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Title	802.16m Frame Structure: Uplink Subframe Aggregation
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Re:	IEEE 802.16m-07/047 - Call for Contributions on Project 802.16m System Description Document
Abstract	This contribution proposes uplink subframe aggregation in the new 802.16m frame structure to address the improved cell coverage requirement and to increase effective uplink data rates seen at the cell edge.
Purpose	Discuss and Adopt
Notice	
Release	
Patent Policy	

802.16m Frame Structure: Uplink Subframe Aggregation

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Introduction

This contribution introduces a new logical concept into the 802.16m frame structure. The proposal gives new 802.16m MS a logical aggregation of consecutive UL subframes to carry one MAC PDU (medium access control protocol data unit) burst.

The contribution also addresses the improved cell coverage requirement as specified in [1] and increases effective uplink data rates at the cell edge. The cell range for mobile stations (MS) is extended by the proposed solution, while an overall desired asymmetric downlink-to-uplink ratio (DL/UL) is maintained and overheads caused by fragmentation are minimized. The proposal of aggregated UL subframes enables the usage of the most robust modulation and coding schemes in power limiting cases for better coverage. It also avoids unnecessary MAC overheads to increase the effective data rate seen at the MAC layer. The proposal also satisfies the legacy support requirement as specified in [1].

We propose that a section on cell coverage be added in the system description document. We recommend that this uplink subframe aggregation proposal be included in the cell coverage section of the System Description Document (SDD).

Proposed SDD Text

[Section] Frame Structure

[Section] Uplink Subframe Aggregation

By aggregating multiple UL subframes into one logical unit for demodulation and decoding, one UL MAC PDU may span over multiple frames such that enough symbol energies are accumulated for better coverage and larger payload can be accommodated for better efficiency. The uplink subframe aggregation logically combines two or more subframe durations into one MS data burst at the cell edge. The allocation is done by the mapping messages carried on the downlink. For mapping messages with specific starting positions for UL bursts, the MS follows the explicit allocation and the BS scheduler ensures that UL zones carrying aggregated subframes are arranged in a way without overlapping with UL zones independent from other subframes. For UL mapping messages with cumulative UL zone allocation, only one length of uplink aggregation can be applied and the size of the aggregated uplink permutation zone cannot be changed before the aggregation ends. It is recommended the aggregation always takes place in the end of the zone and the base station scheduler shall block out the portion of following subframes that is part of the aggregation. If aggregation is allocated in the beginning of a zone when the UL MAP IE is given, its position in the following subframes shall follow a reverse order starting from the end of the zone.

The uplink burst profile encoding in UCD that corresponds to UIUC needs new TLV values for cross-frame logical UL data bursts. As an alternative form of uplink subframe aggregation, the coded data bursts can be repeated, in an HARQ-like manner, without intermittent UL subframes. The uplink subframe aggregation may also be indicated by new extended UIUC-dependent or UIUC2-dependent IE of the UL MAP IE for the number of physical layer UL subframes that should be treated logically as one encoded packet.

Description of Proposed Uplink Subframe Aggregation

Cell Coverage Requirement

The proposed uplink subframe aggregation gives an extra signal space for power limited MS at the cell edge to accumulate bit energies and removes repetitive MAC PDU overheads. Hence, the proposal extends the coverage of the current lowest rate and also improves the effective data rate at the MAC layer.

Backward Compatibility Requirement

The proposed uplink subframe aggregation is transparent to legacy mobile stations.

Power-Limited (Cell-Edge) MS Operation in WirelessMAN OFDMA Reference Systems

To accommodate asymmetric traffic, WirelessMAN OFDMA Reference System [1] allocates unequal number of symbols to downlink and uplink subframes, as illustrated in Figure 1. For example, DL/UL values of the 5/10MHz reference system range from 35:12 to 26:21, with increments of 1 UL OFDM symbol and the total number of DL and UL symbols being 47.

