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

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Abstract We propose and evaluate the Frame Descriptor Table (FDT) concept, a method to increase efficiency of signalling resource allocation in frame based Medium Access Control (MAC) protocols. MAC protocols for Beyond 3G mobile radio networks, also known as IMT-Advanced systems, will operate on high data rate channels resulting in short packet transmission duration. The scheduling overhead per packet must also be reduced, correspondingly. The new concept is suitable also to reduce the MAC control overhead spent per hop in mobile radio systems with Relay Enhanced Cells (REC)s that apply multi-hop communication by dynamically allocating TDMA channels. This paper's focus is on performance evaluation of multi-hop scenarios using analytical models and event-driven stochastic simulations. It is shown that FDT based MAC protocols are suited to increase throughput and reduce delay in REC based cellular radio systems.

Keywords Relay enhanced cell · Multi-hop · MAC protocol · Analysis · Simulation · Frame descriptor table · WINNER · Quality of service · Beyond 3G · IMT-advanced · IEEE 802.11e · IEEE 802.16a · HiperLAN/2

Abbreviations

ACH	Access feedback channel
B3G	Beyond 3rd generation
BCH	Broadcast channel
BS	Base station
CDMA	Code division multiple access
DECT	Digital enhanced cordless telecommunications
DL	Downlink
EXRR	Exhaustive round robin

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FCH	Frame channel
FD	Frame descriptor
FDMA	Frequency division multiple access
FDT	Frame descriptor table
FRN	Fixed relay node
Gbps	Gigabit per second
GPRS	General packet radio service
GSM	Global system for mobile communications
HiperLAN	High performance local area network
IE	Information element
IEEE	Institute of electrical and electronics engineers
IST	Information society technologies
ITU-R	International telecommunications union – radiocommunications sector
MAC	Medium access control
OFDM	Orthogonal frequency division multiplexing
PHY	Physical layer
QoS	Quality of service
RCH	Random access channel
REC	Relay enhanced cell
RN	Relay node
RR	Round robin
RTS/CTS	Request to send/Clear to send
RUT	Remote user terminal
TDMA	Time division multiple access
UL	Uplink
UT	User terminal
VoIP	Voice over internet protocol
WiMAX	Worldwide interoperability for microwave access
W-CHAMB	Wireless channel oriented Ad hoc multi-hop
WINNER	Wireless world initiative new radio
WLAN	Wireless local area network
WMAN	Wireless metropolitan area network
WRC	World radiocommunication conference

1 Introduction

A Beyond 3G (B3G) radio access system is currently under development within the European Union Framework Programme 6 project WINNER (Wireless World Initiative New Radio) [1]. The system will provide ubiquitous access with significantly improved performance compared to today's systems. Peak data rates up to 1 Gbps for short range links under low mobility and up to 100 Mbps link data rate for wide area coverage supporting medium to very high mobility are envisaged to support a wide range of services. To be able to meet these challenging requirements the radio access system must be highly spectrum efficient, able to support Quality of Service (QoS) and multi-hop capable.

The International Telecommunications Union–Radiocommunications sector (ITU-R) Resolution WRC-03 951 "Options to improve the international spectrum regulatory framework" states (under c.): "there is a keen interest in the rational, efficient and economic use of spectrum". Thus, spectral efficiency is a prerequisite for a B3G system to become a member of

IMT-Advanced systems and get access to the respective spectrum expected to be allocated by WRC'07.

B3G systems' air interfaces will be packet based, different from its predecessors and will be able to support QoS by differentiation and prioritisation of packets originating from different sessions, competing for radio transmission. With packet based systems, monitoring and controlling interference will be more important since interference might result in severe degradation of link quality.

Multi-hop communication is now accepted able to either improve capacity or coverage in cellular broadband networks [2]. Besides the WINNER project that is developing RECs, the Institute of Electrical and Electronics Engineers (IEEE), recently, launched a new Task Group 802.16j focussing on mobile multi-hop relaying to be integrated into cellular mobile systems like IEEE 802.16e (WiMAX) [3].

Most MAC protocols in use today are not able to support QoS sufficiently well, perform badly when being applied for multi-hop communication and tend to consume increased overhead percentage when increasing the link data rate. In the following an existent MAC protocol is improved to be able to meet all the needs of a B3G mobile radio network mentioned above.

Chapter 2 summarizes the requirements on MAC protocols for B3G systems whilst current MAC protocols and their properties are being revisited concerning the requirements in Chap. 3. The Frame Descriptor Table (FDT) concept combining the strengths of current MAC protocols is presented in Chap. 4. The concept is being analyzed and simulated and the results are presented and discussed in Chap. 5. Conclusions are given in Chap. 6.

