Frame Descriptor Tables for Minimized Signaling Overhead in Beyond 3G MAC Protocols

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Abstract — **In this paper we assess the performance of the Frame Descriptor Tables (FDT) Concept applied in combination with a highly dynamic resource allocation scheme. Beyond 3G (B3G) Medium Access Control Protocols (MAC) have to meet challenging requirements. In order to support the need for Quality of Service (QoS) and considering the scarce availability of radio resources, B3G MAC protocols must implement an intelligent resource allocation strategy with minimum signaling overhead guaranteeing high spectral efficiency. In this context the FDT concept seems to be a promising candidate. By eliminating redundant description of frame contents across frames the concept helps to reduce signaling overhead in a frame based reservation scheme. To keep as much flexibility as needed it seems reasonable to apply the FDT concept in combination with a highly dynamic resource allocation scheme. Simulations done in the course of this work prove the high quality of this combined approach.**

***Keywords* — Frame Descriptor Table, Dynamic Resource Allocation, Simulation, Signaling Overhead Reduction, MAC protocol, Quality of Service, 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. 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). 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 Time Division Multiple Access (TDMA)[3] channels as utilized in W-CHAMB [4]. The FDT concept effectively combines the merits of both approaches. Within this paper the behavior of a system realizing resource reservation using the FDT concept in combination with dynamic parts is assessed by means of simulations.

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. In section III the simulation scenario used for assessment of the concept is illustrated before the simulation results are presented in section IV. A summary of the results given in section V concludes the paper.

II. General Description

As the FDT concept and different kinds of its application are presented in a detailed fashion in [1], here we only briefly describe the protocol which is used to apply the FDT concept for the assessment presented in the latter sections. Additionally we shortly wrap up the FDT concept in a general way.

A. MAC Protocol

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

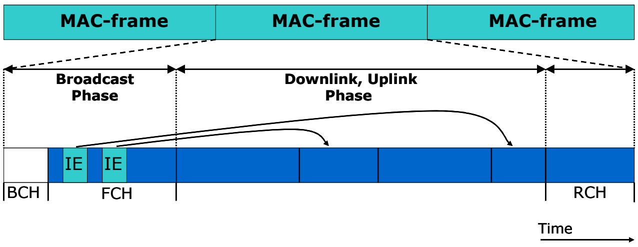

Figure 1. Basic MAC Frame Structure

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 (TDMA). 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. 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 Figure 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 just depicts an exemplary 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 (e.g. caused by VoIP) the master terminal can easily adapt to these needs by referring to two or more FDs in an alternating fashion.

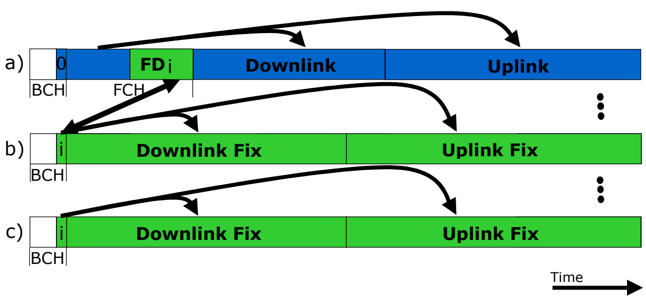

Figure 2. Static Frame

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 FD and the way to announce the FD to the slave terminals is illustrated in Figure 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 Figure 2a)), no FD but an FCH describing the current frame is expected. For the purpose of introducing a new FD_i 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 Figure 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 Figure 2b and Figure 2c.

In some cases a connection only needs few resources infrequently. Reservation of resources for a prolonged period of time would therefore be very inefficient. To effectively accommodate such needs without having to change the layout of the frame and transmitting a new FD, a dynamic portion is included in the frame.

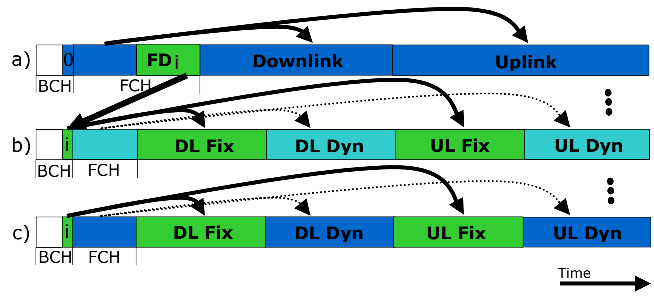

Figure 3. Description of Fixed and Dynamic Portions

As shown in Figure 3a,b, the FD describes the fixed portions of the UL and DL. This information only has to be transmitted once. 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 Figure 3b and Figure 3c the content of the dynamic parts of the frame are changing while the fixed parts correspond to the description of the FD_i.

