Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Title	**A Frame Structure for Multihop Relays**
Date Submitted	**2006-11-12**
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Abstract	The document provides comments regarding the frame structure for WiMAX systems that are enhanced with mobile multihop relays (MMR), and proposes for consideration and adoption a frame structure that balances the flexibility of the relay system with that of limiting the propagation delay.
Purpose	Review and adopt.
Notice	
Release	
Patent Policy and Procedures	

A Frame Structure for Time Division Duplex Multihop Relays

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Introduction

The contribution provides some comments with respect to the frame structure for multihop relays (RSs). As recommended by the working group, the solutions that are provided for multihop RS, should not break the operation of the subscriber station (SS) and/or the mobile station (MS), i.e. a relay station (RS) must be "perceived" by the attached SSs/MSs as a base station (BS). Note, that the solution provided herein, does not preclude for an intelligent SS to be able to receive data both from BS and the RS to which it is attached. Also, the concern is not to address problems like scheduling, frequency allocation planning, etc., but to focus the discussion on the relay frame structure that provides reduced propagation delay and in the same time it is flexible enough to allow a seamless grow of the RS topology, as well as different segment/IDcell assignments.

Although there are many possibilities to design the RS frame structure, the focus herein is to discuss the limitations of what we call single-frame relay (SFR) (see Figure 1) that was proposed for time division duplex (TDD) operation, and how it is possible to enhance it, by providing a new frame structure that allows easy future extension of the topology of relays, and this frame is called subsequently flexible frame structure (FFS).

Some Notations

In the subsequently presented figures, RS0 and RS00 denote the one- and two-hops intermediate relays, respectively, relative to BS; RS0 has the BS as access station, while RS00 has the RS0 as access station. RS_*i* denotes the *i*-th block as labeled in the figure, corresponding to the relay RS. Transmission and reception operations, uplink and downlink, are abbreviated as TX, RX, UL, DL, respectively. A RS has to perform the following tasks, which are enumerated subsequently not in a particular order: downlink traffic transmission (DL-TX) of data, uplink traffic transmission (UL-TX) to transfer data to access station, uplink traffic reception (UL-RX) of the data, and downlink traffic reception (DL-RX) of data from the access station. Note that each RS is an access station for several SSs/MSs, which in the subsequent figures are not shown, because the focus is on the RS frame structure. Also, the SSs/MSs follow the frame structure of the access station. The figures show the evolution in time, and we do not attempt to provide any suggestions of how the scheduler should manage the resources, e.g. usage of frequency subchannels. However, as has been said before, the solution provided allows a wide range of possibilities of segment/IDcell assignments (of course, constrained to the usage model scenario). Also, it is important to note that when discussed on delays introduced by a certain frame structure, it refers to the optimal implementation, which may not be in the practice.