2 Requirements on a B3G MAC Protocol

In wireless systems the MAC protocol is the key function deciding to what extent a system is able to support QoS requirements of the services offered. Using channel state information it allocates the radio channel in TDMA mode to the stations competing for transmission either under central or decentral control such that their QoS requirements are met. A number of MAC protocols have been standardized, each having its pros and cons, but each determining, substantially, the spectrum efficiency and level of QoS a system is able to support.

In the following we summarize requirements of B3G systems on the MAC protocol taking into account the vision of the Next Generation Mobile Networks initiative [4].

1. Future mobile broadband networks will be *packet based*. Besides packet voice, an increasing amount of data traffic is expected requiring very high data rate per session. Real-time support is a must for some classes of data services related to video communication.

2. *Low power consumption* is a severe concern, since most mobile devices are battery operated. The amount of electrical energy that can be stored in a battery is limited by its size. Since mobile devices are mostly designed as small as possible, their battery size is limited. All the transceiver and processor components of a mobile device must consume as little power as possible. Enabling a device to switch off its transceiver unit to sleep mode whenever possible, the MAC protocol can contribute a lot to save power.

3. *Quality of Service:* Transmission of data not only with high rate but also within rigid delay bounds is a must for some real time services such as video conference calls and similar. To enable differentiation between service classes' QoS requirements, and keep the radio interference of a link below some threshold needed to keep a given service error rate, the MAC protocol must be able to reserve radio resources in advance to transmit packets in time according to the service requirements.

4. *Multi-hop operation* introduced to broadband cellular networks based on Fixed Relay Nodes (FRN) is a new technology first proposed in [5] for a WiMAX like system. It is useful to either increase the cell capacity and minimize the transmit power (and interference) when deploying FRNs inside the cell area covered by a Base Station (BS), or to increase coverage range (thereby reducing cabling costs) by deploying FRNs outside the cell area connecting FRNs to the BS with gain antennas. FRNs may also be used to serve areas shadowed from the BS reducing the percentage of non-covered area in a cell. Since FRNs apply decode-and-forwarding of packets in the MAC layer, improvements to the protocol stack might be neccessary [2,6,7].

5. *Spectral efficiency* characterizes a wireless system by the amount of data transmitted per bandwidth unit. Beside many physical layer related parameters, spectral efficiency is substantially affected by the signalling overhead consumed in protocol layers 2 and 3 of the radio system: Radio channel capacity used up to transmit signalling data cannot be used to transmit user data. It is clear that the channel capacity consumed by a MAC protocol to reserve the channel for transmitting a packet should be small compared to the capacity needed to transmit a packet.

3 Potentials and Limitations of State-of-the-Art MAC Protocols

In the following, state-of-the-art MAC protocols will be assessed with respect to their potentials and limitations to be used in packet based wireless broadband systems.

There are many ways to categorize MAC protocols. Our focus is on the efficiency properties of reservation based MAC protocols, clustered into three categories:

- Single packet oriented channel reservation
- Multiple packets transmission supporting (frame based) channel reservation
- Stream data oriented reservation by means of TDMA channel

that differ in the duration of the time interval for which the channel is being reserved per successful access operation. Since all three MAC protocol categories have their strengths and weaknesses, most standardized MAC protocols search to combine and use the strengths only and avoid the weaknesses. The following gives examples of each category.

3.1 Single packet oriented channel reservation

This category of MAC protocols performs channel reservation for a single data packet only and packets belonging to the same source file are being transmitted asynchronously to each other. Thus, on top of an enhanced physical layer (PHY), with improved link bit rates, the overhead percentage will increase dramatically. The IEEE 802.11 MAC protocol [8] is an example. After successful access, the channel is used to transmit one user data packet. (RTS/CTS handshake is an option for channel reservation, again, reserving the channel to transmit one packet, only).

An advantage of this category of MAC protocols is that it can operate based on both, central or de-central control, without care for other transmission attempts occurring competitively.

Disadvantages are the poor scalability with an increasing collision probability of reservation attempts when the number of active stations is increased [9]. Accordingly, the data rate share of a station with increased network load resulting from many competing stations approaches zero and the network capacity substantially depends on the number of active stations [5]. MAC protocols reserving the channel per packet are known to perform badly under multi-hop operation [10] and tend to be unfair and unable to support QoS. To support QoS, a MAC protocol must be able to fairly share the channel among the competing stations and to guarantee transmission of some class of packets within a maximum delay time. Contention based MAC protocols are weak in that aspect. Polling based protocols like IEEE 802.15.1 (Bluetooth) are much better suited in that aspect, however, a central control is necessary and the number of stations participating in a system must be limited to result in spectral efficiency.

