Reduction of Signaling Overhead in Beyond 3G MAC-Protocols using Frame Descriptor Tables

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***Abstract* — This paper focuses on mitigating the amount of overhead arising from the control signaling of frame-based Medium Access Control-protocols. In the wireless world frame-based Medium Access Control-protocols with a centrally controlling entity have the inherent necessity to inform associated stations about the resources they have been scheduled. Most state-of-the-art protocols supporting Quality of Service perform the related signaling on a per-frame basis which leads to a very high dynamic in respect to the layout of the frame. When the control information is designed to describe the whole frame layout in each frame, this results in a high percentage of control data compared to user data to be transferred. As the possible dynamic of the frame layout potentially is not needed and rather it is favorable to keep the resources reserved for more than one frame this can result in a diminished need for signaling. This paper introduces the Frame Descriptor Table which enables the realization of a MAC-frame based protocol with reduced overhead regarding the control signaling.**

***Keywords* — Overhead reduction, MAC-protocol, Quality of Service, Multi-hop, IEEE 802.11e, IEEE 802.16a, HiperLAN/2**

I. Introduction

Within the EU FP6 project WINNER (Wireless World Initiative New Radio) [1] a B3G radio access system is under development. The new 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. Implementing the new air interface one important aspect is the need for a new and more efficient MAC-protocol.

In addition to the characteristics mentioned before, other user demands respectively technical requirements to fulfill these demands have to be taken into account during the design phase of the protocol.

The coexistence with existing radio interfaces must be possible. Moreover the MAC-protocol has to allow for ad hoc capability and low power consumption needs. The support of Quality of Service (QoS) in terms of, e.g., data rates and delay constraints is a high priority. But to reach the performance described above one important feature of the new radio access system which thus also has to be facilitated by the MAC-protocol is a very high spectral efficiency. Therefore the MAC-layer needs to support new technologies like multi-hop transmissions [2][3][4] and advanced antenna solutions, e.g. Multiple Input Multiple Output, Space Division Multiple Access [5]. One key method of the protocol is the reduction of control signaling to reduce the overhead, given as the ratio of transmitted user data per control data needed to realize the transmission.

The requirement for QoS support makes a frame based solution a very likely choice. Many MAC-protocols of already existing systems of the wireless world which incorporate this feature, e.g. 802.11e [6], 802.16a [7], HiperLAN/2 [8], as well as most activities in current research and development, e.g. the area of 802.11n, are working with a MAC-frame based solution.

These protocols with a centrally controlling entity have the inherent necessity to inform associated stations about the resources they have been scheduled. When the control information is designed to describe the whole frame layout in each frame, this results in a high percentage of control data compared to user data to be transferred. As the possible dynamic of the frame layout potentially is not needed and rather it is favorable to keep the resources reserved for more than one frame this can result in a diminished need for signaling. The Frame Descriptor Table (FDT) introduced in this paper enables the realization of a MAC-frame based protocol with reduced overhead regarding the control signaling.

The rest of this paper is structured in the following way. In section II a simplified MAC-protocol is presented, the characteristics of which can easily be mapped onto existing frame-based protocols. Surely these characteristics will be part of future MAC-protocols with a frame structure as basis of the resource allocation. Based on this MAC-protocol the general concept of FDT will be explained before different possibilities of applying it are stated in section III. The achievable improvements are highlighted in section IV before section V summarizes the findings.

II. General Description

The general idea of the concept of FDTs is the “coding” of control information to reduce the amount of data to be sent from terminal to terminal.

To ease the introduction of the new concept, in the following all explanations will assume a frame based MAC-protocol. 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.

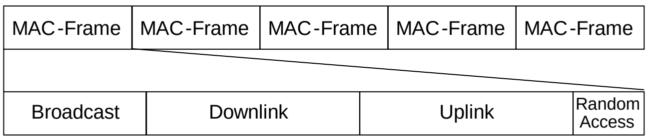

Figure 1. Basic MAC-frame structur

The available 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)) [5]. The adaptation of the concept to a system based on a combination of TDMA with Frequency Division Multiple Access (FDMA) [5] is straightforward.

It is assumed that the medium access is controlled by a master terminal. This master terminal should be able to transmit user data to associated slave terminals which on their part should be able to transmit user data to the master terminal.