III. Simulation Scenario

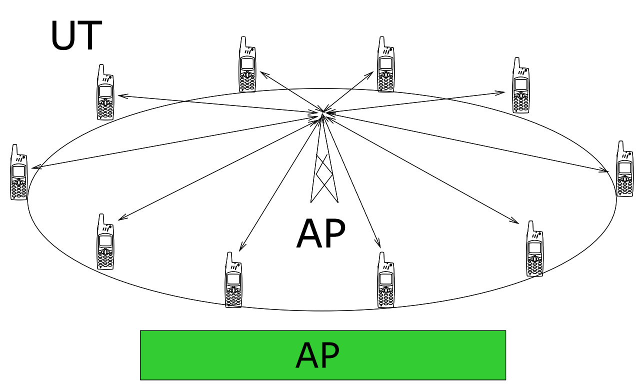

Figure 4. Assessment Scenario

The scenario used for the assessment is shown in Figure 4. It consists of one Access Point (AP) which represents 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

Since the main objective of the 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 maximum transferable bit rate which depends on the applied modulation and coding scheme. The amount of the frame available and used for transmission of user data is given as percentage of the whole frame. Results showing delays are based on a maximum transferable bit rate of 9 Mbps. The simulation results presented in the following were obtained assuming an ideal channel, i.e. no packets were lost. 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].

A. Variable Frequency of FDT Changes

In the first simulation runs performed within the scope of this work one FD is kept within the FDT for a fixed period of several frames. After this period elapses a new FD is calculated and sent out by the AP to the UTs. These substitute the old entry in their FDT for this newly received FD. The efficiency of the concept scales up with the number of stored FDs in the FDT. To get an impression of the potential of the concept and to ease the understanding of the results we have chosen this basic approach of implementing it. Applying the FDT concept in particular this way is a trade-of between flexibility and overhead. If the layout of the frame is kept unchanged for too long, the needs of a connection scheduled within the FD may have changed and resources may be allocated unnecessarily. If the FD is changed too often, the efficiency is reduced. In order to find out which frequency for changing the FD is reasonable, simulations have been carried out with the results presented in Figure 5, which shows the system throughput vs. the system load depending on the interval between changes of FD.

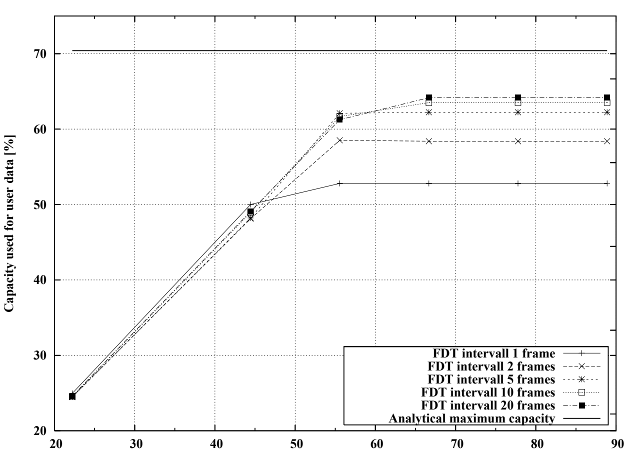

Figure 5. Throughput vs. System Load depending on interval between changes of FD

The system changing the FD in every frame (pure round robin (RR)) is the first to be overloaded. What should be mentioned is the fact that there is no additional overhead because of the use of the FDT concept. The results are exactly the same as for pure RR scheduling without the use of FDs.

The longer the time between two changes of an FD, the less signaling is needed. Thus the throughput increases with increasing intervals between changes of an FD. But another fact becomes apparent when examining Figure 5. The rate of gain in overhead is getting smaller with increasing intervals between FD changes. This becomes intuitively clear when imagining the same amount of signaling being spread out over an increasing interval. The gain is growing logarithmically. The upper limit of this development (Interval between changes of FD $i \rightarrow \infty$) converges to the maximum capacity of 70.4% calculated in [10]. On the basis of this result the interval for changing the FD is set to 5 frames for the other simulations executed in the course of this work.