3.2 Multiple Packet Transmission Supporting (Frame Based) Channel Reservation

With this category of MAC protocols the radio channel is reserved in advance for transmission of multiple packets that may belong to different communication relationships. A periodic frame of fixed duration controlled by a central station (BS) is used to organize the reservation and transmission of multiple packets in either direction, up- or downlink in a frame cycle. Rereservation, usually, is on a per frame basis. Example systems using frame based packet transmission are:

1. HiperLAN/2 [11]
2. IEEE 802.11e for QoS supporting WLAN [12]
3. IEEE 802.15.3 for Ultra Wide band communication on OFDM basis [13]
4. IEEE 802.16a/e (WiMAX) WMAN to connect fixed/mobile stations to the BS in point-to-multipoint mode of operation [3,14]

Compared to MAC protocols based on reservation per packet, the amount of overhead spent per packet is reduced in frame based protocols, resulting in much higher capacity [5]. Thus, with higher link bit rates, this category of MAC protocols will benefit from this way of sharing part of the reservation overhead. Since there is also some individual overhead per packet, the total overhead will grow, but much less than with single packet oriented channel reservation. Frame based protocols offer great flexibility and enable fast adaptation of scheduled resources to changing demand. Compared to other reservation schemes the power consumption of the mobile device is low as it has to switch on its transceiver unit only for receiving the broadcast, which contains an announcement of all assigned resources within the current MAC frame, and when receiving or transmitting data. The rest of the frame it may remain switched off. This category of MAC protocols can differentiate service classes and schedule data according to their throughput and delay requirements as required for real-time services.

The frame structure added to IEEE 802.11 to become 802.11e, able to support QoS leads to a system with central control, with a much better performance than 802.11. Multi-hop operation and ad-hoc networking can be supported by a frame based MAC protocol, too, still able to provide QoS support, as proven for HiperLAN/2 Home Environment Extension [15]. WiMAX has a MAC protocol similar to HiperLAN/2, with similar protocol related performance.

3.3 Stream Data Oriented Reservation by Means of TDMA Channel

With the third category of MAC protocols a TDMA channel is reserved for the whole transmit duration of a data stream and the signalling overhead minimized by this. The ratio of signalling to user data is especially favourable for connections that, once established, are used for a long time. This can be exploited e.g. in multi-hop operations. Here, connections multiplexing the traffic of several other terminals can be established. This way of resource allocation is especially well suited to predict the future use of a channel in terms of interference produced in a system. One user reserves the channel for a long duration. This makes it easier to take into account the interference for other potential users. Protocols establishing TDMA channels will have a favourable ratio of resources used for connection setup to resources used for user data transmission, even under higher link bit rates since the reservation overhead is incurred per connection, not per packet. Any packet transmitted in multiplex is not causing any overhead at all.

Standards like GSM/GPRS [17] or DECT [16,17] are examples. With GPRS TDMA channel establishment is under central control of the BS, whilst with the DECT system the mobile station may suggest a channel and respective TDMA slot under de-central control. Another fully de-centrally controlled TDMA channel based MAC protocol is known from MDCF [18]. Like the frame based reservation scheme, this way of reserving the resources allows for support of QoS. Particularly with regard to multi-hop operations it shows very good performance [18].

4 Frame Descriptor Table Concept

The advantages of the two last mentioned categories of MAC protocols (cmp. Sect. 3.2,3.3), namely low overhead with long lasting connections as well as flexibility and low overhead with fast changing connections, can be combined by the use of the Frame Descriptor Table concept, which has been introduced in [19]. Here we only briefly describe the protocol that makes use of the FDT concept as a basis for understanding the performance evaluation results presented in Chap. 5. Additionally, we shortly wrap up the FDT concept in general.

4.1 Example B3G MAC Protocol

To introduce the FDT concept, we assume a frame based MAC protocol performing channel allocation in the time domain. The extension of the concept to a system comprising Frequency Division Multiple Access (FDMA) or Code Division Multiple Access (CDMA) [16] is straightforward. The MAC protocol is assumed to operate under central control of a BS. A frame is composed of a broadcast, a downlink (DL), an uplink (UL), and a random access phase (see Fig. 1). During the broadcast phase the BS sends out at least a Broadcast Channel (BCH) and a table of contents of the current frame in the Frame Channel (FCH). Inside the BCH information about the controlling terminal, the length of the FCH, and other information irrelevant in the following discussion is transferred. The FCH carries Information Elements (IE) each of which describes for a logical connection the transmissions slot position and length in the following UL and DL phases and carries the sender as well as receiver addresses. During the DL and UL phases user data and control information are sent from the BS to the User Terminals (UT) and vice versa.

One part of the UL phase serves for contention based random access via the Random Channel (RCH) comprising a number of slots specified in the BCH. The RCH is primarily used for association of UTs to the BS.

The FDT concept works for different frame layouts as well.