Single-Frame Relay Structure

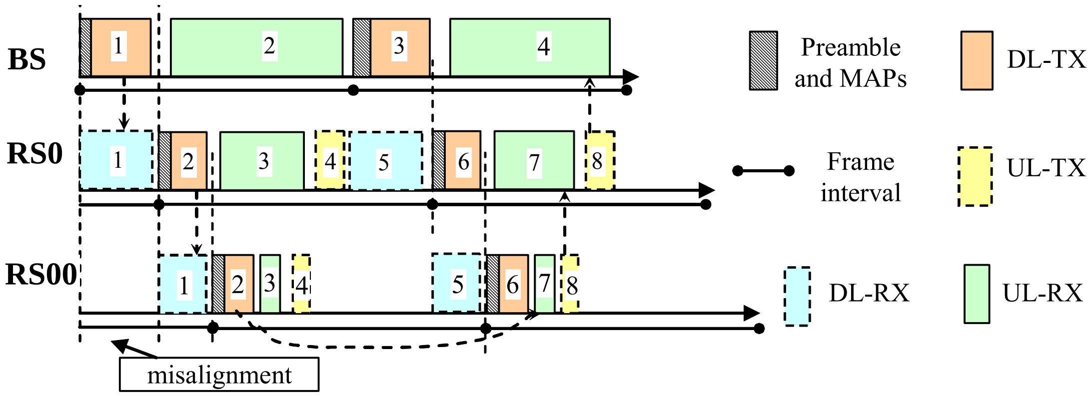

Figure 1—Single-frame relay structure

Figure 1 shows the relays' operation with respect to BS (see [1] and the references therein). The BS sets the beginning of the RS0 transmission frame such that the RS0 receives the corresponding data before a new RS0 frame interval starts, as the misalignment shows. Note that this is a commitment made by BS to RS0, that it will *always* schedule the downlink traffic data for RS0 *before* a new RS0 frame starts. The same thing happens with respect to the relationship between RS0 and RS00: the RS0 schedules the downlink traffic data pertaining to RS00 *before* a new RS00 frame starts.

Note that in the first two frames the interference is avoided, BS, RS0 and RS00 do not transmit in the same time. Also, on the uplink the higher order *n*-hops relays transmit *first*, and this feature limits somehow the flexibility of the whole system. A succession of the events that show the minimum roundtrip delay is presented in Figure 1 with dashed-line arrows: the transmission of BS_1 is received by RS0_1, which at its turn transmits RS0_2 and is received by RS00_1, which transmits RS00_2; the uplink replies are received by RS00 in RS00_7 and transmitted on uplink in RS00_8, which is received in RS0_7 and transmitted on uplink in RS0_8, which is received by BS_4. Thus, BS receives the data in the next frame, i.e. the entire path of relays behaves as a single SS/MS and therefore the system has a minimum propagation delay.

This option comes with a price: the higher order *n*-hops relays in the path of relays have shorter time to operate, i.e. longer idle time intervals. Also, it is observed that downlink transmission interval gets smaller with each additional hop added, which implies that the SSs that have as access station the last RS in the path of relays will have difficulties to maintain their synchronization and proper channel estimation due to the lack of enough pilots tones in the downlink burst. Therefore, the length of the path of relays is very limited.

Another disadvantage of this frame structure is that it severely limits changing the transmission/reception ratio of the BS once it is set, and of course, there are tight scheduling requirements imposed on the entire system.

