Analysis of Potential Savings in Signaling Overhead in Beyond 3G MAC Protocols by the use of Frame Descriptor Tables

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Abstract — **In this paper we analyse the potential savings in MAC signaling overhead by introducing Frame Descriptor Tables. Newly developed mobile radio interfaces beyond 3rd generation (B3G) present a new set of challenges in regard to medium access control protocols. In order to meet high Quality of Service requirements, B3G systems will need to possess an efficient method for reservation of the wireless medium. Hence, new concepts have to be developed in order to enhance the efficiency of resource reservation. This work analyses the promising concept of Frame Descriptor Tables (FDT) introduced in [1]. Assuming a frame based reservation scheme, the concept helps to reduce signaling overhead by eliminating redundant description of frame contents across frames. This is done by caching the description of frame contents 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 analysis done in the course of this work show the positive effects on signaling overhead. The FDT concept is applied in a single-hop as well as in a multi-hop (relaying) scenario. The results presented show a reduction of overhead and establishment of TDMA channels using a MAC protocol employing a frame based reservation is feasible and promising.**

Keywords — **Analysis, 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. The new air interface most importantly requires 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 [7],[9], 802.16a [9], HiperLAN/2 [11] and the establishment of TDMA channels as utilized in W-CHAMB [7]. The FDT concept effectively combines the merits of both approaches.

Analytical calculations have 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. Based on this MAC protocol the general concept of FDT is explained. In section III the scenarios used for assessment of the concept are presented before the achievable savings are analyzed in section IV. A summary of the results and findings 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 analysis presented in the latter sections. Additionally we shortly wrap up the FDT concept in a general way. A detailed description can be found in [1]

A. *MAC protocol*

To explain the FDT concept we assume a MAC protocol performing the resource allocation on a per frame basis. The main characteristics of this protocol are described in this section, as far as they concern frame layout and, without going into detail, description of control data.

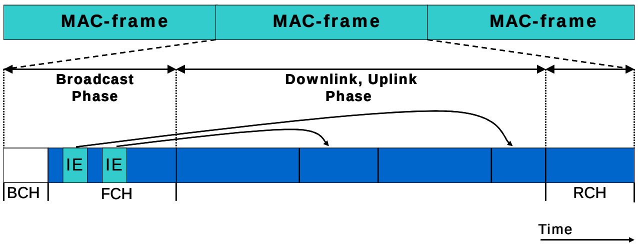

Figure 1. Basic MAC Frame structure

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 (Time Division Multiple Access (TDMA)) [6]. The adaptation of the concept to a system based on a combination of TDMA with Frequency Division Multiple Access (FDMA) [6] or even Code Division Multiple Access (CDMA) [6] 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 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. Thus it is easily possible for the master to change the frame layout by alternately referring two or more FDs if, e.g. there is a certain periodicity in the communication needs of a particular service (e.g.: VoIP).

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 number is included in the 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.

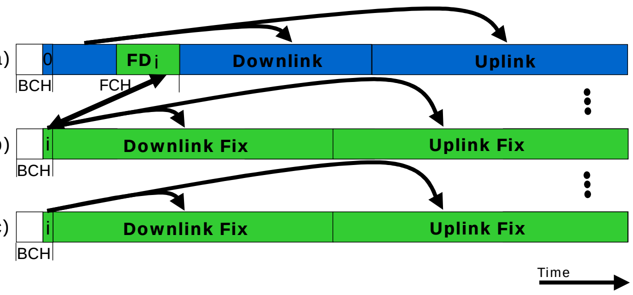

Figure 2. Static Frame

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 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.

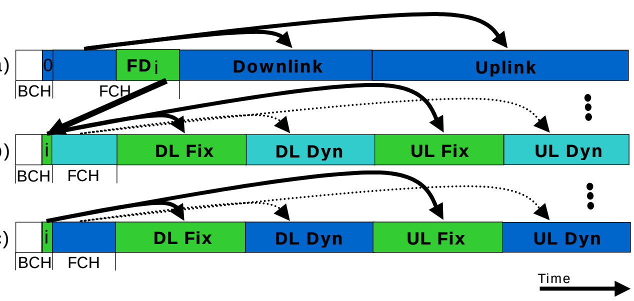

Figure 3. Description of Fixed and Dynamic Portions

As shown in Figure 3b, 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. Scenarios

In this section we present the scenarios on which the assessments of the FDT concept are based. Two scenarios, one for single hop and one for multi-hop are employed. The need for multi-hop based deployment concepts is presented in [5].