The logical relation of such a data exchange is called a connection. In the simplest case one connection exists between a sender and a receiver. But it also could be possible to establish more than one connection. This, beside other things, enables the support of Quality of Service, as it allows for different treatment of the different connections, e.g., in terms of required error rate. A user data transfer between slave terminals is not considered for the sake of simplicity, but would not constrict the concept at all. This definition of tasks could easily be mapped onto cellular communication scenarios where the base station acts as master and the mobile stations can be seen as slave terminals. But just as well the ad-hoc peer to peer communication between mobile terminals could be realized in a way that one of the terminals takes over the master role while the other acts as slave.

The following frame layout is assumed. A frame is composed of a broadcast phase, a downlink (DL) phase, an uplink (UL) phase, and a phase for random access. During the broadcast phase the controlling master terminal sends out at least a beacon and a table of contents (TOC) for the following UL and DL phases.

Inside the beacon information about the controlling terminal, the length of the TOC, and other information irrelevant in this scope are transferred.

The TOC is used to describe all transmissions occurring in the DL and UL phases of the current frame. For each transmission among other things its orientation (DL/UL), the starting point, the length and the receiver are specified.

During the DL and UL phases user data and some 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. The random access phase is used for association of the slave terminals to the master terminal, for requesting resources for an established connection, and for setting up a new connection.

As mentioned before the concept of FDTs is able to work on different frame layouts and similar protocol behaviors as well. This simplified design solely has been chosen to ease the understanding of the following explanations.

Since every connection that is scheduled in a frame has to be described in the TOC, usually the overhead necessary to describe a frame grows with the number of connections scheduled in a frame.

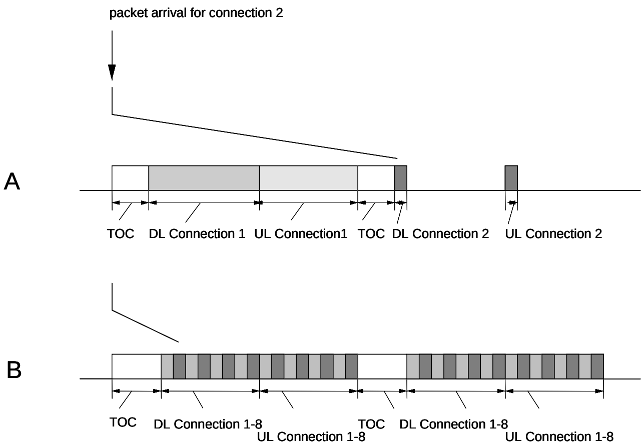

Figure 2. Possible delay constraints of Ex. Round Robin and Round Robin

One way to mitigate excessive overhead would be to schedule as few connections as possible in one frame. This scheduling method is known as Exhaustive Round Robin. If there is enough data in the queue of a connection, one connection could take up the whole frame. Applying EXRR has a severe drawback. Depending on the number of connections with traffic waiting in their queues the delay which can be achieved with this scheduling algorithm can become prohibitively high (see Figure 2).

To prevent unacceptable delays it may be necessary to allow numerous connections to be scheduled in a frame. This improves the achievable delay. Depending on the packet size used by the upper layers the delay may be reduced considerably because the response to a packet may arrive as soon as the next frame as opposed to a delay of several frames using EXRR (see Figure 2).

The concept of FDTs allows for such reduced delays in combination with a reduced overhead. The FDT has the same basic function as the TOC. It describes the contents of the UL and DL phase of a frame. It differs from a TOC in that it is not transmitted every frame, but only in certain intervals. Each FDT transmitted has an ID with which it can be referred to in the following frames for example within the beacon. Therefore it is easily possible to alternate between two or more FDTs if, e.g. there is a certain periodicity in the needs of some connections.

The main advantage of this concept is the resulting decrease in overhead. Changes in the layout of a frame can be coded by simply transmitting a number in the beacon.

III. Applications

There are several ways to employ the concept of FDTs. In the following sections some possibilities are outlined. The necessary random access phase is omitted for sake of brevity.