Frame Structure with Delay-Flexibility Tradeoff

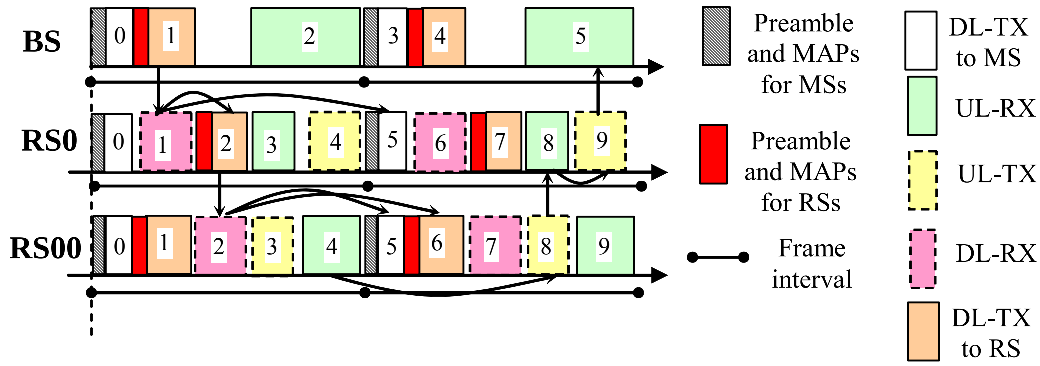

Figure 2—Relays with delay-flexibility tradeoff

Figure 2 shows the option of a relay frame structure that offers some flexibility in adjusting the frame ratio transmission/reception at the expense of increasing the propagation delay. The RS have 2 preambles, one for mobiles and one for the RSs that are attached. At the beginning of each frame, the BS and RSs transmit to MSs (blocks labeled with 0 and 5). It is noticeable that the one-hop relays have the beginning of their RS frame after the DL transmission from the BS, while the two-hop relays have their frames time aligned with that of the BS. BS_1 has to schedule the downstream traffic data for RS0 before RS0_2 begins the upstream traffic reception. Also, the BS has to schedule the upstream traffic reception for its one-hop relays at the end of the frame interval, as can be observed from reception of RS0_4. The interference that may occur because the block RS00_4 is received during the same time interval when RS0_4 transmits on access station, can be avoided easily by a proper scheduling of the subchannels, because both blocks pertain to uplink; this is an advantage of FFS. The one-way propagation delay adds about one frame duration delay for each 2-hops added to the path of relays. For example BS_1 is received at RS0_1, and is transmitted at RS0_2 to be received at RS00_2, in order to transmit it further at RS00_5 and RS00_6. Therefore the one-way delay has been increased by one-frame duration relative to the single-frame structure presented in Figure 1.

The relaxation of the delay requirements provides an increased flexibility of the frame structure. Now it is obvious that increasing the depth of the path of relays is no longer an issue. Also, the burst allocation operation has less stringent requirements compared with that of the SFR.

Another important aspect is that the DL burst duration does not necessarily shrink with additional hops added at the path of relays, as can be seen, for example, from RS0_2 and RS00_1, and comparing these burst durations with those corresponding from Figure 1, RS0_2 and RS00_2. This provides two additional advantages of this frame structure relative to single-frame structure. First, it offers better synchronization and channel estimation to the SSs attached to a RS. Second, the higher order *n*-hops relays can now afford to schedule the data transmission and reception using more robust modulation coding schemes, therefore they are able to reduce the frame error probability, i.e. improve their link reliability. Note, also, that the link reliability can be traded for an increase in the system capacity.

Note that if RS0 is not an access station for another RS, the block RS0_2 (and RS0_7) can be assigned for uplink reception and/or uplink transmission. Similarly, if the RS00 is not an access station for another RS, the block RS00_1 (and RS00_6) can be assigned to RS00_0 (and RS00_5), i.e. to downlink transmission to MSs.

On Scheduling the Bursts

For the SFS, the BS puts the CID of an MS both in the DL and UL-MAPs of the block BS_1, as this frame structure adds no propagation delay.

On the other hand, for the FFS, the round trip propagation delay is one frame for each 2-hops added. Therefore, a BS can't allocate the UL burst in the next frame for the MSs, which are more than one hop away. However this does not pose any problem [2]. The BS knows the number of hops to an MS, and using this information allocates its CID to an UL MAP offset accordingly. For example, considering Figure 2, the BS knows that to reach an MS that has RS00 as an access station, the data has to be relayed via RS0 and RS00, adding a roundtrip delay of 1 frame. Thus, the BS would put the CID of the MS in the DL-MAP of block BS_1 and in the UL-MAP two frames later.

Therefore, it is obvious that the flexible frame structure can handle QoS requirements, although not as stringent as the single frame structure, when the path of relays increases.

Numerical Example that Evaluates the Capacity/Link Reliability

Let's consider a simple example that shows the benefit of the frame structure presented in Figure 2. The following setup is used in the example:

- frame duration is 5 ms, i.e. there are about 50 OFDM symbols/frame;
- BS is access station for *N* SSs/MSs and RS0; RS0 is access station for *N* SSs/MSs and RS00; RS00 is access station for *N* SSs/MSs;
- TTG and RTG intervals are neglected;
- the data traffic assumes full buffer mode and the users have equal priority to access the resources;
- the amount of energy assigned to each user is identical, regardless of the hop and UL or DL, and it is assumed that it is required the energy of one symbol in order to achieve the desired target error rate;
- 3 symbols are used for DL TX in order to cover the preamble and maps.

The metric used in the evaluation is the number of users *N* that can be attached to an access station taking into account, as mentioned before, that each user requires the energy of 1 OFDM symbol in order to receive correctly the data. Obviously, the larger the *N* it is the greater the capacity that the system can support. Note that in practice, higher capacity can be traded for better link reliability.