A. Single Hop

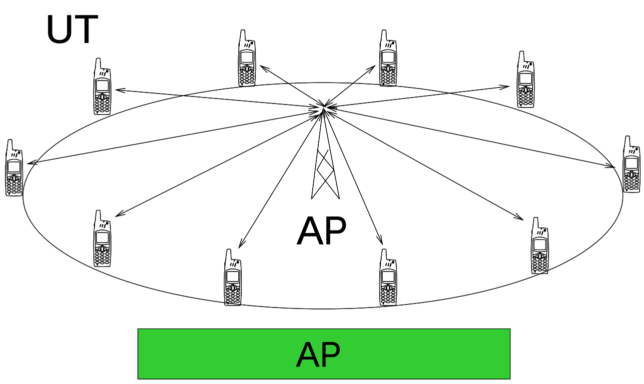

Figure 4. Single hop scenario

The scenario used for single-hop analysis is shown in Figure 4. 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.

B. Multi-hop

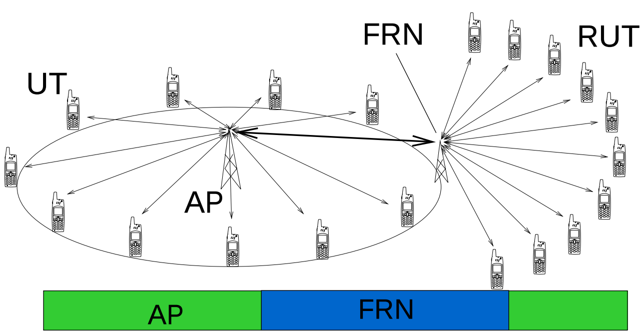

Figure 5. Frame-in-frame multi-hop scenario

The multi-hop scenario used for the analysis of the concept is shown in Figure 5. It consists of one AP 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 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 during the UL phase of the AP MAC frame (length 2ms), as described in [3]. I.e. the frame interval for AP and FRN is 2ms each.

IV. Analysis of Potential Savings in Signaling Overhead

In this section the signaling overhead and the savings of the FDT concept are calculated. The analysis is realized on the basis of the data structures and parameters as specified in [11], [13]. The calculations presented in this section are based on the analysis presented in [3] and [12].

First the overhead necessary in a single hop scenario is calculated. The signaling necessary for two hop operations using the frame-in-frame technique presented in [3] is calculated afterwards. For both scenarios the amount of signaling of the conventional method is compared to the amount of signaling using the FDT technique. In a final step the impact of the physical layer on the total overhead necessary in a system is discussed.

A. Analysis of Overhead in a Single Hop Scenario

For the organization of the data transmission in a single hop scenario the following capacity must be reserved (according to [12] and [3]):

$$L_{Orga} = L_{BCH} + L_{FCH} + L_{ACH} + L_{RCH} + L_{DL} + L_{UL} + L_{TTA} \qquad (1)$$

L_{Orga} is given in Orthogonal Frequency Division Multiplexing (OFDM) symbols. The different components L_{Orga} contains are the OFDM symbols needed for the organization of the associated control channels. The Access feedback Channel (ACH) is transmitted by the AP/FRN at the end of the broadcast phase to inform the UT/RUT about the success of receptions during the RCH of the previous MAC frame. For more details see [11]. L_{TTA} equals the time necessary for the transceiver to switch from transmission to reception and vice versa given in OFDM symbols accordingly.

Since a MAC frame according to [13] has a total of 500 OFDM symbols, the number of free symbols available for payload within a frame can be calculated as:

$$L_{Payload} = 500 - L_{Orga} \qquad (2)$$

In Figure 6 the number of free symbols is plotted versus the number of stations in the radio coverage of an AP for two different scheduling approaches.