A. Description of a static frame

The most basic use of an FDT is the description of a whole static frame. In that case the TOC is substituted completely by specifying the identifier of an FDT. The referenced FDT has to be communicated to the slave terminals beforehand. This possibility of applying the FDT and the way to announce the FDT to the slave terminals is illustrated in Figure 3.

Inside the beacon a field is reserved for announcing the ID

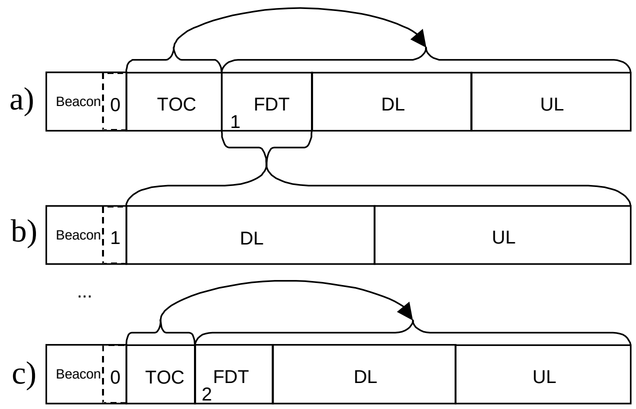

Figure 3. Static Frame

of the FDT which describes the current frame. If the value in this field is 0 (see Figure 3a)), no FDT but a TOC describing the current frame is expected. For the purpose of introducing a new FDT the master terminal sets the identifier in the beacon to 0. The following TOC (which is expected after receiving value 0 in the field of the FDT ID in the beacon) then describes the transmission of an FDT and possible DL and/or UL transmissions. The FDT which will be transmitted has a unique identifier. In this example it is chosen to be 1. This identifier can be used in subsequent frames to identify the FDT used for the description of the frame layout (see Figure 3b)). If the layout has to be changed, e.g. due to the setup of a new connection, the process is repeated (see Figure 3c)).

B. Description of a frame with dynamic portions

This method incorporates a dynamic portion into the frame.

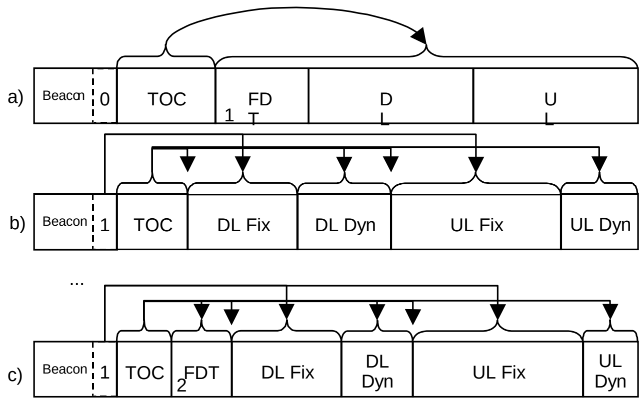

Figure 4. Description of Fixed and Dynamic Portions

There are cases in which a connection only needs few resources infrequently. Reservation of resources for a prolonged period of time would therefore be wasteful. To easily accommodate such needs without having to change the layout of the frame and having to transmit a new FDT, a dynamic portion is included in the frame.

A classification of connections would aid the process of determining where to schedule a new connection. If it is known a-priori that a given connection is needed very infrequently only, there should be a means to communicate this to the scheduler.

As shown in Figure 4b, the FDT 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 FDT given in the beacon.

In addition to these fixed portions, there are dynamic portions of UL and DL as well. In this mode, there always has to be a TOC in the frame. If there is data which is transmitted in the dynamic portion, these transmissions have to be described. But even if there is no data in the dynamic portion the empty part has to be described by the TOC. The empty part is necessary because the fixed portion cannot take up the whole frame. There must be room where the dynamic portion can be scheduled. This causes some overhead, but since the main parts of the frame are already described by the FDT, this overhead is marginal.

The positions of the fixed UL and DL portions may change from frame to frame and independently from each other. In order for this to work, an FDT can only describe the relative positions of transmissions within an UL or DL portion. The offset of each of these blocks has to be specified separately. An additional field in the beacon would be the ideal place for such a transmission. It has several advantages over transmitting the offsets e.g. during the TOC. The most notable advantage is that it enables the slave terminal to receive and to transmit during the times specified in the FDT, even if the TOC was not received correctly, or not received at all. If the layout of the fixed portions has to change, a new FDT can be transmitted either using a frame which is completely described by a TOC (see Figure 4a)), or during the dynamic portion of the frame (see Figure 4c)).