4.2 General FDT Description

The Frame Descriptor (FD) is an element with an unique ID, containing IEs that describe the frame layout, i.e. the contents of the UL and DL phases. It differs from an FCH in that it is not transmitted every frame, but only in certain time intervals. Each UT maintains an FDT

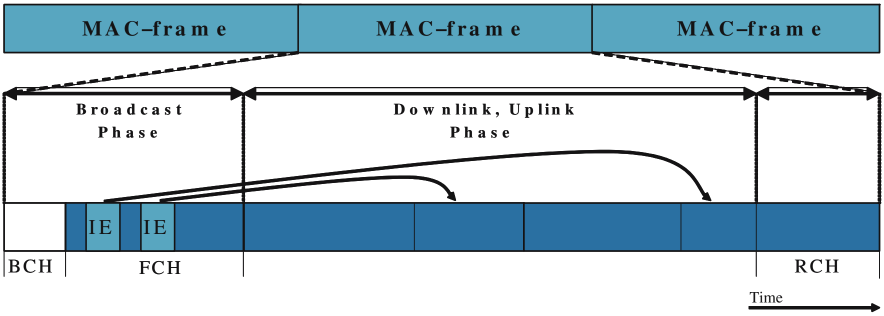


Fig. 1 Basic medium access control frame structure

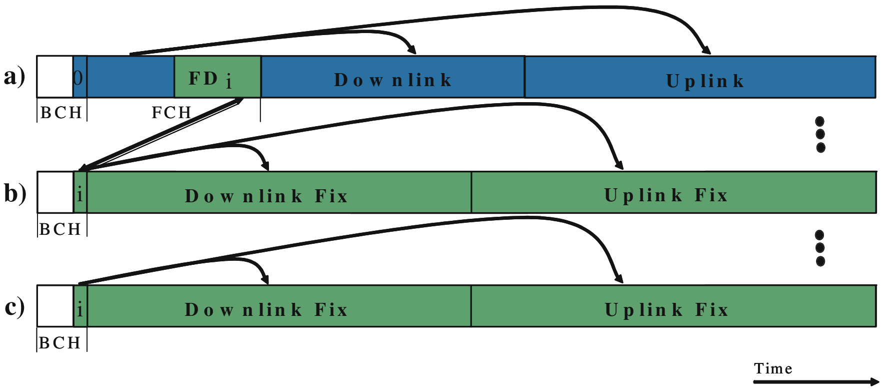


Fig. 2 Frame descriptor describing a static frame

where it stores all received FDs indexed by its ID. By means of the ID an FD can always be referred to by the BS. UTs can look up the content of the FD by searching their FDT for the respective ID. If a particular service has some periodicity in packet transmission (e.g. VoIP), the BS can adapt to this by referring to two or more FDs in an alternating fashion.

The main advantage of the FDT concept is a reduction of signalling overhead contained in the frame based MAC protocol. The description of the frame layout is source coded by representing it in the form of short IDs. In the following it is assumed that the ID of the FD used during transmission of a certain frame is included in the BCH. For ease of understanding of the FDT concept, two examples of its application are presented in the following:

Example 1: The simplest way of using an FD is the description of a static frame. There, the FCH is substituted by an ID specifying an FD, see Fig. 2. The FD that is referenced by the ID must be broadcast to the UTs beforehand.

The BCH carries a field serving to broadcast the ID of the FD describing the current frame. If a new FD_i is introduced by the BS, it sets the identifier in the BCH field 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) that must be stored in the FDT of each UT. Whenever the BS wants to reuse this FD to describe the layout of a current frame, it announces the ID (i) in the BCH as illustrated in Fig. 2b,c. Simulation results presenting the capacity gain by reducing the frame overhead by using FDTs in that way are contained in [20].