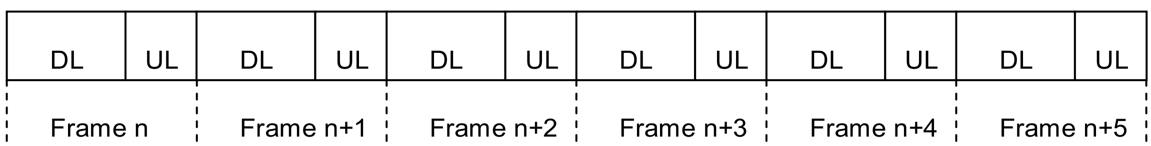

Figure 1: WirelessMAN OFDMA Reference Systems TDD frame with downlink and uplink subframes

Several inefficiencies can be identified with the existing UL subframe allocation.

The downlink coverage and the uplink coverage are differentiated by maximum transmitted power allowed for base stations (BS) and MS's. Typically there can be two-order differences, e.g., 20W versus 200mW. For MS's at the cell edge, it is important to impart as much energy as possible to the information bits in order to maximize the coverage. In order to maximize the time of transmission, it is preferable to use as few subchannels as possible. Thus, in power-limiting cases, the freedom of allocating radio resources on the uplink becomes one dimensional – only longer time duration can be used to accumulate more energy per information bit. The shorter UL duration, combined with the different order of maximum transmitted power UL, further limits the coverage.

As the power limiting case imposes constraints on the accumulated energy per information bit, the number of MAC payload bits decreases as the UL duration becomes shorter. As a result, the percentage of overhead associated with each MAC PDU increases and the throughput seen by upper layers degrades. For detailed numerology of the MAC PDU efficiency, the reader is referred to the appendix.

Proposed Uplink Subframe Aggregation

By aggregating multiple UL subframes into one logical unit for demodulation and decoding, one UL MAC PDU may span over multiple frames such that enough symbol energies are accumulated for better coverage and larger payload can be accommodated for better efficiency. This is illustrated in Figure 2.

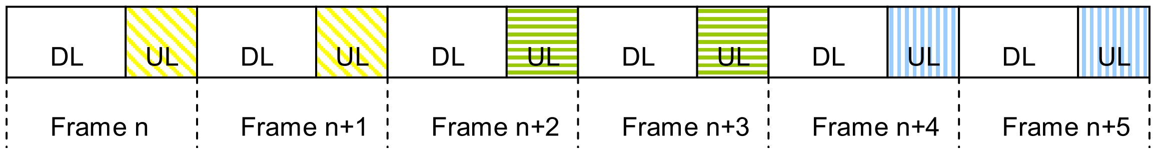

Figure 2: Example of a frame structure with aggregated uplink subframes (the same color/pattern represents one logical uplink data burst)

The proposed uplink subframe aggregation logically combines two or more subframe durations into one MS data burst at the cell edge. The allocation is done by the mapping messages carried on the downlink. Detailed descriptions of the associated mapping messages are given in the appendix.

Conclusions

This contribution addresses the improved cell coverage requirement as specified in [1] and proposes uplink subframe aggregation to increase effective uplink data rates at the cell edge. The fully backward-compatible proposal of aggregated UL subframes enables the usage of the most robust modulation and coding schemes in power limited cases for extended coverage. It also avoids unnecessary MAC overheads to increase the effective data rate seen at the MAC layer. We recommend that the proposed uplink subframe aggregation be included in the cell coverage section of the System Description Document (SDD).

References

[1] IEEE 802.16 Broadband Wireless Access Working Group, "IEEE 802.16m System Requirements", IEEE 802.16m-07/002r4, Oct 19, 2007.

[2] IEEE Std 802.16e-2005 and IEEE Std 802.16 Cor2/D3, "IEEE Standard for local and metropolitan area networks, Part 16: Air Interface for Fixed and Mobile Broadband Wireless Access Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed and Mobile Operation in License Bands,"

[3] WiMAX Forum™ Mobile System Profile, Release 1.0 Approved Specification (Revision 1.4.0: 2007-05-02)

Appendix

Detailed Numerology of Power-Limited (Cell-Edge) MS Operation in WirelessMAN OFDMA Reference Systems

If we are limited to the time duration of one uplink sub-frame, the current uplink subframe allocation is not as efficient in the following ways