C. Description of subunits of frames

Dividing up the frame in different units and describing them independently may have an influence on the overhead necessary to signal changes in these subunits. The separation of the FDTs for subunits would allow modifying the connections in each subframe independently.

1) Separation of UL and DL description

One way to subdivide the frame would be to describe the UL and the DL in different FDTs, each announced in the beacon (see Figure 5). If for example a connection needs more resources in the UL, the DL does not necessarily have to change. Thus, the FDT describing the DL does not have to be transmitted.

In Figure 5a) a TOC is transmitted describing the whole frame including the UL and DL FDTs with the IDs 2 and 3 respectively. These FDTs are used in the following frames (see Figure 5b)) to describe the UL and DL Parts. If e.g. an UL connection requests more resources, only the UL FDT with the ID 3 has to be updated (see Figure 5c)). In Figure 5d) the new FDT is referenced and used for the description of the UL. In this case the beacon has two fields, one containing the ID for the UL FDT and one the ID for the DL FDT.

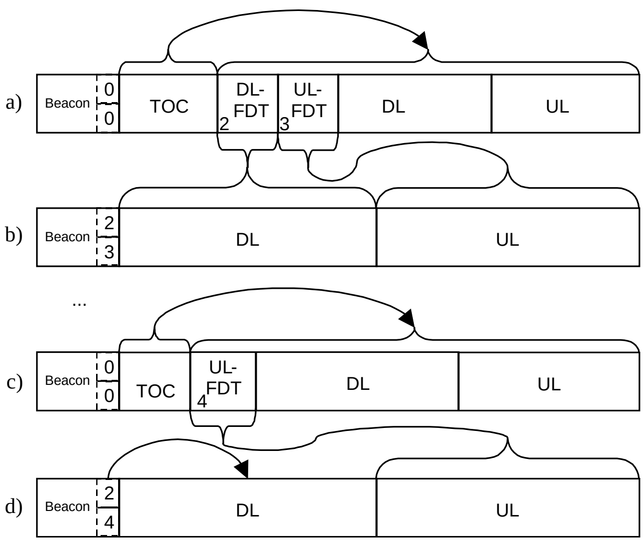

Figure 5. Separate description of UL and DL

2) Hierarchical division of frames

A further step would be a hierarchical subdivision of the UL and DL parts in sections of the same PHY mode/burstmode. One FDT could describe the changes of PHY modes in the frame and another could describe the transmissions in each PHY mode.

The concept of subdividing frames into sub-units would be especially useful if assuming a grouping of transmissions of the same burst mode. This concept of grouping is used e.g. in IEEE 802.16a. [7].

One FDT is used to describe the changes in burstmode during the frame. Other FDTs are used to describe the contents of each block of the same burstmode. This way, connections using the same burst modes can be changed without interfering with the scheduling of connections in other burst modes.

This can be of importance if different classes of connections use different burst modes. E.g. data connections using high bit rates (high PHY mode) are more likely to have high fluctuations of bandwidth needs (therefore necessitating frequent changes in frame layout) than connections carrying voice traffic.

D. Differential coding

All the aforementioned ways of employing FDTs can be enhanced further by additionally using differential coding of new FDTs. If there are only a few parameters of an already established frame layout or even of a connection described in an FDT will have to be changed for the specification of a new FDT, transmitting a whole new FDT would be wasteful. Instead an already known FDT could be modified to fit the new situation. This would involve transmitting only the parts of the FDT that actually have to change. An example is given in Figure 6.

In the figure you can see the plain case of describing a static frame with an FDT (see Figure 6a)+6b)). If the FDT has to change, a frame with a TOC describing this frame is transmitted. In this frame there is a differentially coded FDT which modifies the FDT with ID 1. The modified FDT receives the ID 2 with which it will be referred to during the following frames.