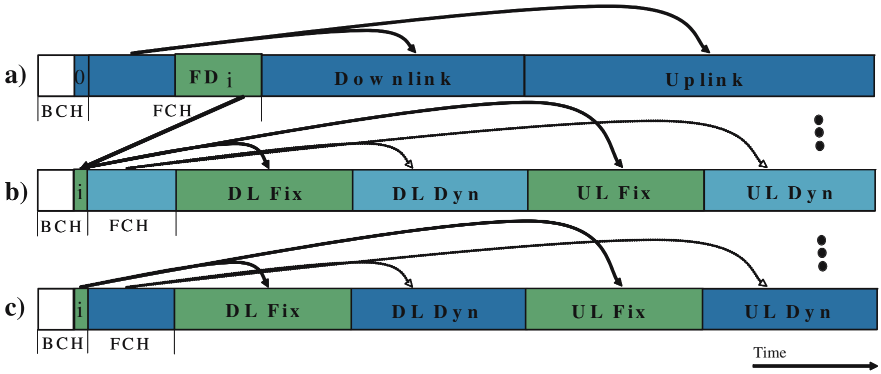


Fig. 3 Description of fixed and dynamic portions

Example 2: A connection might need only few resources and rarely. FDT based reservation of channel slots for a long time duration would then be very inefficient. To cover this needs, a dynamic portion *DL Dyn/UL Dyn* is included to the frame, as shown in Fig. 3b. The FD describes the fixed portions of UL and DL and the related information is transmitted only once (cp. Fig. 3a). The dynamic portions of UL and DL phases are described in the FCH. As visible from Fig. 3b,c, the content of the dynamic portion of the frame are changing while the fixed parts correspond to the description of the FD_i. The improvement of throughput and delay performance by adding dynamic parts is discussed in [21].

4.3 Frame Descriptor Tables in Multi-hop Networks

As explained above FDTs allow to reduce overhead by decreasing the amount of signalling. When applying frame based MAC protocols for multi-hop operation, e.g., in RECs [2,7] overhead reduction is even more important, since signalling for channel access control must be performed per hop and overhead grows with increased number of hops. FDTs may keep the amount of signalling overhead in RECs small, e.g., when fixed or partly fixed connections are used for data relaying.

In a REC there is one BS serving several UTs and at least one FRN. The FRN is seen as a UT by the BS and as a BS by its associated Remote User Terminals (RUT). The DL data to or UL data from the RUT is multiplexed to one single TDMA channel connecting FRN and BS. That channel can be expected to have a more or less fixed capacity-over-time requirement. Instead of specifying a long standing, slow its capacity changing channel in every frame anew, it may be specified by an FD, saving bandwidth assigned to transmit signalling messages and freeing capacity to serve UTs associated single-hop to the BS. Fixed TDMA channel allocation on the UL may, in addition, save messages otherwise needed to signal resource requests by an UT to be processed by the BS.

5 Performance Evaluation

After presenting the multi-hop scenario studied, where the traffic performance is evaluated, the results gained from analytical calculation and event driven simulation using FDTs are discussed.

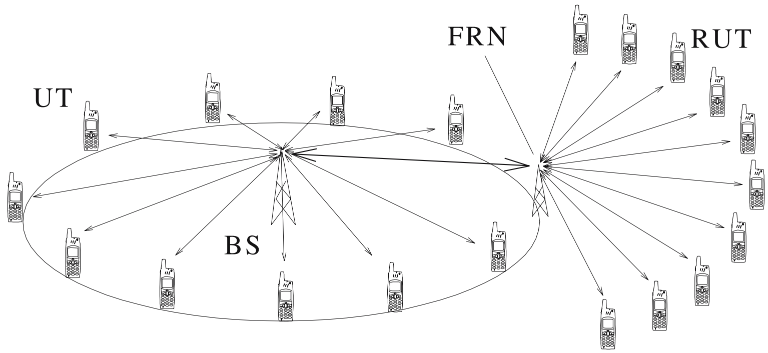


Fig. 4 Multi-hop scenario

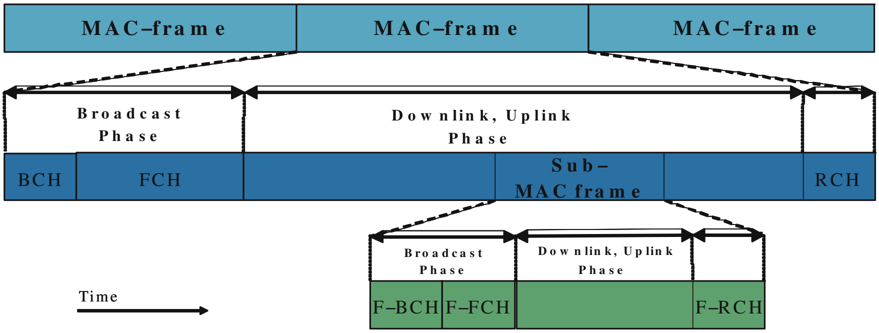


Fig. 5 Frame-in-frame multi-hop concept

The scenario used for analysis of the FDT concept is shown in Fig. 4. It comprises one BS, 20 UTs and one FRN that is non-mobile, at a fixed position. About ten UTs are attached directly to the BS each having one UL and one DL connection and 10 RUTs are attached to the FRN, contributing the same load as the UTs in the cell served by the BS. On the first hop between BS and FRN all downlink data targeted to an RUT, and vice versa, are multiplexed to one TDMA channel.