B. Description of Frames with Dynamic Portions

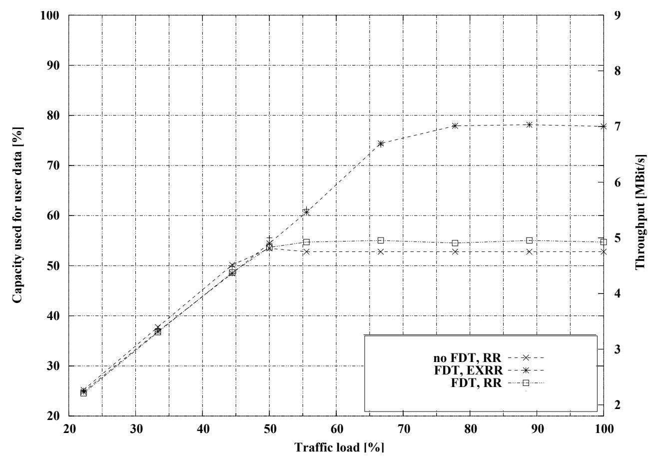

Figure 6. Throughput vs. System Load depending on scheduling algorithm

The usage of the FDT concept is not limited to describing whole frames. As shown in section II.B, the FD can be used to describe parts of a frame as well. This enables the use of different scheduling algorithms within one frame. The effects of such a usage with respect to the throughput are shown in Figure 6. The scenario for this simulation is the same as before.

The scheduling strategy used has an impact on the overhead necessary for MAC and PHY operation. Because of this the achievable throughput of the system depends on the scheduling algorithm used. The most signaling is needed when using pure RR scheduling (no FDT, RR). This results in the lowest throughput as can be seen from Figure 6. Less than 55% of the frame capacity can be utilized for user data.

In this simulation series two strategies using the FDT concept are examined as well. One of them uses half of the frame for transmitting data using connections which have been described in FDs. The other half of the frame is described by a regular FCH using RR scheduling (FDT, RR).

The resulting throughput is not increased significantly. This is because a lot of the overhead necessary in RR scheduling comes from preambles of the exemplarily assumed PHY [9]. But the FDT concept lessens the signaling overhead of the MAC layer.

This becomes obvious when examining the last curve describing the run of the third variation of scheduling examined here (FDT, EXRR). This time, the half of the frame which is described by the FCH is scheduled using Exhaustive Round Robin (EXRR). The part described by the FD is scheduled using RR. This is the most effective alternative in terms of throughput. The FCH is very short, since it only has to describe a single connection or two. The FD which describes a lot of connections using RR scheduling only has to be transmitted every 5 frames. This results in a capacity used for user data of nearly 80% of the frame capacity. Thus this strategy outperforms both others by providing about 25% more frame capacity for user data.

The performance of the delay is influenced as well by the usage of FDs as can be seen in Figure 7 showing the downlink mean delay versus the system load depending on the scheduling algorithm.

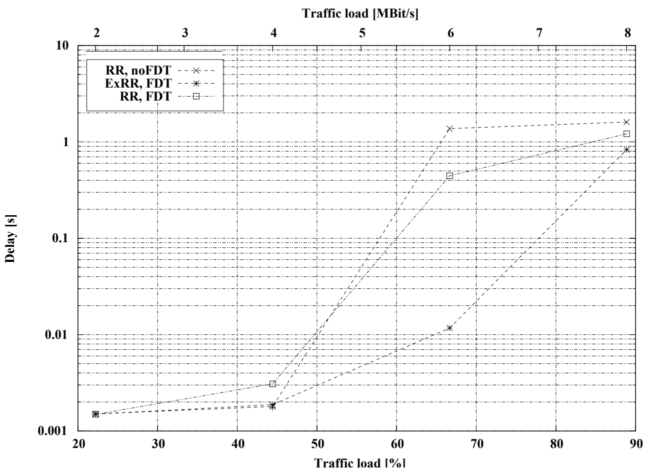

Figure 7. Mean downlink delay vs. System Load depending on scheduling algorithm

At a certain amount of traffic load [%] the delay is increasing rapidly. Like it was the case for the throughput, the strategy applying a combination of FDT concept together with EXRR outperforms the others significantly in terms of mean delay.

The performance of the combination of RR together with the FDT concept shows higher mean delays for low traffic up to 50% compared to pure RR. In exchange it outperforms pure RR at higher loads. The reason is that for low loads the static resource allocation of the FDT can be outperformed by the dynamic of the RR whereas at higher loads the FDT concept reduces the signaling overhead in such a way that the gained capacity helps to reduce the mean delay.

V. Conclusions

This paper shows that the concept of Frame Descriptor Tables in combination with a highly dynamic resource allocation scheme is a promising way of minimizing the signaling overhead in MAC protocols while offering high flexibility in fulfilling QoS requirements.

First simulation results provide the basis for the decision to set the interval for changing the FD to 5 frames as this number seems to provide a good compromise between overhead and flexibility when applying the FDT concept.

By introducing dynamic portions described by the FCH in addition to the part described by the FD the combination of FDT concept together with EXRR scheduling shows the potential of the FDT concept both in terms of enhanced throughput as well as in terms of reduced mean delay.

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

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