For the relay using SFS presented in Figure 1, it has been already mentioned that the bottleneck is the last hop, where the RS00 operates for a very short period of time. So, BS_1, RS0_2, RS00_2, RS00_3, RS00_4, and RS0_4 have to fit into one frame duration. Thus this can be written as:

	$3+3\ N_1\ 1$	BS_1 has 3 symbols for preambles and serves 3 N_1 users (that are attached to BS, RS0 and RS00), each occupying 1 symbol
	$3+2\ N_1\ 1$	RS0_2 has 3 symbols for preambles and serves 2 N_1 users (that are attached to RS0 and RS00), each occupying 1 symbol
	$3+\ N_1\ 1$	RS00_2 has 3 symbols for preambles and serves N_1 users, each occupying 1 symbol
	$N_1\ 1$	RS00_3 receives data from N_1 users, each occupying 1 symbol
	$N_1\ 1$	RS00_4 transmits data from N_1 users, each occupying 1 symbol
	$2\ N_1\ 1$	RS0_4 transmits data from 2 N_1 users (that are attached to RS0 and RS00), each occupying 1 symbol
Total	50	

Thus, the average number of users for single-frame relay structure is $N_1 = 4$, i.e. the system can serve about 12 users per cell in one frame duration.

For the relay using FFS presented in Figure 2, the bottleneck is the RS0, which has to fit into one frame duration RS0_1 up to RS0_4. This can be written as:

	$3+N_2$ 1	RS0_0 has 3 symbols for preambles and transmits data for N_2 users (that are attached to RS0), each occupying 1 symbol
	$3+2\ N_2$ 1	RS0_1 has 3 symbols for preambles and receives data for 2 N_2 users (that are attached to RS0 and RS00), each occupying 1 symbol
	$3+\ N_2$ 1	RS0_2 has 3 symbols for preambles and serves N_2 users (that are attached to RS00), each occupying 1 symbol
	$2\ N_2$ 1	RS0_4 receives data from 2 N_2 users (that are attached to RS0 and RS00), each occupying 1 symbol
	$2\ N_2$ 1	RS0_3 transmits data for 2 N_2 users (that are attached to RS0 and RS00) to BS, each occupying 1 symbol
Total	50	

Thus, the average number of users for the flexible frame relay structure is $N_2 = 5$, i.e. the system can serve about 15 users per cell in one frame duration.

As can be observed, for this simple example, the flexible relay frame structure offers about a 25% capacity improvement relative to single-frame relay frame structure. Therefore, a relay system implementing the FFS can trade capacity for higher link reliability than that implementing SFS, i.e. for the same capacity the FFS has a better link reliability. While the system efficiency of the SFS decreases with each additional hop added, this is not the case for the FFS, for which the efficiency does not change, i.e. the bottleneck will always be the one-hop relays that have the BS as access station.

Comparison

The following table compares the two frame structures presented herein.

Feature	**Single-frame structure (SFS)**	**Flexible frame structure (FFS)**	**Comments**
Centralized scheduler	Yes	Yes	Centralized scheduler has to take into account the delay for the FFS, if more than 1 hop is involved.
Distributed scheduler	Yes	Yes	SFS may not have enough time to do decoding and schedule data immediately, thus may introduce delay.
Bottleneck	Last hop relay	First hop relay	FFS has more flexibility to deal with additional RS hops.
Capacity	Bad	Good	FFS utilizes better the frame duration interval.
Link reliability	Bad	Good	FFS reliability depends mainly on the reliability of the first hop. For SFS, the reliability of *all* hops is important; SFS has longer idle intervals that are not

Feature	Single-frame structure (SFS)	Flexible frame structure (FFS)	Comments
			used to improve the link reliability.
Adding RS in the	Bad	Good	FFS is very flexible. For SFS can be very difficult.
One way-delay	Good	Bad	FFS adds about one frame delay per 2-hops. SFS has no delay.
Synchronizatio n	Bad	Good	SFS has shorter transmission bursts cycles that can result in poor synchronization.

Conclusions

The contribution detailed some drawbacks of the single-frame relay structure:

- inflexibility with respect to adding new hops;
- shorter transmission bursts can produce poor synchronization and channel estimation, the scheduling requirements are very tight.