5.1 Analysis of Potential Savings in Signalling Overhead

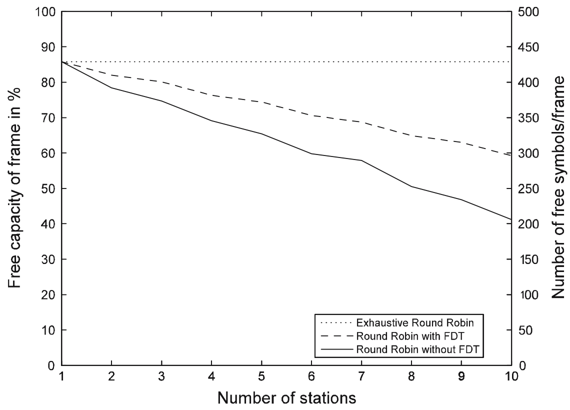
The amount of signalling data required for a MAC frame based protocol without FDT is compared to that when using the FDT concept. The following analysis is based on the one presented in [6,22] and assumes application of the frame-in-frame concept to serve multi-hop links, using data structures and parameters as specified in [11,23] (see Fig. 5).

Accordingly, for the second hop, a complete sub-MAC frame, containing broadcast, UL and DL phases is inserted, one per FRN, into the generic MAC frame controlled by the BS. The generic MAC frame is used for communication between BS and FRN, which in turn applies the sub-MAC frame to control information exchange between FRN and RUT.

A BS may reach n_{UT} UTs and n_{FRN} FRNs on the first hop. An FRN serves n_{RUT} RUTs on the second hop. Thus, the total number of connections to RUTs is:

$$n_{RUT-ges} = n_{RUT} \cdot n_{FRN} \tag{1}$$

Fig. 6 Free symbols in a MAC frame in the multi-hop scenario



Each UT or RUT has n_{bi-con} bidirectional connections, that need resources scheduled for in each MAC frame. FRNs are assumed not to generate data traffic on their own. Assuming all connections are served within one MAC frame according to an exhaustive Round Robin (EXRR) scheduler the number of symbols needed for signalling is:

$$\begin{aligned} L_{Orga} = & L_{BCH} + L_{FCH} + L_{ACH} + L_{RCH} + L_{DL} + L_{UL} + L_{TTA} \\ & + L_{F-BCH} + L_{F-FCH} + L_{F-ACH} + L_{F-RCH} + L_{F-DL} \\ & + L_{F-UL} + L_{F-TTA} \end{aligned} \tag{2}$$

L_{Orga} is given in OFDM symbols needed to carry the information contained in the respective control channels, e.g., L_{ACH} is the number of symbols used by the ACH [11]. L_{TTA} represents the time equivalence to switch the transceiver from transmit to receive or back. Index F refers to the sub-MAC frame.

Since a MAC frame carries a total of 500 OFDM symbols (cp. [11]), in a two-hop scenario the total number of symbols available for user data transfer is

$$L_{Payload} = 500 - L_{Orga} \tag{3}$$

Figure 6 shows the amount of symbols per MAC frame, free for user data transmission on the first and second hop, versus the number of stations present in the multi-hop scenario. The number of stations ($n_{Station} = n_{UT} + n_{RUT}$) with $n_{UT} = \lceil n_{Station}/2 \rceil$ and $n_{RUT} = \lfloor n_{Station}/2 \rfloor$. A new set of IEs is needed for every new three stations and related TDMA channels, resulting in the irregularities of the curves representing the number of free symbols under Round Robin (RR) scheduling without using FDTs.

Under EXRR scheduling it is assumed that each UT has sufficient data in its output queue to fill a whole frame so that each MAC frame carries one bidirectional connection, only serving one UT attached to the BS and another one for the FRN, and the next MAC frame serves the next UT active in the cell. This results in a minimum overhead of ~14% of the frame representing the lower limit. As visible from Fig. 6, the overhead is independent of the number of stations in a cell. It is not very likely that stations will always have ready data to fill a MAC frame by one station only. Therefore, the results shown for RR scheduling give a more realistic picture.

Under Round Robin all UTs are served with equal capacity share of the channel within each frame so that with increased number of stations the number of connections increases that are scheduled in a MAC frame, resulting in increased overhead. Thus, scheduling 10 stations uses up almost 60% of the frame by signalling overhead consumed by IEs transmitted in the FCH, as well as by PHY overhead introduced by preambles preceding every DL and UL transmission.

When FDT is applied under RR scheduling, the overhead is reduced significantly, e.g., when serving 10 stations, the overhead reduction is about 20%. As mentioned above, FDT saves the signalling messages transmitted in the FCH when operating without FDT, which is most of the MAC overhead. The preambles related overhead in the PHY depends on the number of transmissions scheduled in a frame and is the reason for the slow but steady slope of the curve shown.

