ON THE MINIMIZATION OF OVERHEAD IN RELAY ENHANCED MOBILE RADIO NETWORKS

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ABSTRACT

In this paper, the Frame Descriptor Table (FDT) concept, invented to enable MAC protocols applying a frame based reservation strategy to cope with the requirements of 4G mobile radio networks, is evaluated concerning its efficiency in Relay Enhanced Cell (REC) scenarios. MAC protocols for 4G mobile radio networks, also known as IMT-Advanced systems, will operate on high data rate channels resulting in short packet transmission duration. With the help of the FDT concept the resulting increased overhead can be reduced and thus the MAC protocol is able to work in a highly efficient way. To improve the multi-hop communication applied in mobile radio systems with RECs the minimization of overhead is of particular importance. Based on analytical calculations in this paper it is shown that FDTs are very well suited to minimize the overhead in RECs and therefore are a means to enable MAC protocols meeting the demands expected from 4G mobile radio networks.

I. INTRODUCTION

A 4G radio access system is currently under development within the European Union Framework Programme 6 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 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 4G system to become a member of IMT-Advanced systems and get access to the respective spectrum expected to be allocated by WRC'07.

4G systems' air interfaces will be packet based, different from its predecessors and will be able to support QoS by differentiation and prioritization 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 [5]. Besides the WINNER project that is developing RECs, the Institute of Electrical and Electronics Engineers (IEEE), recently, launched a new Task Group 802.16j focusing on mobile multi-hop relaying to be integrated into cellular mobile systems like IEEE 802.16e (WiMAX) [14]

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 the FDT concept, invented to enable MAC protocols applying a frame based reservation strategy to cope with the requirements of 4G mobile radio networks is evaluated concerning its efficiency in REC scenarios.

The remainder of this paper is organized as follows: Section II surveys existing MAC protocols concerning their potentials to become a candidate for 4G mobile radio networks. The Frame Descriptor Table (FDT) concept combining the strengths of existing MAC protocols is presented in section III. For the different REC scenarios presented in section IV, based on analytical calculations, the concept is evaluated in section V. Conclusions are given in section VI.

II. GENERAL

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 to the stations competing for transmission either under central or decentral control such that their QoS requirements are met.

Beside other information the control signaling needed for the allocation process is regarded as overhead as the resources consumed for this purpose cannot be assigned to the stations.

The overhead percentage, i.e. the percentage of control signaling to user data, measures the efficiency of a MAC protocol and strongly influences its performance. Typically the control signaling is done with the lowest modulation and coding scheme (MCS) and therefore with the lowest link data rate resulting in the need for many resources compared to the user data, which, depending on the channel state, are likely to be transmitted with a higher MCS and therefore with a higher data rate, consuming few resources only.

Enhanced frequency bands supplemented by an advanced, on enhanced OFDM and multiple antenna technologies based physical layer (PHY) of 4G systems, foreseen for most systems currently being under way, will increase the maximum possible data rates offered on top of the PHY, tremendously.

Thus the amount of resources consumed by the user data is reduced whereas the resources necessary for control signaling will keep constant without any design changes.

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To enable the envisaged high spectral efficiency and data rates while supporting minimized delays compared to nowadays mobile radio networks also on top of the MAC layer, the MAC protocol needs to be designed in a way that the overhead percentage is kept to a minimum.

Existing, packet based MAC protocols can cope differently with the before mentioned requirements for different deployments respectively applied scenarios:

Legacy IEEE 802.11 [7], basing on CSMA/CA shows its strength in its simplicity and for an appropriate number of associated stations also in an adequate performance. But with an increased number of stations, in the worst case, the link data rate provided by the PHY is consumed totally by control signaling (overhead) of the MAC protocol. Performing channel reservation for a single data packet only on top of an enhanced PHY, with improved link bit rates, the overhead percentage will increase dramatically. Moreover the protocol does not allow supporting QoS.

On this account the standardization of QoS supporting IEEE 802.11e [9] was initiated, which, alike IEEE 802.15.3 for Ultra Wide band communication on OFDM basis [10] as well as IEEE 802.16a/e [11], [14] (WiMAX) to connect fixed/mobile stations to the base station (BS) in point-to-multipoint mode of operation are working on a frame based reservation developed in the framework of HiperLAN/2 [8] standardization. A periodic frame of fixed duration controlled by a central station (BS) is used to organize the reservation and transmission of multiple packets in direction, up- or downlink in a frame cycle. Re-reservation, usually, is on a per frame basis. Therefore the available resources can be allocated to the associated stations in a highly dynamic manner. By applying adequate scheduling schemes this is also possible for a high number of stations at a reasonable amount of overhead. Since most of the reservation overhead is not spent per packet an increased link bit rate will not increase the overhead percentage as in the before mentioned system. The feasibility of layer 2 relaying with frame based reservation has been shown in [3],[4],[5],[12].

