242; e-mail: ole.klein@comnets.rwth-aachen.de).

Michael Einhaus, Alexander Federlin, and Erik Weiss are with Communication Networks, RWTH Aachen University, Faculty 6, Kopernikusstr.16, D-52074 Aachen, Germany (e-mail: {ein|afe|erw}@comnets.rwth-aachen.de).

It is assumed that 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.

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 a specific example 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 FD 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.

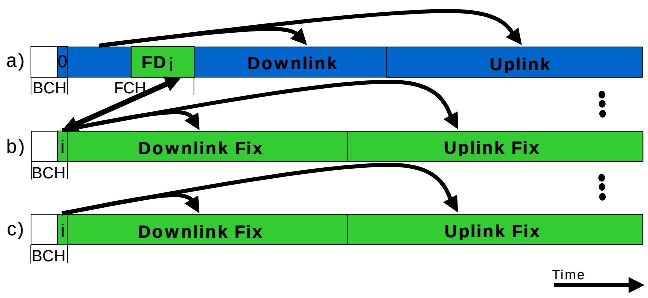

Fig. 2. Static Frame

III. 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) [14], developed at ComNets [11]. The tool allows carrying out performance evaluations by means of event driven stochastic simulations. The WNS uses a modular approach. For this work the module PRIME (Protocol of next generation Radio Interface for a Modular Environmnet) was utilized on top of the RISE (Radio Interference Simulation Engine) which provides a realistic radio channel model for 5 GHz including motion and fading.

The PRIME implements basically a frame based MAC protocol as described in section II.A. It has a hybrid architecture consisting of two parts. Firstly the structure and flow of the protocol is implemented using SDL (Specification and Description Language). With the help of the tool SDL2SPEEETCL [12] the protocol is translated to C++ based on the SPEETCL [13]. Secondly the data structures and complex algorithms such as scheduling are implemented in C++.

This has the advantage that the flow of the data and signals can be quickly understood and modified using SDL and on the other hand data structures and complex algorithms are more efficiently implemented using the C++.

B. *Scenario*

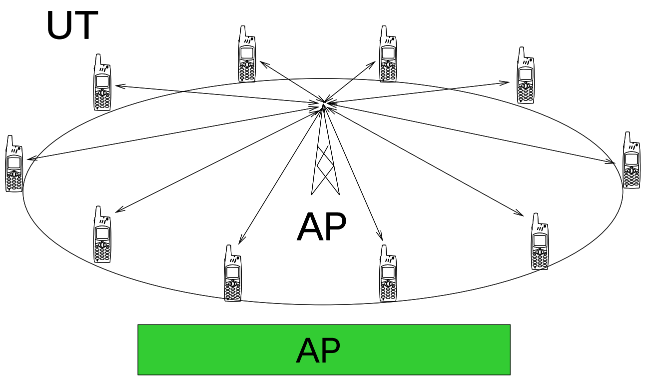

Fig. 3. Assessment scenario

The scenario used for the assessment is shown in Fig. 3. It consists of one Access Point (AP) representing the master serving 10 User Terminals (UT) representing the slaves. Each of these UT has one UL and one DL connection. All connections have the same load. The AP controls a MAC frame with a length of 2ms.

IV. 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 FDT, 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.

First of all we will discuss the influence of the introduced concept on the delay of data packets above the MAC layer. To explain the impact of applying the FDT concept we will compare the probability density function of the downlink delay versus the load using Round Robin scheduling (RR) with and without applying the FDT concept. The delays of the scenario given in III.B were measured in an identical setting with and without application of the FDT concept.

The concerning curves can be found in Fig. 4 for the case without FDT respectively in Fig. 5 for the case with FDT.

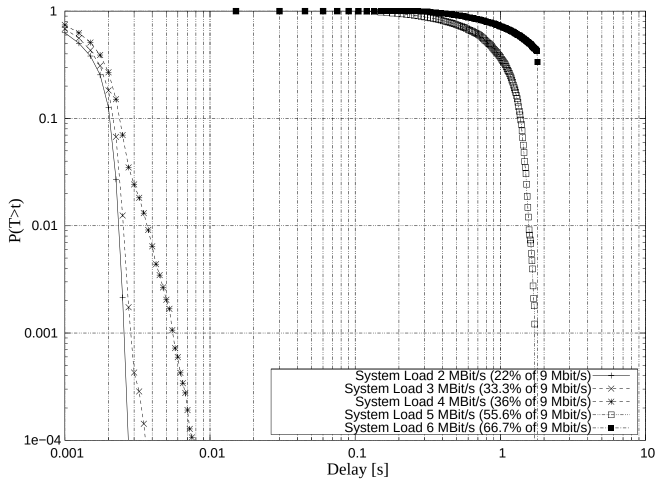

Fig. 4. Pdf of downlink delay vs Load using Round Robin scheduling without FDT

Fig. 4 shows that for all levels of system load (from 22% up to 66,7%) the delay with at least a probability of 99,9% is very close to a maximum delay which increases from below 3ms for a load of 22% up to below 3s for a load of 66,7%. Thus it can be concluded that the MAC protocol is able to support Quality of Service (QoS). Of course the achievable level of QoS is depending on the amount of load the system has to support.