5.2 Simulation Results

In the following we apply event driven stochastic simulation to present the contribution of FDTs to reduce overhead. The relative capacity gain is shown, since the absolute value is not so important. For that purpose, the traffic load is normalized to the maximum data rate according to the modulation and coding scheme of the radio link used. The capacity that is available for user data transfer is given as the percentage of the MAC frame capacity. The delay results shown are for 9 Mbps PHY data rate. All the simulation results presented in the following are obtained assuming an error free radio channel. The traffic load comes from a Poisson source generating 48 byte packets. The size of the MAC queue storing packets coming from higher layers in each terminal is 1000 packets. All parameters of the MAC and PHY are chosen as specified in [11] and [23]. Different from the analysis presented before, multi-hop operation is simulated using alternating MAC frames to serve either the first hop around the BS or the second hop around the FRN, with a frame length of 2 ms. Thus the frame repetition period for both, BS and FRN is 4 ms.

To be able to analyze the performance gain from the FDT concept, system throughput and delay is determined in the scenario introduced beforehand for an error free channel for both, with and without using the FDT concept.

5.2.1 Without FDT Concept

Under RR scheduling without using FDTs, the capacity of the MAC frame used for user data equivalent to the system throughput vs. normalized traffic load on local links, established between BS and UTs is shown in Fig. 7 and for normalized traffic load on the relay link, established between BS and FRN, in Fig. 8.

It is visible in Fig. 7 that the system throughput decreases with increased load. The reason for that is that under low load generated by the UTs local to the BS, most of the throughput is generated by the relay link between BS and FRN that is heavily overloaded. With increased load of the local UTs more competing connections have to be scheduled. concurrently, per MAC frame thereby increasing overhead. Thus the overall throughput of the system is reduced.

The fact that the relay link is in overload becomes clear from Fig. 8, where the throughput is plotted vs. the normalized load on the relay link for various load on the local links. The throughput does not change when increasing the load on the relay link, since it is in overload, already.

This is apparent from Fig. 9 where the DL end-to-end delay for the link between BS and RUT is shown. The delay of this two-hop link solely depends on the load generated by the local UTs and is in the order of one second. This also confirms the overload condition of this link.

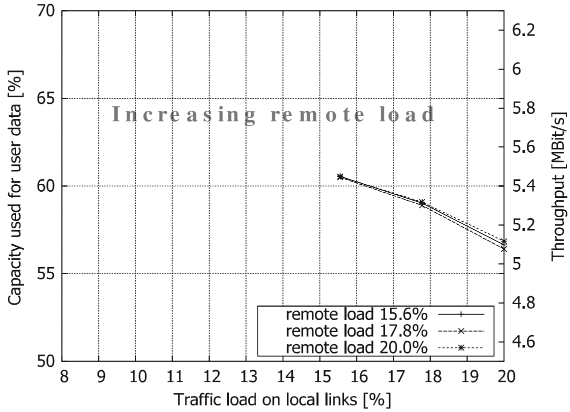


Fig. 7 Throughput versus normalized traffic load on local links whithout using FDTs

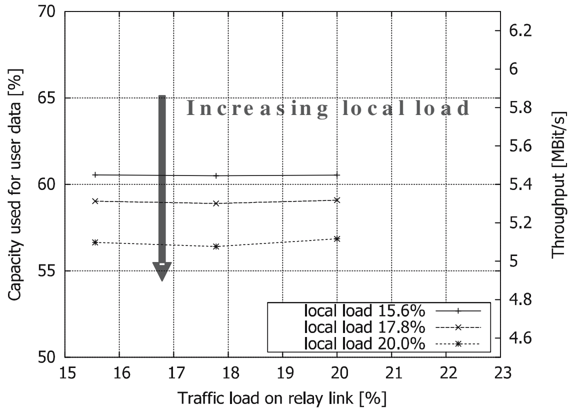


Fig. 8 Throughput versus normalized traffic load on relay link whithout using FDTs