1. Inability to utilize most robust modulation and coding scheme at peak power for maximum coverage: This is best illustrated by an example of minimum uplink data rates listed in Table 2. The most robust modulation and coding scheme (MCS) provided by 802.16 OFMDA is rate-1/2 QPSK with 6 repetitions. In this example, assume that the mobile terminal has already reached its uplink power limit and only one subchannel is allocated for maximum possible received energy per tone. Then, when the system is configured with DL/UL ratio 35:12, the most robust MCS (rate-1/2, QPSK with 6 repetitions) cannot be used with one subchannel. Instead, only 4 repetitions can be used. To extend the coverage with more repetition, the only option is to enable hybrid automatic repeat request (H-ARQ). However, the effective

data rate will be a result of dividing the data rate of the first subpacket by the number of frames during the entire transmission. In the aforementioned example, 9.6kbps will be reduced at least below 3.2kbps. The most robust MCS (rate-1/2 QPSK with 6 repetitions) is only supported at higher DL/UL ratio, e.g., 29:18.

Table 1: Most robust data rate supported by certain system set-up

UL/DL ratio	# subchannel	# channel symbols	MCS	payload	repetition factor	data rate
35:12	1	192	QPSK, rate-1/2	48 bits	4	9.6kbps
29:18	1	336	QPSK, rate-1/2	48 bits	6	9.6kbps

2. Inefficiency in providing service coverage: Another problem is the packing efficiency of the medium access control (MAC) protocol data unit (PDU). In addition to the payload, each MAC PDU contains a 6-byte header and a 4-byte CRC for ARQ. If HARQ is enabled, extra 2-byte physical layer CRC is mandatory by the current standards. Therefore, when the size of uplink burst is limited because of subchannelization, the percentage of MAC PDU payload, hence the effective data rate seen by upper layer services, drops significantly. If VoIP service is carried by a system with the setup in Table 2, the 19.2kbps physical data rate can only support 16 bit vocoder payload every 5 ms, translating to 3.2kbps effective data rate for the VoIP service flow. The efficiency is obviously too low. Note that the use of AES-CCM adds 12 bytes of extra overhead per MAC frame, and this has not been taken into account in the above analysis.

Table 2: Upper-layer effective data rate and physical data rate

# required subchannels	total PHY payload bits	MAC overhead	MAC PDU payload	PHY data rate	Effective data rate
1	96 (12B)	80	16	19.2kbps	3.2kbps
2	128 (16B)	80	48	25.6kbps	9.6kbps
DL:UL ratio = 35:12 MCS: QPSK rate-1/2, 2 repetitions					

3. Excessive UL-MAP IE overhead on downlink: Continuing the example in Table 2, we examine the downlink overhead requirement for delivering 48 bits of MAC PDU payload. For a cell-edge power-limited MS, the BS allocates one subchannel and rate-1/2 QPSK with 2 repetitions to maximize its coverage. From Table 2, three uplink subframes, hence three UL-MAP's, are need to carry 48 bits of MAC PDU payload. Each UL MAP IE requires 32 bits for an uplink data burst (16-bit CID, 4-bit UIUC, 12 bits for duration and repetition coding indication). Thus the downlink overhead (>32 bits) used to schedule each uplink subframe (with a MAC PDU payload of 16 bits) becomes excessive for providing coverage to the cell-edge mobile terminals.

Detailed Uplink Subframe Aggregation Signalling

For systems using SUB-DL-UL-MAP, there is no ambiguity in the location of each UL zone. The slot offset indicating the beginning of each UL zone is clearly signaled in the SUB-DL-UL-MAP. The UL zone that carries aggregated subframes is arranged by the BS scheduler such that it does not overlap with UL zones that are independent from other subframes. The uplink burst profile encoding that corresponds to UIUC values needs new addition. Currently, Table 612 for OFDMA in Chap 11.3.1.1 defines uplink burst profile encoding with values 0-52. It is suggested that certain values from 53 to 255 be taken to indicate 2x, 3x and 4x uplink frame aggregation for a logical QPSK rate-1/2 burst. In addition, the repetition can be replaced with an HARQ-like retransmission. The difference is that the coded data bursts are repeated without intermittent UL subframes. Rather, the retransmission occurs in the immediate subsequent UL subframes at a predetermined number of times. The deterministic retransmission without CRC is another form of repetition. If desired, ACK/NACK can be enabled for early termination gain. However, 2 bytes of extra CRC overhead reduces the number of MAC PDU payload bits and hence the effective data rate.

