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Re:	IEEE 802.16m-08/016r1, Call for SDD Comments and Contributions (2008-03-20) for the following topic: Hybrid ARQ (protocol and timing)
Abstract	This contribution proposes hybrid-ARQ (HARQ) protocols, the HARQ control signaling and timing for IEEE 802.16m
Purpose	To be discussed and approved by TGm.
Notice	
Release	
Patent Policy	

Hybrid ARQ Protocols and Signaling for DL and UL Transmissions

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1. Introduction

This contribution focuses on hybrid-ARQ (HARQ) protocols, the control signaling and HARQ timing based on the new frame structure proposed for IEEE802.16m [1]. In the basic frame structure in 802.16m, there are two types of sub-frame: 1) the regular sub-frames with six OFDMA symbols and 2) the irregular sub-frames with five or less OFDMA symbols. The co-existence of regular and irregular sub-frame makes the HARQ allocation more complicated than the legacy system. Furthermore, the reduced transmission time interval (TTI) in IEEE802.16m provides the flexibility to minimize the HARQ process delay and round trip time(RTT) within the new frame structure.

The HARQ protocols for both downlink and uplink are discussed in TDD mode. Based on the comparison of advantages and disadvantages of candidate HARQ protocols in terms of effective throughput, signaling overhead, scheduling flexibility, processing delay etc., we propose:

- In one PHY frame in TDD duplex scheme, ***irregular subframe*** (if existing) shall be put at the end of downlink portion and all uplink (UL) subframes are constrained to be ***regular***.
- Asynchronous adaptive HARQ as the DL HARQ operation.
- DL HARQ region should be restricted to a two dimensional region (frequency domain and subframe domain) consisting only of ***regular subframes***. Irregular subframe shall not be allocated to HARQ processes.
- Synchronous non-adaptive HARQ as UL HARQ operation.

2. Background

HARQ [2] can be employed to maintain high throughput and reliability simultaneously over the time-varying channels. Two types of hybrid ARQ schemes are of particular interests in the design of wireless systems, namely, Chase combining [3] and incremental redundancy (IR) [4]. In HARQ with Chase combining, the same sequence from original transmission is sent again to the receiver upon the ARQ request. To detect the information, the receiver first applies the maximum-ratio combining (MRC) to the received multiple copies of the symbol sequence and then performs the channel decoding based on the MRC outputs. In IR based HARQ, additional parity bits are transmitted during the retransmissions. The receiver performs the decoding directly on all received sequences. With IR hybrid ARQ, the throughput performance can be improved with a coding gain in additional to the diversity gain. Both Chase combining and IR HARQ have been adopted in IEEE 802.16e [5].

In terms of the (re)transmission timing, the HARQ can be classified as being synchronous or asynchronous. In synchronous HARQ, the retransmissions are restricted to occur at known time instants. While in asynchronous HARQ, the retransmissions may occur at any time. For asynchronous HARQ, additional signaling of HARQ retransmission is required, e.g., the HARQ process number, the retransmission frames or subframes. For synchronous HARQ, such control signals can be omitted.

In terms of the transmission form, HARQ can also be classified as being adaptive and non-adaptive. In adaptive hybrid ARQ, the transmitter may change the attributes of the retransmission packet at each retransmission block including the modulation, coding rate, resource block allocation, etc. In non-adaptive hybrid ARQ, all these attributes for the retransmissions are exactly the same as that from the original transmission and they are known to the receiver from the MAP signal for the first transmission.

3. HARQ Protocols for IEEE 802.16m

3.1 Chase Combining and IR HARQ

Compared to Chase combining, IR HARQ has the potential of achieving higher throughput performance. However, in low SNR, Chase combining may outperform IR HARQ. On the other hand, the HARQ system with Chase combining has a lower complexity since IR HARQ requires more control signaling for the retransmissions, e.g., redundancy version, that has to be sent to the receiver. Furthermore, IR HARQ requires larger buffer size at the receiver. The buffer size increases for each IR retransmission. It is also necessary to buffer bit-level soft information instead of the symbol-level soft information at the receiver. Therefore, we propose continuing to support both Chase combining and IR in IEEE 802.16m as in IEEE 802.16e. In Table 1, we summarize the HARQ schemes to be supported in IEEE 802.16m for both DL and UL transmissions.