Particularly with respect to QoS supporting multi-hop communication, MAC protocols reserving periodic time slots (TDMA channels) behave advantageously. Since the information needed for the allocation of resources only has to be signaled once during flow setup, being valid for multiple packets, and moreover the packets of different applications can be multiplexed to one flow, the overhead in principle does not necessarily increase with an increasing number of stations. This beneficial behavior regarding the overhead is obtained at the expense of reduced dynamic in resource allocation.

III. Frame Descriptor Tables

The advantages of the two last mentioned categories of MAC protocols, 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 [1]. 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 section V. Additionally, we shortly wrap up the FDT concept in general.

A. *Example frame based reservation 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) [6] 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 Figure 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.

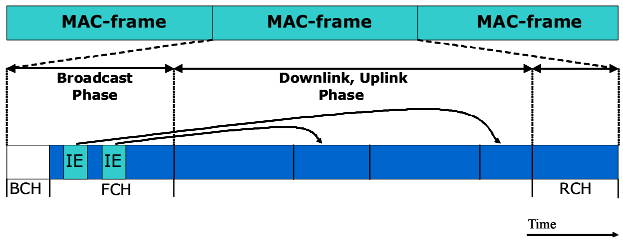

Figure 1: Basic medium access control frame structure

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.

B. *Frame Descriptor Table Concept*

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 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 signaling 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, an example of its application is presented in the following:

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 Figure 2. The FD that is referenced by the ID must be broadcast to the UTs beforehand.

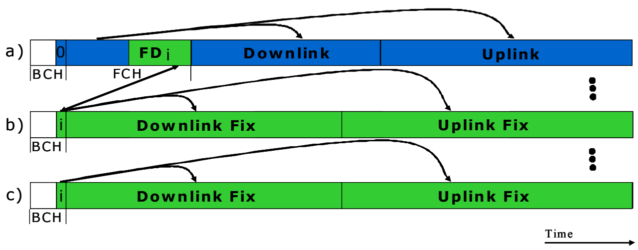

Figure 2: FDT concept with one FD describing a whole frame

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 Figure 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 Figure 2b, Figure 2c.

C. 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 [4], [5] overhead reduction is even more important, since signaling 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 relay node (RN). The RN is seen as a UT by the BS and as a BS by its associated UT. The DL data to or UL data from the UT associated to the RN is multiplexed to one single TDMA channel connecting RN 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 signaling 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.

IV. Evaluation Scenarios

To investigate the performance of the FDT concept in RECs we use the scenarios depicted in Figure 3. In each scenario up to 10 UTs are served, each with one up- and one downlink by one BS supported by a) 1 up to d) 4 RNs. When adding a UT it is associated to the BS/RN which has the least number of UTs already associated, prioritizing the BS.

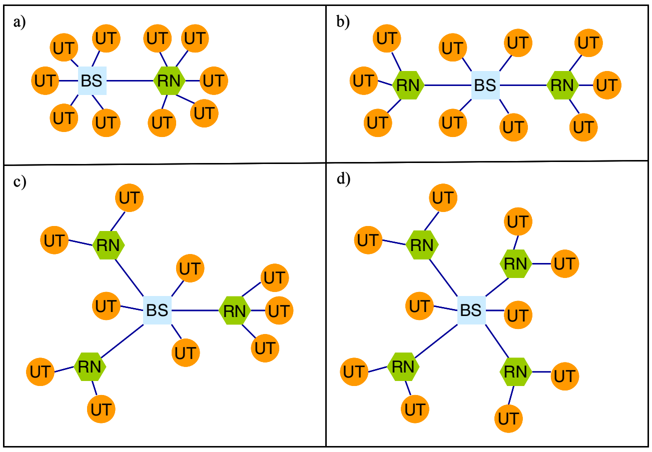

Figure 3: Evaluation Scenarios with 10 UT associated to 1 BS and a) 1RN, b) 2RN, c) 3 RN, d) 4 RN

V. Performance Evaluation

To evaluate the performance of the FDT concept in RECs in the following we analytically calculate the overhead originated by the PHY and the MAC layer, normalized to the overall available resources. From this the amount of resources available for transmission of user data can be derived. The resulting throughput depends on the MCS applied to those resources and is out of scope of this work. The analysis is based on the one presented in [3] and assumes application of the frame-in-frame concept (see [3]), establishing one sub-MAC frame per associated RN inside the frame controlled by the BS, to serve multi-hop links, using data structures and parameters as specified in [8], [13].