For systems using regular UL MAP, a minor modification is introduced to the new 802.16m MS. The regular UL MAP allocates the bandwidth by block allocation and slot allocation. The block allocation specifies the position and the shape of the assigned frequency-time resource and applies to the following uplink signals: Fast feedback (UIUC=0), HARQ ACK channel (UIUC=11 with type = 8), CDMA ranging and bandwidth request (UIUC = 12) and PAPR/sounding/safety zone (UIUC = 13).
For UL data bursts, the regular UL MAP assigns frequency-time resources by the rule of slot allocation. That is, the starting position for slot allocation is determined by considering the prior allocation appeared in the UL-MAP and shall be the lowest numbered non-allocated subchannel on the first non-allocated OFDMA symbol. The length of each uplink data burst is given by its UL MAP IE. The position of each uplink data burst shall start immediately following the previous UL MAP IE and shall advance in the time axis. When the end of the UL zone has been reached, the allocation shall continue at the next subchannel from the start of the zone.
Under the rule of slot allocation, the uplink subframe aggregation is illustrated in Figure 3. As an example, there are 6 bursts in 2 uplink subframes. We assume bursts #1 and #2 are transmitted by mobile terminals at the cell edge and require twice the information bit energies as that provided by transmission over a single-frame at the base station for coverage. We further assume all other bursts (#3 through #6) only need a single subframe for enough information bit energy. The logic of combining uplink subframes for burst #1 and #2 while maintaining the existing UL MAP IE slot allocation goes as follows:

1. At frame #n, the downlink sends UL MAP IE's for bursts #1 through #4. The UL MAP IE's for bursts #1 and #2 are intended for cell-edge MS's to transmit in two consecutive uplink subframes #n and #(n+1). The MS's for burst #3 and #4 are in better channel conditions and will only transmit during uplink subframe #n.
2. The UL MAP IE's for burst #1 and #2 carry data burst profiles (UIUC =0,1,…,10) mapped to new values defined in the UCD TLV encoding.
    a. Uplink burst profile encoding for OFDMA is specified in Table 612 in Section 11.3.1.1 of [1], where values 0-52 of Type 150 (FEC and modulation) have been used.
    b. We suggest some values from 53 to 255 be used for 2-, 3- and 4- subframe logical uplink burst with rate-1/2 CTC and QPSK modulation.
3. Due to the sequential arrangement of slot allocation, a UL MAP IE that allocates the data burst of more than one UL subframe should not placed in arbitrary position in UL MAP or sub-DL-UL-MAP. It is recommended to put uplink subframe aggregation UL MAP IE either in the beginning part or the last part of uplink allocation.
    a. When sub-DL-UL-MAP is used, multiple lengths of uplink subframe aggregation can be applied without ambiguity because each sub-DL-UL-MAP specifies the exact starting position of its UL MAP IE's.

b. When UL MAP is used, only one length of uplink aggregation can be applied. The aggregated allocation always lies in the end of UL bursts.
    i. The size of a uplink permutation zone cannot be changed before the aggregation ends
    ii. It is recommended the aggregation always takes place in the end of the zone and the base station scheduler shall block out the portion of following subframes that is part of the aggregation.
    iii. If aggregation is allocated in the beginning of a zone when the associated UL MAP IE is given, slots of those data bursts in the aggregated subframes in the following frames shall follow a reverse order starting from the end of the zone. The anchor UL MAP (sent in the frame contains the first UL subframe of the logical aggregation) for aggregated UL subframe delineates the last part of the subsequent physical UL subframes. For each UL MAP IE intended for a connection with aggregated UL subframes, its corresponding UL slots are placed in the reverse order of slot allocation in the subsequent UL subframes.