	HARQ Schemes	IEEE 802.16e	IEEE 802.16m
DL	Chase combining	√	√
	IR Convolutional Codes	√	√
	IR CTC	√	FFS
	IR for other FECs	Not supported	FFS
UL	Chase combining	√	√
	IR Convolutional Codes	√	√
	IR CTC	√	FFS
	IR for other FECs	Not supported	FFS

Table 1: HARQ schemes to be supported in IEEE 802.16m.

As shown in Table 1, in IEEE 802.16e, the HARQ with Chase combining, IR convolutional codes (CC) and IR convolutional turbo codes (CTC) are supported in both DL and UL transmissions. In IEEE 802.16m we propose to continue supporting Chase combining and IR-CC. Since IEEE 802.16m targets to provide the reliable date transmission with a much higher rate than IEEE 802.16e, the current decoding throughput of CTC may not support such high rate. It is desirable to consider other coding schemes. Therefore, whether or not continue to support IR CTC in IEEE 802.16m is FFS. In IEEE 802.16e, low-density parity-check (LDPC) codes have been included as an FEC option. However, the LDPC codes defined in IEEE 802.16e are not fully rate-compatible (RC). Hence the IR LDPC is not supported in 16e. To support IR LDPC in IEEE 802.16m standard, fully RC-LDPC codes should be standardized. Since FEC schemes will be discussed in the following meetings, the supporting of IR for other FEC codes in IEEE 802.16m is FFS.

3.2 HARQ Operations

It has been shown in [7] that an HARQ scheme with the capability of changing the retransmission timing and packet format, i.e., asynchronous adaptive HARQ, can significantly increase the link level throughput. With the flexibility on the transmission timing and resource block allocation, asynchronous adaptive HARQ also provides scheduling flexibility so that it can fully exploit the multi-user diversity gains. The baseline frame structure prepared in [6] provides the subframe structure that significantly reduces the round trip time (RTT). The H-ARQ retransmission can be triggered after a shorter time period than that in IEEE 802.16e, e.g. 4.3ms for 16m vs. 20ms in 16e [6]. Although the HARQ retransmission delay is shortened, since IEEE 802.16m intends to support high mobility, the channel can still varies within the duration of one HARQ process. Having the potential to achieve optimal resource allocation for the retransmissions in a time varying channel, asynchronous adaptive HARQ is desired in the new standard. It is worth noting that even when the channel does not vary much for the MS with low-mobility, the adaptive HARQ can still provide a certain single-user (SU) throughput gain. The other advantage of the asynchronous adaptive HARQ is that it is easy to avoid collision with high prioritized services, e.g., persistently scheduled VoIP MS, MBMS [8]. Compared with asynchronous adaptive HARQ, the synchronous non-adaptive HARQ operation reduces the control signaling overhead and lowers the operational complexity.

Downlink HARQ

Based on the above discussion, to achieve higher SU throughput, as well as multi-user (MU) sum throughput, we propose that adaptive asynchronous HARQ should be adopted for DL transmission in IEEE 802.16m. The other reason that supports the proposal of adaptive asynchronous HARQ as DL HARQ in IEEE 802.16m is the irregular subframe that is defined in the new baseline frame structure proposed for IEEE 802.16m [6]. The regular subframe and irregular subframe shown in [6] is recaptured in Fig. 1 for the frame structure with DL:UL=5:3 in TDD duplex scheme. As shown in Fig. 1, we can see that the regular subframe contains 6 full OFDM symbols, but the irregular subframe contains 5 full OFDM symbols. The mixture of regular and irregular subframe structure in one PHY frame is different from the regular slot structure defined in IEEE 802.16e. Therefore, for the non-adaptive synchronous HARQ process in which the first transmission is scheduled in the irregular subframe or in the two or more subframes that contain the irregular subframe, the retransmission has to be transmitted in the same manner with the irregular subframe in the following DL/UL frame. Hence the RTT for the HARQ process increases.