This form of modifying FDTs could also be applied to

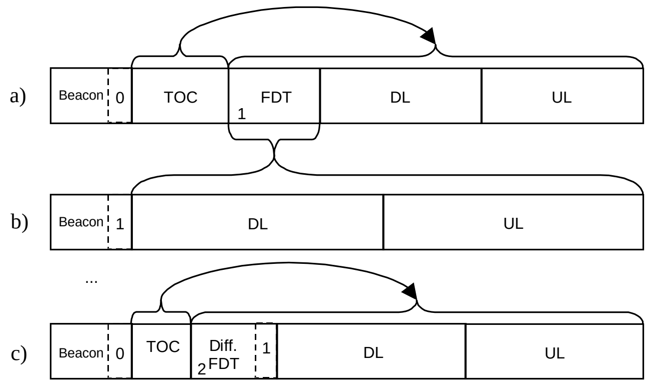

Figure 6. Differentially coded TOC/FDT

TOCs. The TOCs themselves could receive IDs and be stored at the slave terminals so they can be referred to again and modified in subsequent frames. This concept is shown in Figure 7.

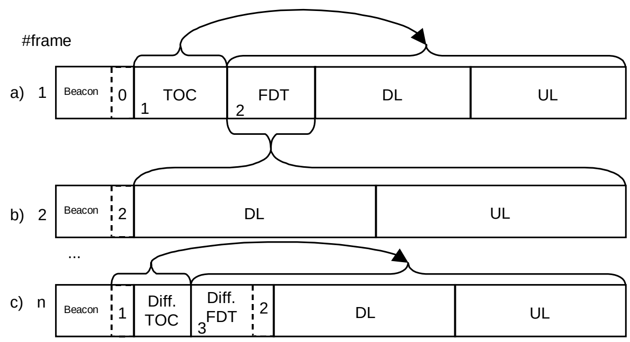

Figure 7. Usage of differential coding for FDT and TOC

There is still the possibility to transmit a complete TOC and a complete FDT (see Figure 7a)), but both can be transmitted differentially as well. In this example, the TOC describing the first frame (see Figure 7a)) is modified in frame n (see Figure 7c)). It is not necessary to transmit a whole new TOC. The TOC with the ID 1 is referenced in the beacon. In this case another flag has to be set in the beacon to announce the presence of a differential TOC. In the dynamic case this could be omitted. The differential TOC describes the differences between frame n and frame 1. In addition, the FDT transmitted in frame n is not a completely new one, but the FDT with the ID 2, with modifications.

IV. ACHIEVABLE IMPROVEMENTS

As shown in the section before the concept of FDTs allows for a reduction of overhead by decreasing the amount of control signaling. When examining multi-hop solutions for frame based MAC-protocols [2][3] it becomes obvious that this reduction will get even more important. A drawback of the multi-hop MAC-protocol is the fact that control signaling is needed for each hop. This results in an increasing overhead with an increasing number of hops. With the help of FDTs this overhead can be kept small. Considering a multi-hop solution which establishes fixed or even partly fixed connections for the relaying of data, implementing the concept of FDT in such MAC-protocols is even more promising.

The opportunity for reducing the amount of control data strongly depends on the dynamic of the layout of the MAC-frame. In the case that the layout never changes, integrating FDTs has the highest effect. The content of the FDT has to be transmitted to the slave terminals only once in this case. The worst case is the layout of each frame differing completely from the layout of the other frames. In this case no reduction of overhead is possible. But it is important to notice that we do not introduce additional overhead either, compared to the conventional way of transmitting control data. In most cases though, some similarities can be found between frames. The enhancement introduced by the use of FDTs then depends on the amount of similarity found in the frames. We have to keep in mind of course that the storage of FDTs needs some memory and that the number of FDTs we can store presents a technical boundary.

V. CONCLUSIONS

The concept of Frame Descriptor Tables introduced in this paper is a promising means to mitigate the need for resources necessary to transmit control information in wireless mobile radio systems of the next generation. Different ways of applying this concept were shown. The efficiency of this concept depends mainly on the scenario in which it is employed. In the best case of connections with relatively constant needs for bandwidth, the gain can be substantial. Especially when taking multi-hop scenarios into account in which the saving in resources is adding up in each hop. In the rather unlikely worst case where there are many very bursty connections, the gain is diminished, but no additional overhead is introduced either. This makes the concept of FDTs a valuable method for achieving the high spectral efficiency necessary in B3G mobile radio systems

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