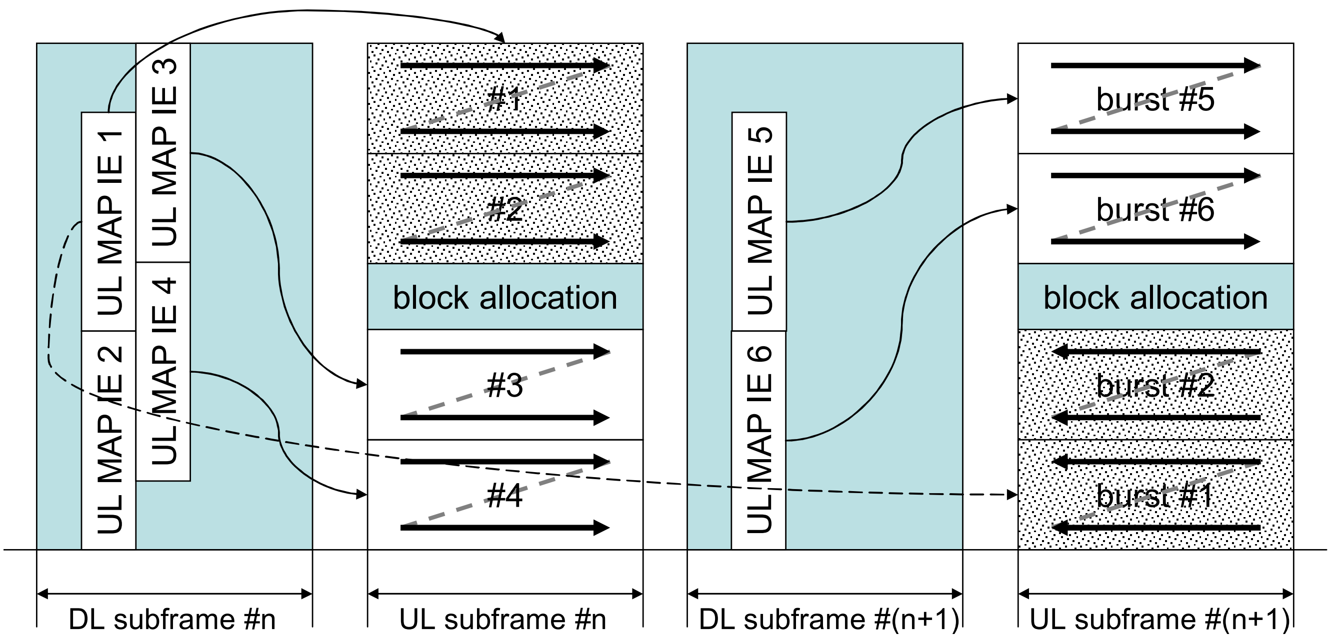

Figure 3: Block allocation, slot allocation and uplink subframe aggregation for UL MAP

One might argue that ranging coverage would be a pre-requisite for data coverage. This can be solved by either consecutively allocating the mobile with ranging channel access, or converting the reserved bit in UL MAP IE with UIUC=12 into a persistent bit. That is, a 1 indicates the terminal is allocated with the ranging channel continuously and a 0 indicates that it is the last UL subframe in the continuous ranging allocation. Such reserve bit toggling is also strictly backward compatible with existing terminals.

The uplink subframe aggregation can also be implemented by introducing new extended UIUC-dependent or UIUC2-dependent IE of the UL MAP IE to indicate the number of physical layer TDD frames whose UL subframes the scheduled terminal should treat logically as one encoded packet. If it is desired to use the current burst profile indicators (UIUC between 1 and 10) for the newly aggregated UL formats, additional TLV values can be added to the PHY-specific section of UCD. Both methods (new UIUC dependent IE's or new TLV in UCD) are strictly backward compatible with existing terminals.