A. Variable Periodicity of FD Updates

In the first investigation performed within the scope of this work one FD is assumed to be 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 BS 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 periodicity for changing the FD is reasonably, investigations have been carried out with the results presented in Figure 4, which shows the overhead vs. total number of UTs scheduled per frame, depending on the periodicity of the FD updates in the scenario with 2 RN (comp Figure 3) when applying the FDT concept for all frames, BS controlled as well as RN controlled ones.

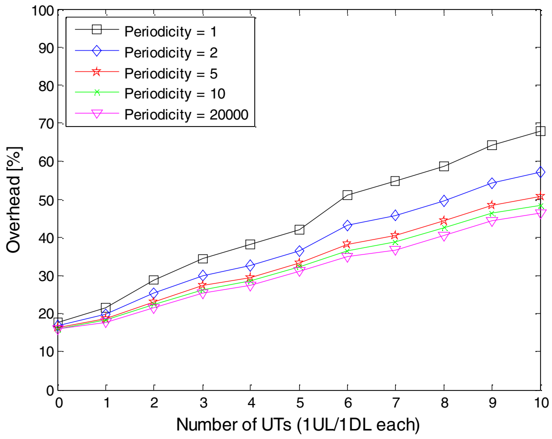

Figure 4: Overhead with FDTs vs. total number of UTs scheduled per frame depending on the periodicity of FD updates (2 RN)

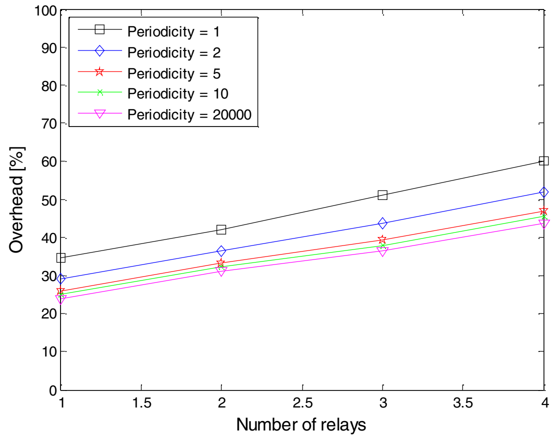

Figure 5: Overhead with FDTs vs. number of RNs depending on the periodicity of FD updates (5 UT)

When changing the FD in every frame (Periodicity = 1) the overhead increases most of all up to nearly 70 % when scheduling 10 UTs per frame. The run of the resulting overhead curve is identical to the result when not applying the FDT concept at all as there is no additional overhead introduced by the FDTs themselves.

The longer the time between two changes of an FD, the less signaling is needed. Thus, the overhead can be reduced by increasing the periodicity of FD changes. But another fact becomes apparent when examining Figure 4. The rate of gain in overhead is getting smaller with increasing periodicity of 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. Thus the highest investigated periodicity (Periodicity = 20000) converging at about 46% overhead can only reduce the overhead arising at a periodicity of 5 by about 5%.

With the results given in Figure 5 showing the overhead vs. number of RNs depending on the periodicity of the FD updates in a scenario with 5 UTs scheduled per frame when applying the FDT concept for all frames this phenomenon proves true also for different numbers of RNs.

On the basis of these results the periodicity for changing the FD is set to 5 frames for the upcoming investigations as this seems to be a reasonable tradeoff between flexibility in resource allocation and efficiency regarding the overhead.

B. *Performance of the FDT concept in REC*

The following investigations are serving the evaluation of the performance of the FDT concept in REC scenarios. Therefore the overhead originated when a BS, supported by 2-3 RN, serves up to 10 UTs (comp. Section II) is computed. The resulting overhead vs. the number of UTs scheduled per frame, applying Round Robin scheduling with/without FDTs is shown in Figure 6. Moreover the overhead without FDTs, resulting, when no respectively one UT is scheduled per frame, is given to ease readability.

The results for the case without FDTs, given in Figure 6a) show an overhead of about 10% for no UT increasing to about 12% for 1 UT and up to 40% for 10 UTs. It is visible that applying FDTs in the case of 10 UTs the overhead can be reduced about 18%. Moreover, also in the case of no UTscheduled per frame, the overhead is reduced as the resources to be allocated by the BS to serve the RN are incurred independent of the number of scheduled UTs and are allocated more efficiently with the help of FDTs.