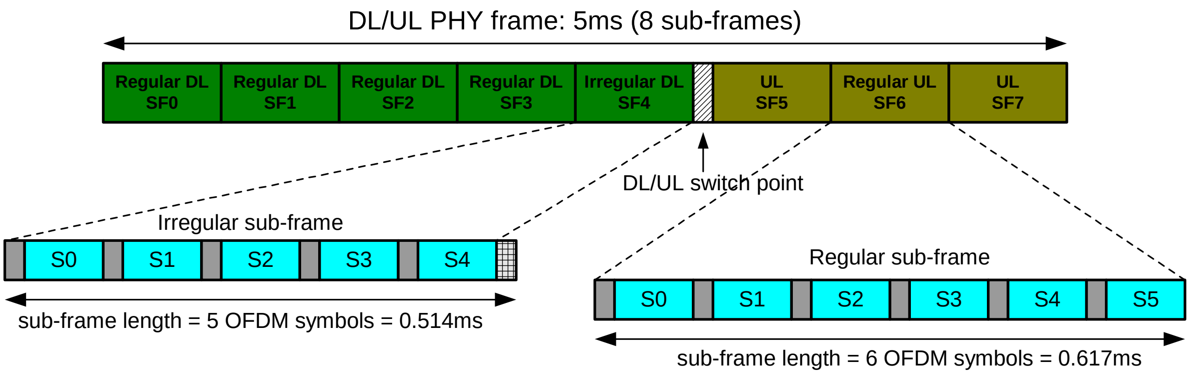

Figure 1: Regular and irregular sub-frames in TDD duplex scheme (CP=1/8 Tu)

Uplink HARQ

Similar problem exists in the UL transmission if non-adaptive synchronous UL HARQ is adopted in IEEE 802.16m. The UL HARQ is proposed in [8] with reduced control signal. However, for one particular UL HARQ timing diagram, if the irregular UL subframe exists, it will cause the subframe mismatching problem. Fig. 2 shows such dysfunctional timing diagram for non-adaptive synchronous UL HARQ with DL:UL=2:6. As shown in Fig. 2, the UL subframe 6 is an irregular UL frame. For HARQ process 4, the first transmission is in the UL subframe 4 which is a regular subframe. Based on the non-adaptive synchronous HARQ protocol in [7], it is retransmitted at UL subframe 6. However, since the UL subframe 6 is irregular, the retransmission has to be redefined to another subframe. The UL subframe 6 should be defined for a new HARQ process. Similar mismatching problem exists in HARQ process 6. Therefore, if we adopt non-adaptive synchronous UL HARQ, to solve such mismatching problem, we need to restrict the UL subframes to be all regular in the baseline frame structure. If adaptive UL HARQ is adopted in IEEE 802.16m, we do not have such restrictions on the UL subframe. Note that UL HARQ can still be synchronous to save some control signals.