Benefit of Uplink Subframe Aggregation

The benefit of uplink subframe aggregation is better coverage for better effective data rate seen by the higher layer. This is clearly demonstrated in Detailed Uplink Subframe Aggregation Signalling

For systems using SUB-DL-UL-MAP, there is no ambiguity in the location of each UL zone. The slot offset indicating the beginning of each UL zone is clearly signaled in the SUB-DL-UL-MAP. The UL zone that carries aggregated subframes is arranged by the BS scheduler such that it does not overlap with UL zones that are independent from other subframes. The uplink burst profile encoding that corresponds to UIUC values needs new addition. Currently, Table 612 for OFDMA in Chap 11.3.1.1 defines uplink burst profile encoding with values 0-52. It is suggested that certain values from 53 to 255 be taken to indicate 2x, 3x and 4x uplink frame aggregation for a logical QPSK rate-1/2 burst. In addition, the repetition can be replaced with an HARQ-like retransmission. The difference is that the coded data bursts are repeated without intermittent UL subframes. Rather, the retransmission occurs in the immediate subsequent UL subframes at a predetermined number of times. The deterministic retransmission without CRC is another form of repetition. If desired, ACK/NACK can be enabled for early termination gain. However, 2 bytes of extra CRC overhead reduces the number of MAC PDU payload bits and hence the effective data rate.

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4. At frame #n, the downlink sends UL MAP IE’s for bursts #1 through #4. The UL MAP IE’s for bursts #1 and #2 are intended for cell-edge MS’s to transmit in two consecutive uplink subframes #n and #(n+1). The MS’s for burst #3 and #4 are in better channel conditions and will only transmit during uplink subframe #n.
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   i. The size of a uplink permutation zone cannot be changed before the aggregation ends

   ii. It is recommended the aggregation always takes place in the end of the zone and the base station scheduler shall block out the portion of following subframes that is part of the aggregation.

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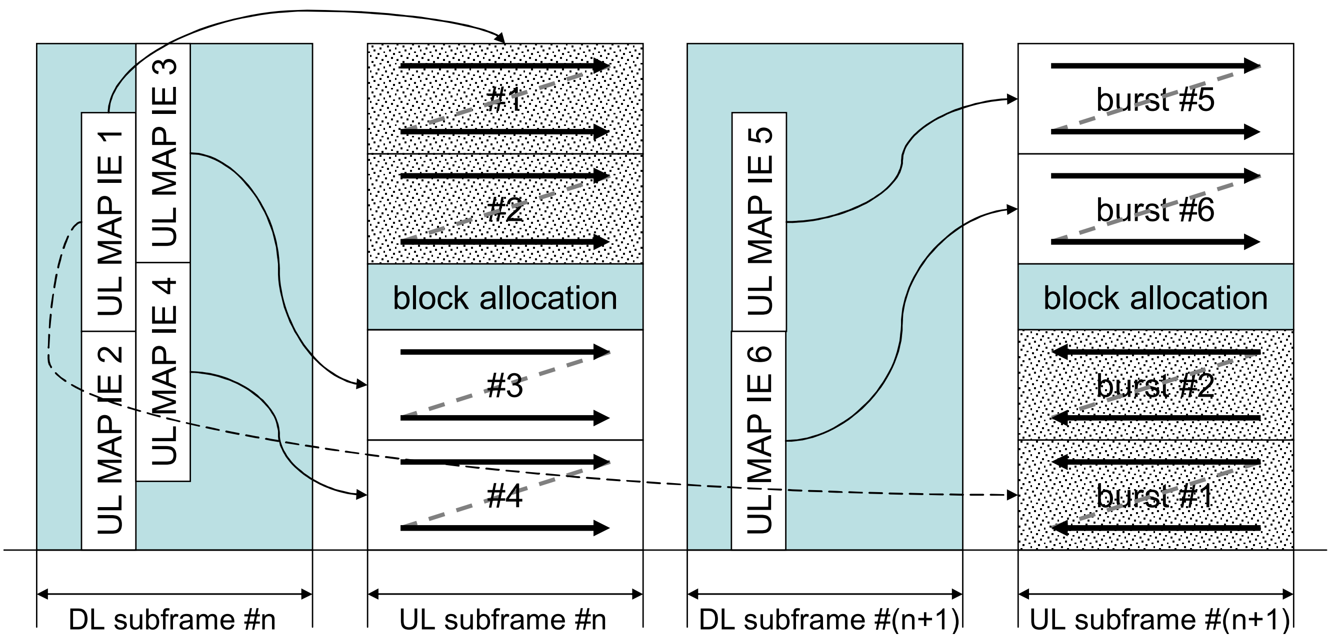