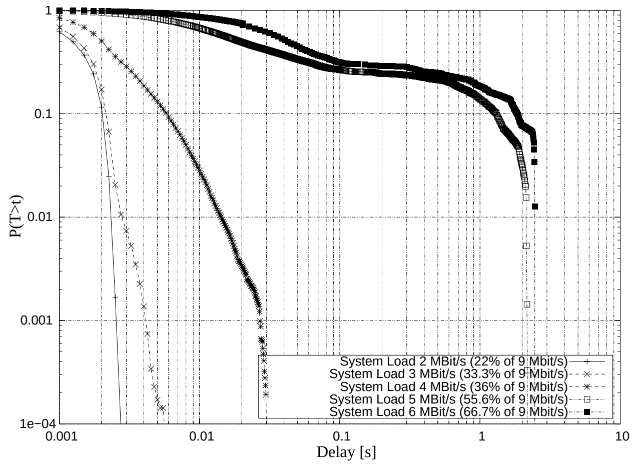

Fig. 5. Pdf of downlink delay vs Load using Round Robin scheduling with FDT

Comparing the results to the ones achieved when applying the FDT concept presented in Fig. 5 one can see that in particular in the case of medium (36%) and high (more than 50%) load the maximum delays increase stronger. The reasons are the simplified simulation assumptions to allow only one changing FD. This leads to a situation in which resources are allocated in the FD for connections which do not have packets in the queues to be transmitted. The worst case assumption of poisson traffic even aggravates the situation as the packets drop into the MAC queues extremely bursty. By allowing the use of more than one FD, multiple FDs could be announced each adapted for different situations regarding the fill level of the MAC queues. But even with the worst case assumptions made within this work a positive effect can be seen looking at the high load curves presented in Fig. 5. By applying the FDT concept the probability of achieving delays reduced by a factor of 100 is about 30% higher compared to the pure RR curves given in Fig. 4.

In Fig. 6 the throughput is plotted versus the traffic load for the simulations with and without FDT.

As can be seen the utilization of the frame at low loads is better using RR scheduling without FDT. This is because at low loads the assignment of resources for a duration of, in this case, 5 frames tends to waste resources by assigning them to connections which do not need them right now. These resources are used more efficiently if the assignment takes place every frame. This disadvantage is more than compensated by the saving of overhead at higher loads.

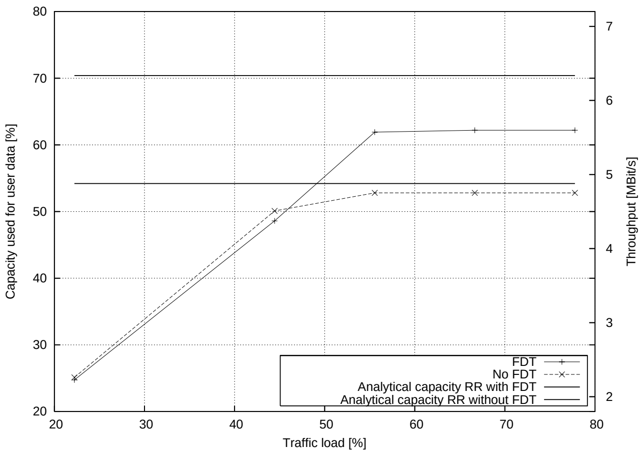

Fig. 6. Throughput vs Load using Round Robin scheduling with and without FDT

In keeping with the calculations presented in [10], the maximum percentage of a frame used for transmission of user data with 20 connections (10 UL and 10 DL) using the RR scheduling method and polling is between 50% and 55%. The analytical capacity (see [10]) for RR scheduling of 54.2% is not quite reached due to imperfect scheduling in the simulator. With the use of FDT this percentage can be raised to between 60% and 65%. This is less than the 70% presented in [10]. The reason for this discrepancy is the fact that the periodical transmission of the FD has not been included into the calculations. In this simulation this takes place every 5 frames.

V. Conclusion

The results given within this paper emphasize the relevance of the concept of Frame Descriptor Tables. It has shown to be a promising way of minimizing the need for resources necessary for the transmission of control information in wireless mobile radio systems.

By applying the FDT concept the probability of achieving delays reduced by a factor of 100 is about 30% higher compared to pure RR.

Describing the layout of a whole frame with the help of FDs the throughput saturates at significantly higher loads and provides about 10% more frame capacity to be used for user data.

The reduction of the maximum delays shown within this work will be possible by allowing more complex simulation assumptions and could additionally be improved by introducing a dynamic part in the frame which allows a Frame Channel beside the usage of the FD in parallel to describe parts of the frame more promptly (see [1]). This will be investigated in upcoming papers.

Summarizing one can say the results show the value of the FDT concept with respect to achieving high spectral efficiency necessary 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.

The authors would like to thank Prof. Walke for the fruitful discussions contributed to this work.

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] Martin Steppler. SDL2SPEETCL – An SDL to C++ Code Generator. AixCom GmbH, [Online]. Available: http://www.aixcom.com, 2002

[13] Martin Steppler. SPEETCL – SDL Performance Evaluation Tool Class Library. AixCom GmbH, [Online]. Available: http://www.aixcom.com, 2002

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