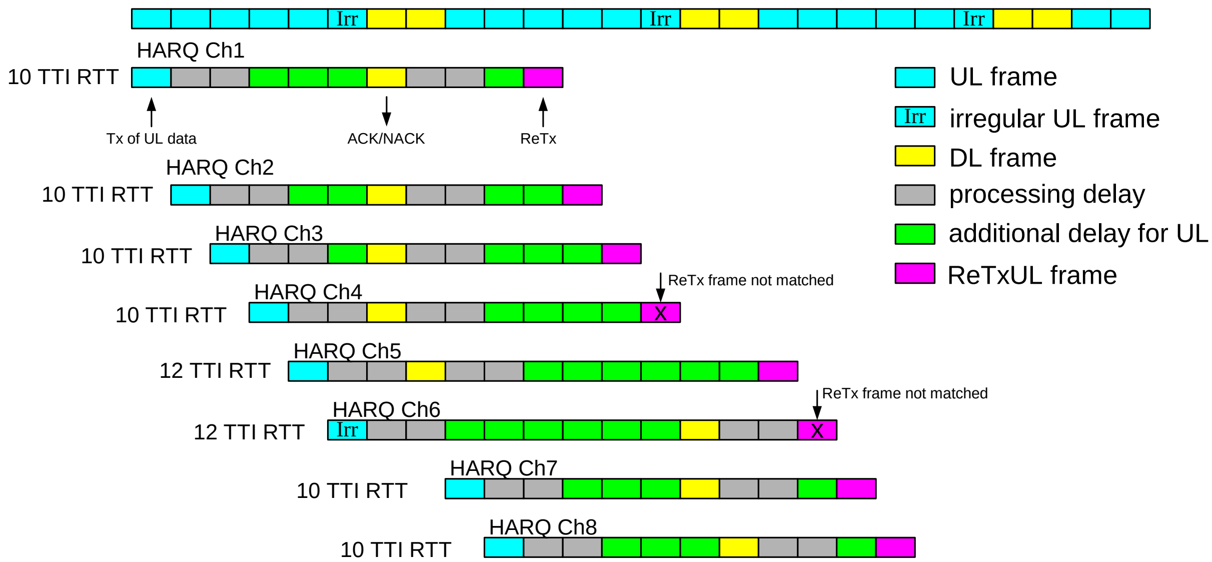

Figure 2: Mismatch problem in non-adaptive synchronous UL HARQ with irregular UL subframe (DL:UL=2:6)

3.3 HARQ Control Signals

In IEEE 802.16e, one or more two-dimensional data regions are defined in HARQ DL MAP IE for HARQ subbursts. All subbursts within the data region shall only support one HARQ mode. The HARQ subbursts are allocated in a frequency-first manner by filling the subchannels in one OFDMA symbol first and then moving to the next OFDMA symbol within the HARQ data region. Such HARQ subburst allocation methods reduce part of signaling overhead. However, the subbursts in one date region experience almost the same channels. To fully exploit the advantages of multiuser-diversity for asynchronous adaptive HARQ, we can allocate the resource block for each HARQ subburst.

Table 2 summarizes the signaling for resource allocation of HARQ data regions in IEEE 802.16e and the proposed the signaling for the resource allocation in 16m. As shown in Table 2, in 16e, the HARQ data regions is defined by the OFDMA symbol offset, subchannel offset, number of OFDMA symbols, and number of subchannels. Based on the baseline frame structure of 16m in [6], we propose that the HARQ data burst or HARQ data region is defined by OFDMA subframe offset, subchannel offset, number of OFDMA subframes, and number of subchannels/resource block (RB) as shown in Table 2. Each 5ms frame consists of 8 subframes. Hence, we assign 3 bits for subframe offset and 3 bits for number of subframes. For subchannel offset, and number of subchannels (or RB), since the resource block structure in 16m is still under discussion, e.g. RB(9,6), RB(12,6), RB(18,6) etc. proposed in [9,10], we tentatively assign 8 bits for subchannel offset and number of subchannels, respectively, to accommodate all cases. Thus the total number of bits for HARQ data region or HARQ subburst allocation is now 22, with 7 bits less than that in 16e.

IEEE 802.16e		**IEEE 802.16m**	
OFDMA symbol offset	**8**	**OFDMA subframe offset**	**3**
Subchannel offset	**7**	**Subchannel offset**	**8**
Number of OFDMA symbols	**7**	**Number of subframes**	**3**

Number of subchannels	**7**	**Number of subchannels or RB**	**8**
Total bits	**29**		**22**

Table 2: Signaling overhead (number of bits) for resource allocation.

We then summarize the required signaling over head for every (re)transmission in adaptive asynchronous HARQ.

Component fields in AA HARQ	**Number of bits**
Resource allocation	**22**
Duration assignment	**2**
Modulation scheme	**2**
Payload size	**5**
HARQ process numbers	**3**
Redundancy version	**2**[1]
New Data indication	**1**
CRC	**16**

Table 3: Signaling overhead for adaptive asynchronous (AA) HARQ.

The payload size and redundancy version can be changed based on the FEC scheme and maximal information block length allowed in 16m that is to be determined in the future meetings.