In order to alleviate these problems, a relay frame structure that provides more flexibility at the expense of increasing the one-way propagation by about one-frame duration per 2-hops is proposed. Thus, the proposed relay frame structure offers:

- a seamless increase of the relays' path length;
- relaxed time requirements for scheduling, possibility to use more robust modulation coding schemes for a reliable transmission;
- an increase in the system capacity;

References

[1] F.-C. Ren, C.-L. Hsiao, C.-C. Tseng, and W.-H. Sheen, "Recommendation on PMP mode compatible TDD frame structure," IEEE C802.16mmr-05/27r2, http://www.ieee802.org/16/sg/mmr/contrib/C80216mmr-05_027r2.pdf

[2] H. Zheng, Y. Saifullah and S. Maheshwari, "Relay Support for Scheduling, Bandwidth Request and Allocation Mechanism," IEEE C802.16j-06/188

MMR Frame Structure Proposal

[In section 8.4.4 insert the following]

MMR-BS frame structure

The MMR-BS frame structure is presented in Figure 3. It comprises three subframes. The first subframe is assigned to transmission on access downlink to MSs. Note that the DL-MAP and UL-MAP may include IEs that provide information for the RSs. The second subframe is dedicated to downlink RS transmission. It can start immediately after the end of the first subframe as Figure 3 shows. The position of the beginning of this subframe relative to the beginning of the frame can be changed; however all the RSs have to be informed by this situation. The third subframe is dedicated for uplink reception from both MSs and RSs, and must begin at least after a TTG interval following the end of the second subframe. The end of third subframe must end such that at least a RTG interval is before the beginning of the next frame.

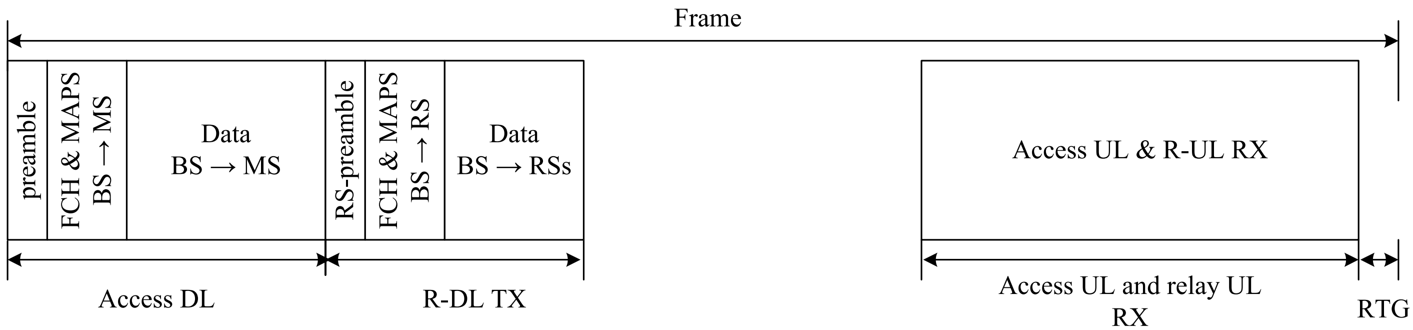

Figure 3. Frame structure for a BS.

RS frame structure

Figure 4 and Figure 5 shows the frames structures for the RS that are at an odd and, respectively, even number of hops from the BS.