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. The effective data rate is defined by dividing the number of MAC PDU payload bits with the total time duration of aggregated frames. As seen in Table 2 and Detailed Uplink Subframe Aggregation Signalling

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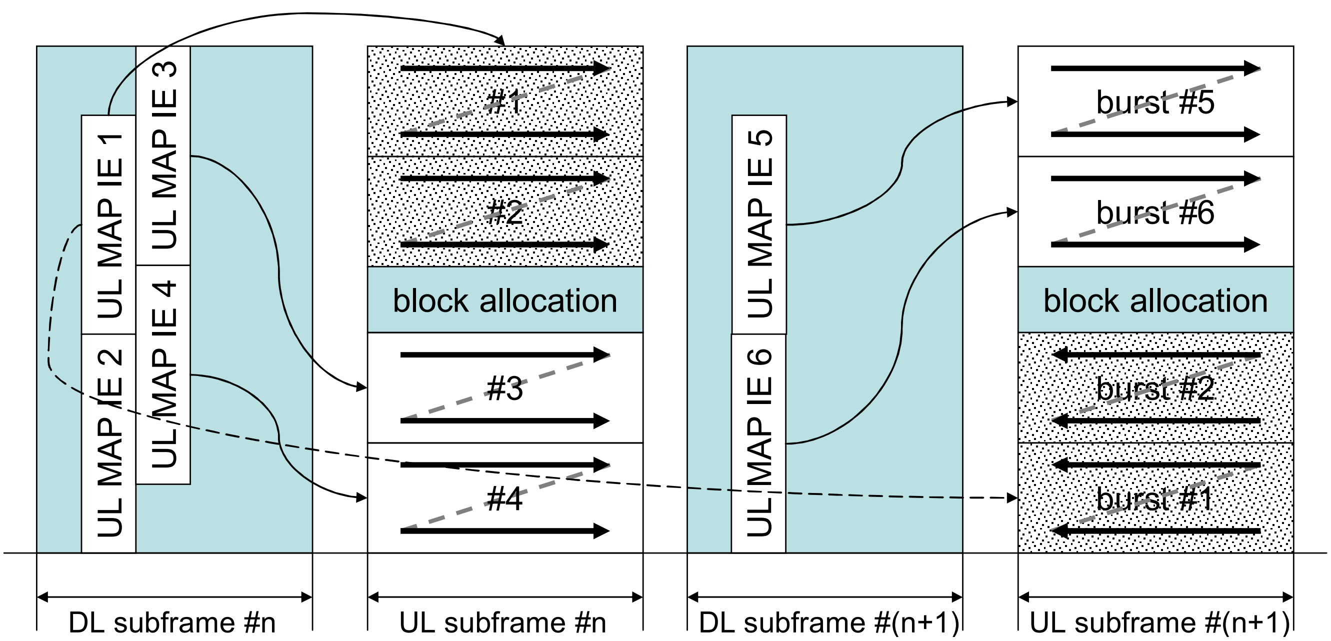

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, to deliver 9.6kbps uplink effective data rate, 2 subchannels must be used to provide sufficient number of channel symbols.
All the configurations shown in Table 3 deliver the same energy per information bit, thus have equivalent coverage performance.

Table 3: Illustration of coverage extension and upper-layer effective data rate improvement by using uplink subframe aggregation under DL:UL ratio = 35:12 with MCS = QPSK rate-1/2, 2 repetitions

# aggregated subframes	total PHY payload bits	MAC overhead	MAC PDU payload	PHY data rate	Effective data rate
1 (1 subchannel)	96 (12B)	80	16	19.2kbps	3.2kbps
2	192 (24B)	80	112	19.2kbps	11.2kbps
3	288 (36B)	80	208	19.2kbps	13.86kbps
4	384 (48B)	80	304	19.2kbps	15.2kbps