3.4 HARQ Timing

As shown in Fig. 2, the processing delay (including the propagation delay) is assumed to occupy a period of two subframes before sending the ACK/NACK signal [8]. Therefore, as shown in Fig. 3, for DL HARQ with DL:UL=6:2, if the resource block for a DL HARQ process contains the last DL frame, the additional delay for retransmission is caused by waiting for UL subframe to send the ACK/NACK feedback. The total delay for retransmission is then 12 subframes.

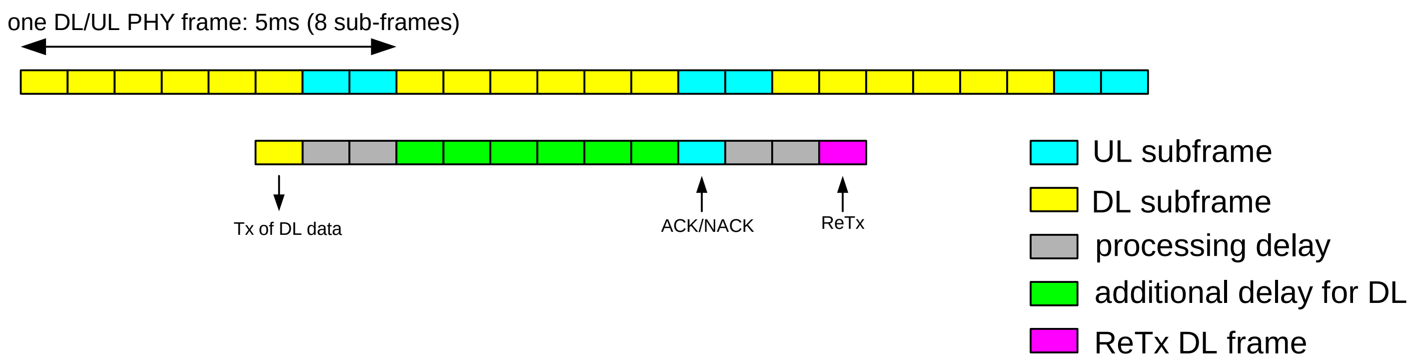

Figure 4: Additional delay for DL HARQ (DL:UL=6:2)

To ameliorate the long delay shown in Fig. 4, we propose the following restrictions on the DL HARQ and the frame structure in IEEE 802.16m.
1) The irregular subframe (if existing) is always allocated at the last subframe in the downlink transmission.
2) The DL HARQ process should not occupy the last subframe.

[1] For downlink, the redundancy version may increase to 8(3-bit) if the maximum retransmission number is increased to 8. For 802.16m, it is affordable with shorter TTI and HARQ retransmission.

With these two restrictions, the RTT delay for DL HARQ is always minimized if the processing delay meets the two-subframe timing requirement. We now discuss the timing requirement for the processing delay in detail. As shown in Fig. 5, the worst case is that the first transmission of a DL HARQ process is at the regular DL subframe SF4. The processing delay allowed for fast feedback is two subframes including one irregular DL subframe, plus DL/UL switch interval. For regular UL subframe, the time is 0.617ms. Since irregular DL subframe may contain five or less OFDM symbols [1], therefore, the time for irregular DL subframe may vary from 0.308ms (for 3 full OFDM symbols) to 0.513ms (for 5 full OFDM symbols). Including DL/UL switch interval (TTG = 0.1057ms in 802.16e [5]) ms, the total TTI (1 DL irregular subframe, TTG, 1UL subframe) requirement is then 1.03 ms (assuming 3 full OFDM symbols in the DL irregular subframe). It should be noted that since we propose the adaptive asynchronous DL HARQ, such process delay requirement is not necessary for all DL HARQ processes. We propose this frame structure to facilitate the fast retransmission and minimize the average delay for DL HARQ.