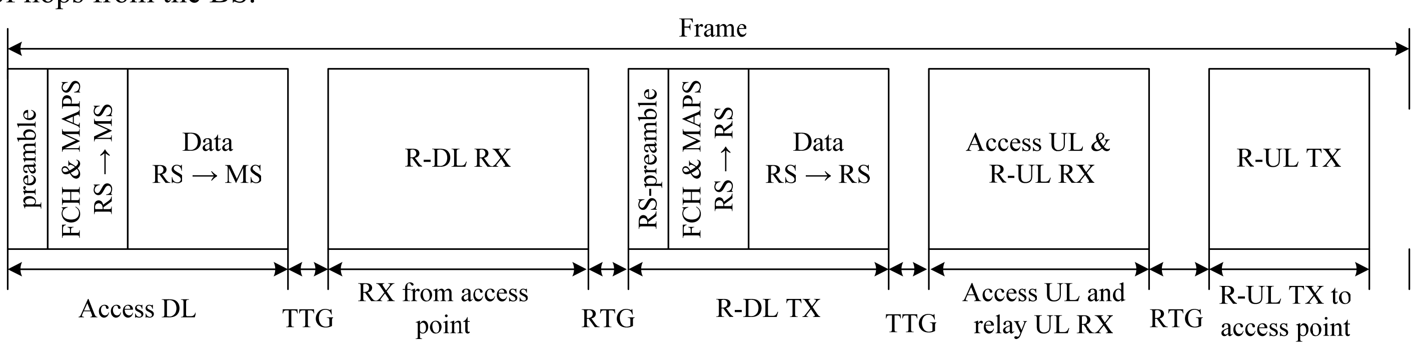

Figure 4. Frame structure for an RS that is at an odd number of hops from BS; the block "Downsteam TX to RS" is not present when the RS does not act as an access point.

Referring to Figure 4, the frame start with a first subframe dedicated, as in the BS case, transmission to access downlink MSs. The second subframe is specific to RS and is aligned to receive the data transmitted by the access station. The third subframe is assigned to transmission for downlink RSs that have as the access station the current RS. The fourth subframe is dedicated for reception of the data both from access downlink MSs and from downlink RSs that have as the access station the current RS. The fifth subframe is dedicated for transmission of data to the access station. Between the subframes one and two, three and four, respectively, a TTG time interval is accommodated. Similarly, between the subframes two and three, four and five, respectively, a RTG time interval is accommodated.

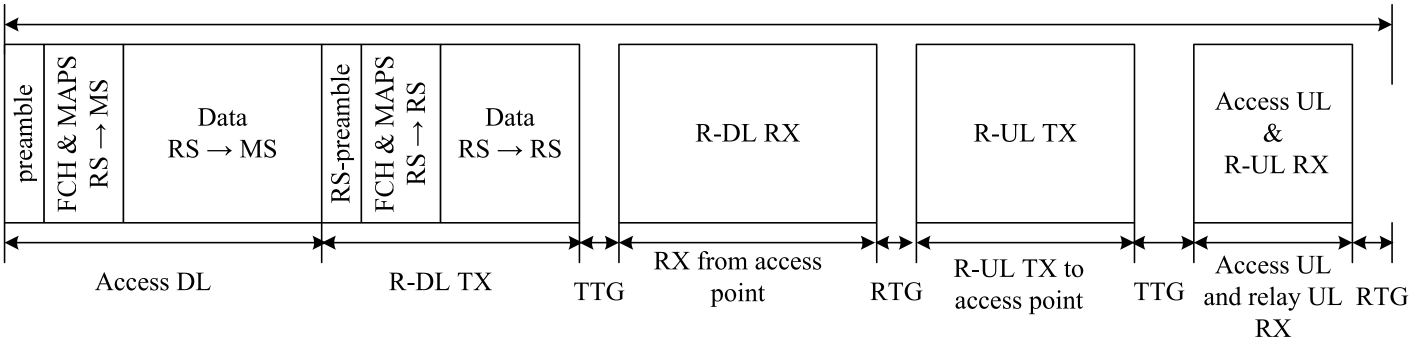

Figure 5. Frame structure for an RS that is at an even number of hops from BS; the block "Downsteam TX to RS" is not present when the RS does not act as an access point.

Referring to Figure 5, the frame start with a first subframe dedicated, as in the BS case, transmission to access downlink MSs. In the second subframe data is transmitted to the RSs that have the access station the current RS. The third subframe is aligned to receive data from the access station. The fourth subframe is dedicated for transmission of data to access station. The fifth subframe is dedicated for reception of data both from access downlink MSs and from downlink RSs that have as the access station the current RS. Between the subframes three and four, and five and next frame, respectively, a RTG time interval is accommodated. Similarly, between the subframes two and three, four and five, respectively, a TTG time interval is accommodated.