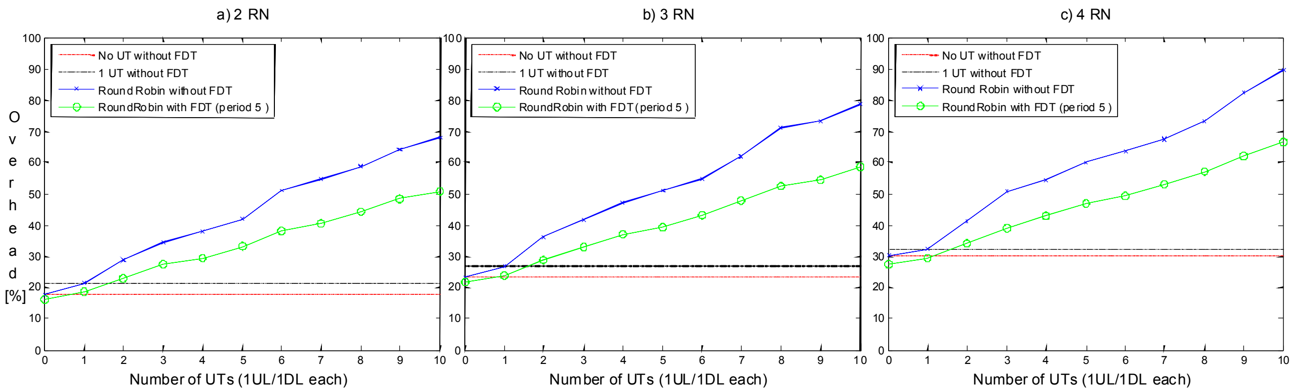

Figure 6: Overhead with/without FDTs vs. total number of UTs scheduled per frame with a) 2RN, b) 3RN, c) 4 RN

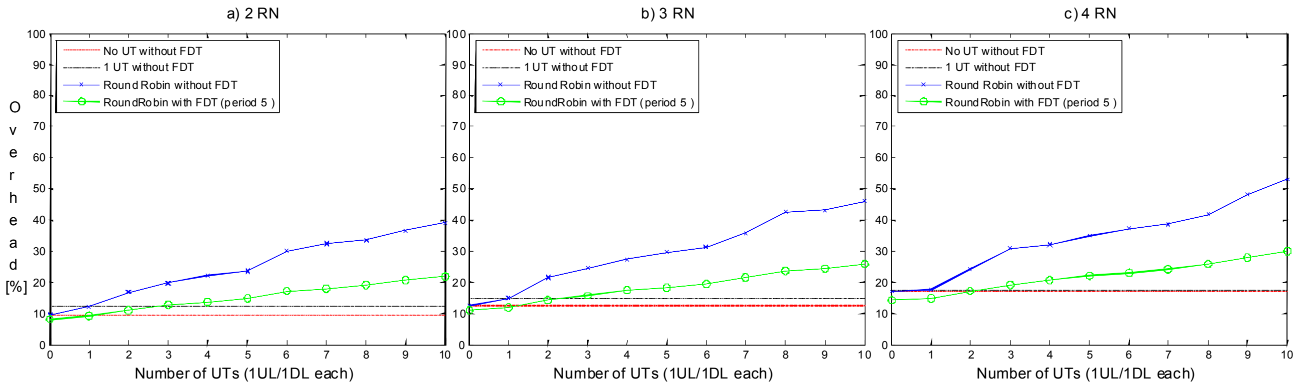

Figure 7: Pure MAC overhead with/without FDTs vs. total number of UTs scheduled per frame with a) 2RN, b) 3RN, c) 4 RN

The expected increase of this generic overhead when increasing the number of RNs in the scenario is visible from Figure 6 b) and c) giving the results for 3 respectively 4 RNs and amounts to 18% with 4 RN. Comparing the results for 10 UTs it is visible that the application of FDTs allows for a reduction of overhead of about 20% for 3 RN and for even more than 20% for 4 RNs.

Figure 7 shows the results for the same scenarios omitting the overhead introduced by the PHY, e.g. preambles. It is visible that the possible reductions of overhead are identical to the ones given in Figure 6 and from this it becomes clear that the reduction of overhead achieved with FDTs is only based on a more efficient MAC protocol. But on the other hand it can be reasoned that a more efficient PHY offers the possibility to even more enhance the efficiency of systems applying a frame based reservation strategy.

VI. CONCLUSIONS

After surveying existing MAC protocols concerning their potentials to become a candidate for 4G mobile radio networks the Frame Descriptor Table (FDT) concept combining the strengths of existing MAC protocols is presented. The main focus of this work is on the performance evaluation of the FDT concept, amongst others, invented for minimizing the overhead introduced by MAC protocols using a frame based resource reservation strategy, in REC scenarios. It turns out that the, with a rising number of deployed RNs, increasing amount of overhead, can be reduced significantly. Moreover this effect of reduction amplifies the more RNs are in the REC.

VII. ACKNOWLEDGEMENTS

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