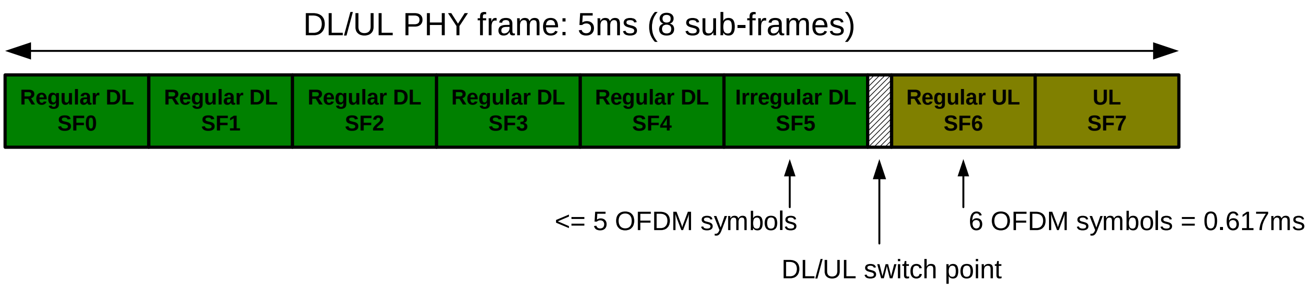

Figure 5: Timing requirement for the processing delay (DL:UL=6:2)

Another advantage for using only regular DL subframes for DL HARQ is to save the memory resources when determining transmission formats (including encoding block size, modulation type, rate and number of occupied RB etc). In 802.16e, the transmission formats for IR HARQ are defined in a loop-up-table (LUT) (e.g. Table 505 for DL IR HARQ and Table 507 for UL IR HARQ in IEEE 802.16e standard [5]), which is based on the fact that all resource blocks (termed slot in 16e) are identical. The irregular RB in 802.16m will incur additional loop-up-table and memory resource for the transmission formats. Thus we propose HARQ allocation is restricted to the regular DL subframes.

The typical timing of DL and UL HARQ is illustrated in Fig. 5 and Fig. 6, respectively, as follows.

Ex-1: DL HARQ Timing

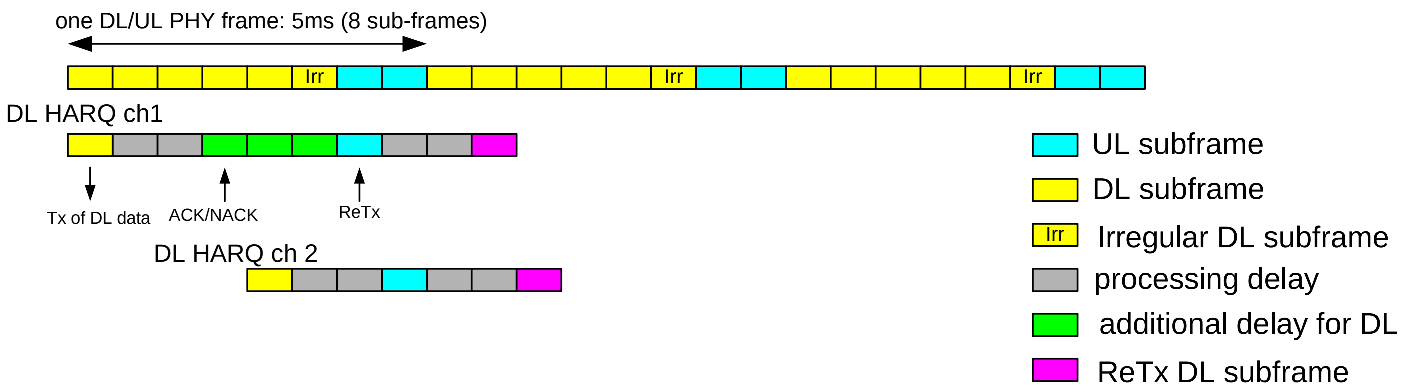

Figure 5: DL HARQ timing (DL:UL=6:2)