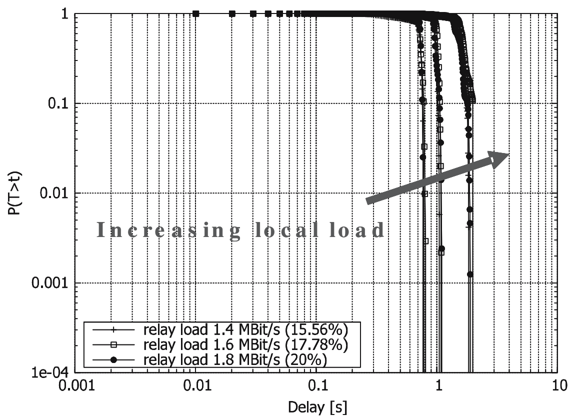


Fig. 9 Downlink end-to-end delay without using FDT

Fig. 10 Throughput versus normalized traffic load on local links using FDTs

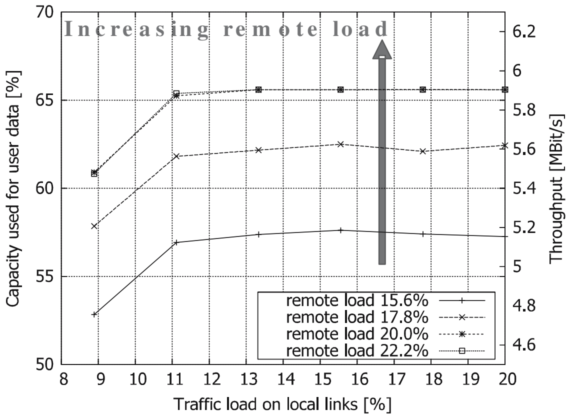
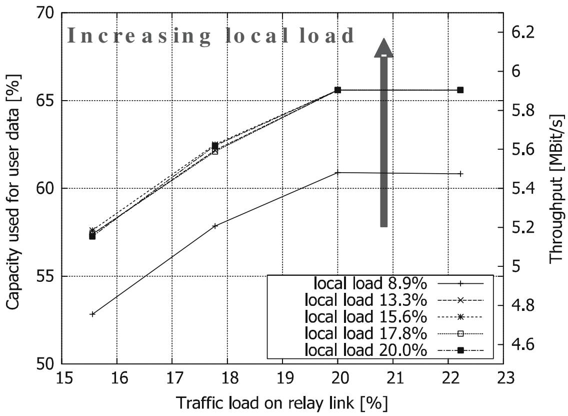


Fig. 11 Throughput versus normalized traffic load on relay link using FDTs



5.2.2 With FDT Concept

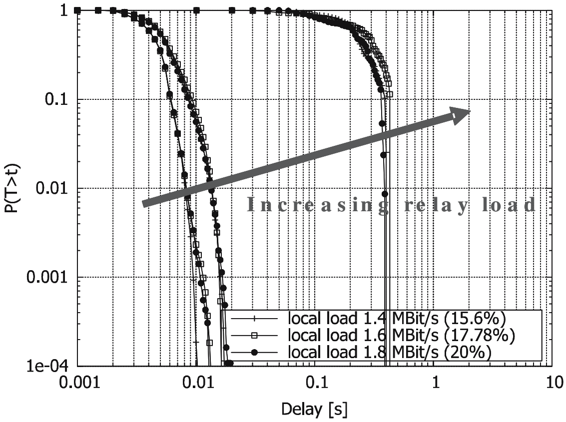
Without using FDTs under RR scheduling, the relay link is in overload condition. When using the FDT concept, a channel of fixed capacity can be established between BS and FRN ensuring that this link obtains a certain capacity not depending on the load imposed by the local UTs. In addition, the capacity consumed for signalling during the broadcast phase is reduced, too.

The simulation results presented in the following, have been generated with half of the frame reserved for channel to link BS and FRN, specified by an FDT. According to the results without FDT the throughput vs normalized traffic load on local links respectively the relay link are shown in Fig. 10 and Fig. 11.

In Fig. 10, the links between the BS and the local UTs and vice versa reach overload at 11%, earlier, since only half of a frame is available to carry their load. The other half is reserved for the link between BS and FRN. It is visible that the system throughput is increased by 5% when using FDTs (from 60% to 65%).

In Fig. 11 it becomes visible that when using FDTs the throughput goes into saturation only at a much higher traffic load (about 20%) on the relay link. In contrast, without using FDT (see Fig. 8) saturation is reached already below 16%. This applies in general, independent of the load by local UTs.

Fig. 12 Downlink end-to-end delay with frame descriptor tables



The DL end-to-end delay for the link between BS and RUT with FDT is shown in Fig. 12. It does not depend on the traffic load of the local UTs anymore, but only on the load on the relay link. This can be expected, since the same amount of resources are provided for the relay link, no matter how much traffic load there is on the links to local UTs. Moreover it can be seen that the delay compared to Fig. 9 is reduced, substantially.

6 Conclusions

After revisiting potentials and limitations of current MAC protocols for use in B3G mobile radio systems, key requirements on future MAC protocols have been identified. The FDT concept is introduced as a candidate solution covering some of the requirements named. It appears well suited to be used with MAC frame based protocols, in particular, in multi-hop scenarios to reduce the signalling overhead. Simulation results show the FDT concept able to increase throughput and reduce end-to-end delay.

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Alexander Federlin studied Electrical Engineering at the RWTH Aachen University where he received his diploma in 2005. During his studies he already gained experience in the area of protocols working for the Chair for Communication Networks as a student worker. Here he also finished his diploma thesis on the subject of efficient MAC Protocols for the next generation of mobile radio communication. He continued his work in this field before joining his current employer Ericsson GmbH as a Solution Integrator in October 2005.

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