The following assumptions are made in the calculation:The number of active bidirectional connections per UT and frame is $n_{bi\text{-}con} = 1$. That means the minimum number of active connections per frame is one UL and one DL. For this calculation Automatic

Repeat Request (ARQ) acknowledges are not considered. The number of RCH slots is $n_{RCH\text{-}Slots} = 1$.

Using exhaustive round robin (EXRR) it is assumed that each terminal has enough data in its queue to fill a whole frame. This means that each frame contains one bidirectional connection (so in fact one UL and one DL connection), no matter how many stations are in the cell. This results in an amount of overhead (~7% of the frame) that can be regarded as the lower limit. As can be seen from Figure 6 the overhead is independent of the number of stations in a cell.

Round robin scheduling serves all connections equally and integrates the same fraction of each into the frame. With a growing number of stations in a cell consequently the number of connections scheduled in one frame increases. This results in an increase in overhead. Applying round robin for 10 stations almost 30% of the frame is occupied by overhead. This overhead consists of signaling overhead resulting from IEs transmitted in the FCH as well as PHY overhead resulting from preambles preceding every DL respectively UL transmission.

The results of round robin with FDT show that the overhead can be reduced significantly. Serving 10 stations the reduction of overhead is greater than 10% of the whole frame. The FDT technique eliminates the signaling that has to take place in the FCH. The PHY overhead induced by the preambles depends on the number of transmissions scheduled in a frame. This explains the slow but steady fall of the result.

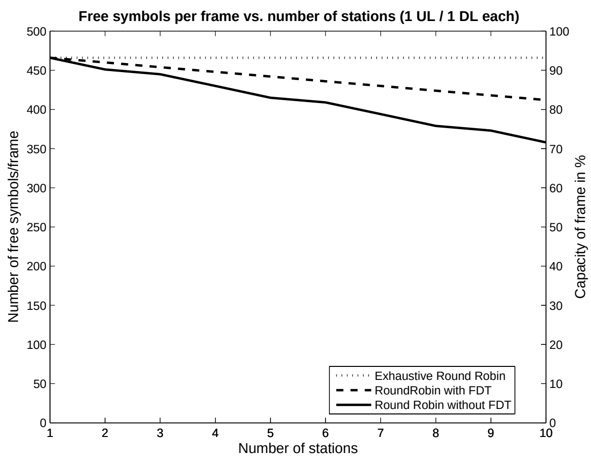

Figure 6. Comparison of free symbols in a MAC frame

If in addition to the connections used for the transmission of user data an additional signaling connection per terminal is scheduled (polling), in the worst case the percentage of the frame used for the transmission of user data drops to below 55% for 10 stations using the round robin scheduling method (see Figure 7).

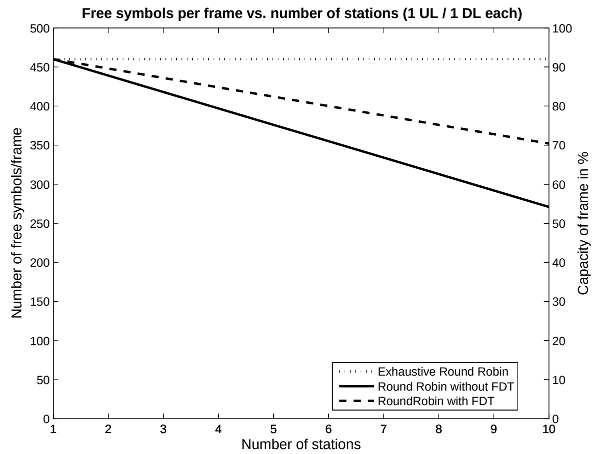

Figure 7. Comparison of free symbols in a MAC frame with the use of polling

B. Analysis of Overhead in a Frame-in-Frame Multi-hop Scenario

The Frame-in-Frame multi-hop concept proposed in [3] is another example of the possible savings using FDT. In short this concept proposes inserting a complete forwarding frame with broadcast, uplink and downlink phase into the regular AP controlled MAC frame. This inner frame could be used for communication of the AP with a FRN which in turn passes information to RUTs associated with the FRN.