Ex-2: UL HARQ Timing

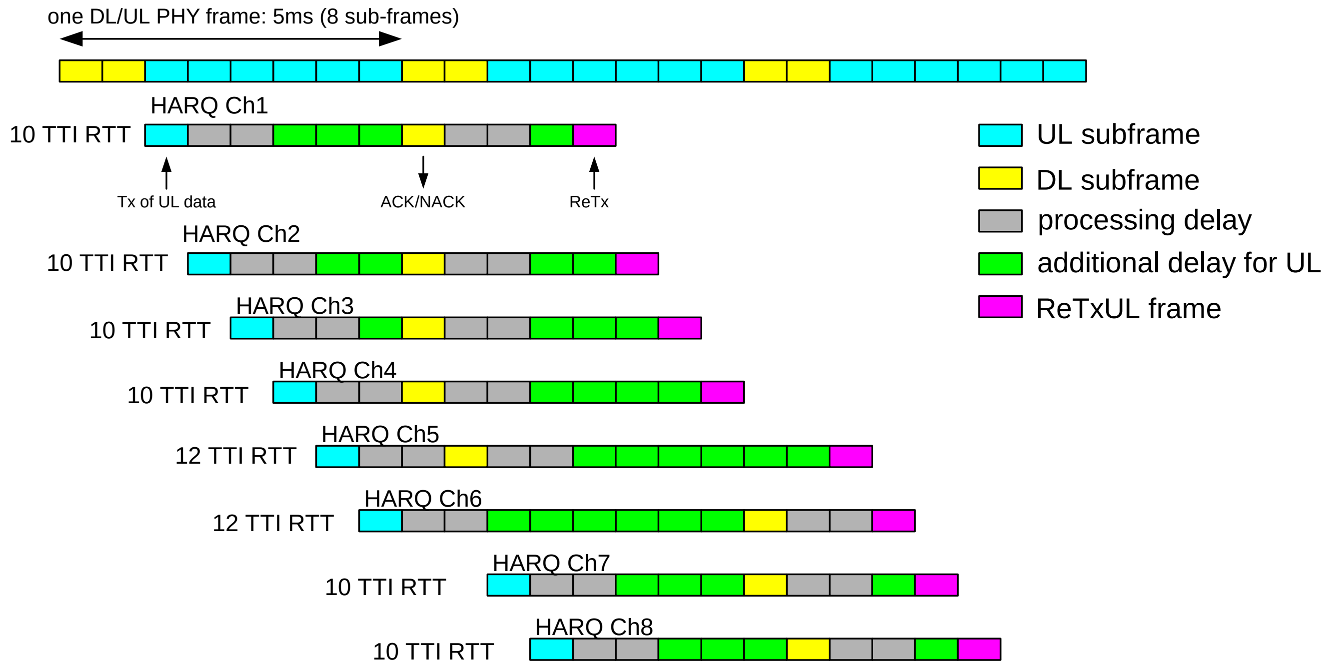

Figure 6: Non-adaptive synchronous UL HARQ timing (DL:UL=2:6)

4. Conclusion

We would like to propose the following text proposal **for the 802.16m SDDs [3]**

[Insert the following text to subclause 11.4.1 Basic Frame structure]

================================= *Start of Proposed Text*============================

There are two types of sub-frames: 1) the regular sub-frames which consist of six OFDMA symbols and 2) the irregular sub-frames that consist of five or less OFDMA symbols. Among downlink (DL) subframes, irregular subframe (if having) shall be put at the end of downlink portion. All uplink (UL) subframes are constrained to be regular.

================================= *End of Proposed Text*============================

[Insert the following text to 802.16m SDD]

================================= *Start of Proposed Text*============================

x.1 Downlink HARQ operation

x.1.1 DL HARQ allocation

DL HARQ region is restricted to a two dimensional region (frequency domain and subframe domain) consisting only of ***regular subframes***. Irregular subframe shall not be allocated to HARQ processes.

x.1.2 DL asynchronous adaptive HARQ

x.2 Uplink HARQ operation

x.2.1 UL HARQ allocation

UL HARQ region is restricted to a two dimensional region (frequency domain and subframe domain) consisting only of regular subframes.

x.2.2 UL synchronous non-adaptive HARQ

================================= *End of Proposed Text*==============================

5. References

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[8] C802.16m-08/151, "Downlink Control Structure related to Hybrid-ARQ".

[9] C80216m-08/152r1, "Physical Resource Allocation Unit in IEEE 802.16m Downlink (Editorial change)".

[10] C802.16m-08/175r1, "Proposal for IEEE 802.16m DL Resource Blocks and Channelization".