An AP can reach n_{UT} UTs and n_{FRN} FRNs on the first hop. The FRNs serve n_{RUT} RUTs each on the second hop. Thus, the total number of connections to RUTs results in:

$$n_{RUT-ges} = n_{RUT} \cdot n_{FRN} \quad (3)$$

Each UT or RUT has $n_{bi\text{-}con}$ bidirectional connections, for which resources are scheduled in each frame if requested. FRNs are only used as relays. If they have connections on their own, they have to be accounted for as separate UTs.

Assuming all connections are scheduled within one frame (EXRR) the number of symbols necessary for handling the signaling of the system with relaying concept can be calculated:

$$\begin{aligned} L_{Orga} &= L_{BCH} + L_{FCH} + L_{ACH} + L_{RCH} + L_{DL} + L_{UL} \\ &+ L_{TTA} + L_{F-BCH} + L_{F-FCH} + L_{F-ACH} + L_{F-RCH} \qquad (4) \\ &+ L_{F-DL} + L_{F-UL} + L_{F-TTA} \end{aligned}$$

The index F refers to the forwarding frame. Since a MAC frame has a total of 500 OFDM symbols, in a two hop scenario a total of

$$L_{Payload} = 500 - L_{Orga} \quad (5)$$

symbols are available for transferring user data.

In Figure 8 the amount of free symbols in a MAC frame is plotted versus the number of stations present in a multihop scenario. The scenario consists of one AP, one FRN and a variable number of UTs/RUTs. The number of stations ($n_{Station} = n_{UT} + n_{RUT}$) is increased in such a way that the number of UTs is $n_{UT} = \lceil n_{Station} / 2 \rceil$ and the number of RUTs is $n_{RUT} = \lfloor n_{Station} / 2 \rfloor$. This, and the fact that a new set of IEs is necessary for every three connections explains the irregular run of the curve displaying the number of free slots using round robin scheduling without FDTs.

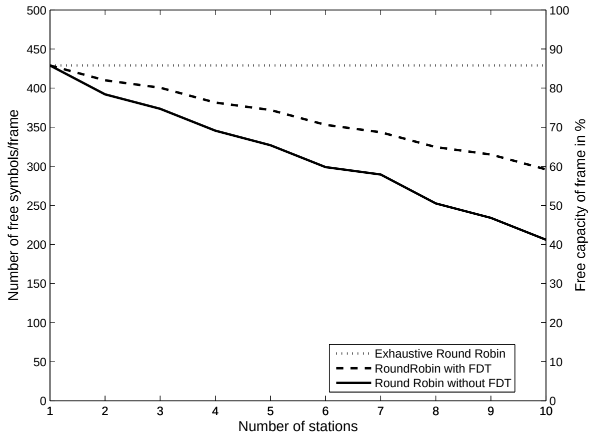

Figure 8. Comparison of free symbols in a MAC frame in the case of multi-hop

Examination of Figure 8 reveals that the amount of signaling necessary to realize multi-hop operation is substantial. The amount of free symbols available in each frame can drop to less than 50%. This amount of signaling overhead can be reduced significantly by applying the FDT technique. Again, the difference between the results for FDT and the application of EXRR is a result of the amount of PHY overhead necessary for preambles preceding each transmission.

C. *Impact of PHY on Overhead*

As mentioned before the calculations presented in the previous sections were based on the parameters given in [11], [13], which define a Long Channel (LCH) as the smallest data unit to be used for payload. LCHs of connections which have a common pair of sender and receiver are grouped together in one transmission, a so-called PDU train (see Figure 9a)). The physical layer [13] requires preambles preceding every PDU train. As shown above, reducing the number of necessary preambles is part of the advantage of the exhaustive round robin scheduling strategy.

Newly developed physical layers may not provide the possibility of grouping the data together. In order to support higher data rates, very exact and numerous measurements of the channel may have to take place. This may necessitate preambles and pilot symbols not only preceding every PDU train, but every however named chunk of information transmitted on the channel (see Figure 9b)). This would diminish the advantage of the exhaustive round robin scheduling strategy as it is presented above.

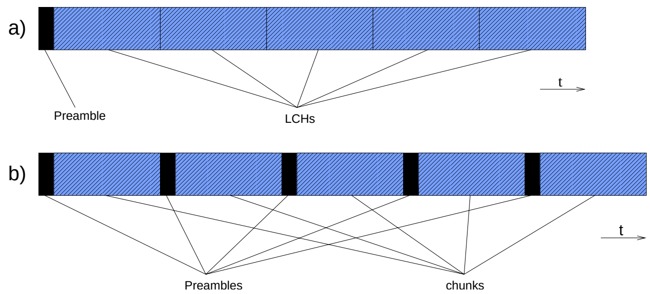

Figure 9. Comparison of H/2 PHY with possible new PHY structure

In order to calculate the impact of such a PHY on the FDT concept, the equations used above were modified to represent a PHY demanding a preamble of 1.5 OFDM symbols (6 µs) for every chunk. The duration of a chunk is assumed to be the duration of a Long Channel (LCH), at a PHY mode of 18 Mbps which results in a duration of 24 µs.

A higher PHY mode would shorten the duration of a chunk and thus the ratio of user data to PHY overhead would become even worse.

For this calculation equation (2) is changed to:

$$L_{Payload} = 500 - L_{BCH} - L_{FCH} - L_{ACH} - L_{RCH} - L_{TTA} \cdot \left(1 - \frac{1{,}5}{6}\right) \quad (6)$$

As the results presented in Figure 10 show, with such a PHY, the FDT technique could completely eliminate the drawbacks of round robin presented in the sections before. The signaling needed on the PHY level is the same for both scheduling strategies and the signaling on the MAC level can be reduced as shown in section A. As can be seen in Figure 10, the level of overhead necessary with the FDT technique is no longer dependent on the number of stations present in a cell.

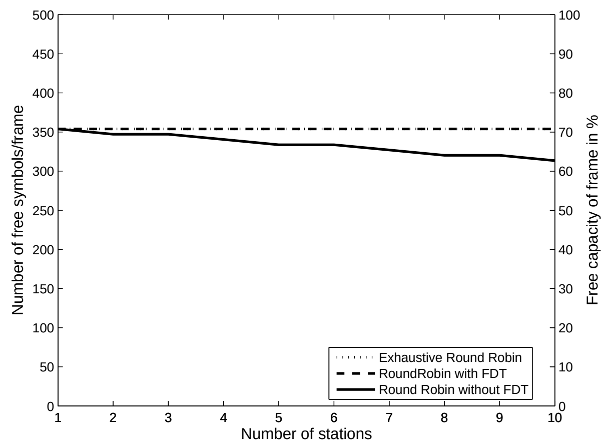

Figure 10. Number of free symbols vs. number of stations using an alternative PHY

This calculation is not a holistic analysis of this complex issue. Its focus is to provide an estimation of the effects that could be observed using a different PHY. For a complete analysis one would have to know the actual ratio of preambles to chunks of user data proposed for a future physical layer. The length of the preambles as well as the length of the chunks have a big impact on the result of such an analysis. Because research on these issues is still ongoing, a detailed examination is not feasible at this time.

V. CONCLUSIONS

Within this paper it has been shown that the concept of Frame Descriptor Tables is a promising means to mitigate the need for resources necessary to transmit control information in wireless mobile radio systems of the next generation.

The performed analysis indicates that in a single-hop scenario the FDT technique in the best case can eliminate the signaling needed to allocate resources in a MAC protocol applying a frame based reservation scheme.

The substantial amount of signaling necessary to realize multi-hop operation in such a MAC protocol can be reduced significantly by applying the FDT technique.

The presented results are based on the parameters specified in [11] and [13] and a very likely model for a future system PHY was presumed to investigate the benefits of the FDT concept in B3G systems.

It turned out that the foreseen scheme to be used in future PHYs even strengthens the capability of the concept. We can conclude that the FDT concept is able to make the signaling nearly independent of the number of stations to be served.

This makes the concept of FDTs a valuable method for achieving high spectral efficiency necessary in B3G mobile radio systems

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