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Re:	Task Group Review of IEEE P802.16-REVd/D2-2003
Abstract	Changes to OFDMA PHY
Purpose	Adoption
Notice	
Release	
Patent Policy and Procedures	

1 Overview

This contribution proposes various enhancements to the OFDMA PHY mode to provide better coverage and capacity. The following features are add,

- AMC sub-channels and band selection
- Hybrid-ARQ
- High-efficiency uplink sub-channel structure
- Coverage enhancing safety channels

2 AMC sub-channels and band selection

AMC stands for Adaptive Modulation and Coding. AMC sub-channels take advantage of the optional AAS permutation available in the OFDMA PHY specification to provide sub-channels there use a contiguous block of sub-carriers. These sub-channels together with the fast uplink channels available to OFDMA can be used to rapidly assign a modulation and coding combination that is most applicable to the specific sub-channel, that is expected to experience flat fading behavior because of its structure.
The AMC sub-channels enable employing 'water-pouring' type of algorithms for most efficient use of the DL farme.

3 Hybrid-ARQ

Hybrid-ARQ feature is an optional feature intended to enhance the robustness of bursts transmitted by the BS. Hybrid-ARQ is supported both in the downlink and the uplink, and builds on the fast uplink feedback channels available in the OFDMA mode.
It is known that Hybrid Automatic Request (HARQ) is very efficient against the channel quality difference. In case of the previous transmission failure (NACK), HARQ schemes retransmit more redundancy and receiver combines whole redundancy received. The combining makes more SNR and coding gain against the change of channel condition.
There are many variants in HARQ schemes. Among them, chase combining (CC) and incremental redundancy (IR) are cited in many literatures. When the previous transmission is failed CC sends the same copy that was sent in the previous transmission and IR sends part of codeword that may different from previous first transmission. The IR scheme shows better performance due to the additional coding gain over the CC. Thus, the IR scheme is very viable solution for 802.16d OFDMA FEC.
For the implementation of IR scheme, the generation of sub-packets from the mother codeword is necessary. Further, the subpacket should show a complementary property for better performance.

For CTC and 802.16 OFDMA, the following requirements should be satisfied with FEC structure.
1. FEC structure should support IR type HARQ scheme.
2. For the support of IR type HARQ scheme, the sub-packet should show complementary property.

H-ARQ (Hybrid Automatic Repeat reQuest) can be used to mitigate the effect of channel and interference fluctuation. H-ARQ renders performance improvement due to SNR gain and time diversity achieved by combining previously erroneously decoded packet and retransmitted packet, and due to additional coding gain by IR (Incremental Redundancy). Figure 1 illustrates the throughput difference between H-ARQ and other scheme. The rightmost orange line depicts the system throughput of conventional ARQ scheme without soft combining, the blue line depicts that of Chase combining, and the leftmost pink line depicts that of IR. As can be seen in the figure, Chase combining can expand the operating region by 3dB over conventional ARQ scheme without soft combining, and IR can expand it by additional 2dB. This can be greatly beneficial to the system operation. In fading channels with terminals in motion, the received SNR would be in very broad region in contrast to AWGN channel. In such a case, call drop may be frequent even if multiple retransmission is performed without soft combining. However with soft combining, the operating region would be expanded to enable the reliable communication. In brief, H-ARQ is the technique proposed to overcome the adaptation error of the AMC(Adaptive Modulation and Coding) in fading channel.

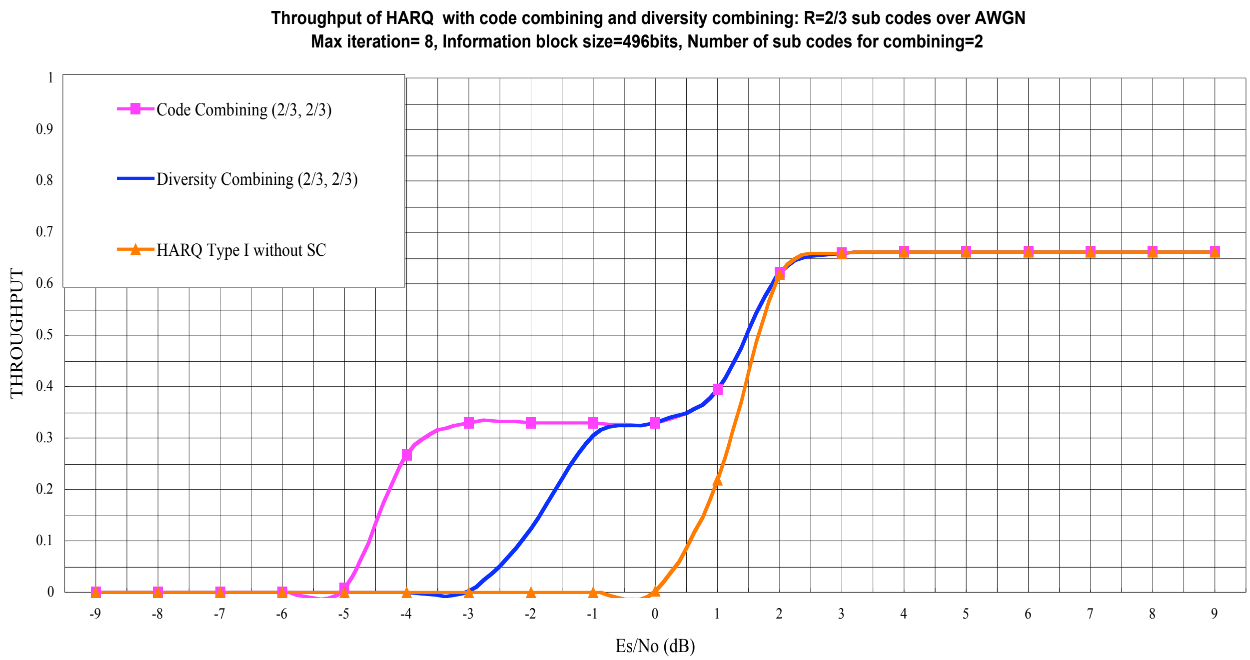


Figure 1. Soft combining gain in H-ARQ

4 High-efficiency uplink sub-channel tile

The high-efficiency uplink tiles enable better efficiency in the UL for SS with slowly changing air-link conditions. These tiles are combined with the existing high-mobility tiles to enable optimized usage of the UL BW.

5 Coverage enhancing safety channels

Coverage enhancing safety channels are channels intended to provide reduced interference zones within the coverage area of a BS that may interfere with other BS. These reduced interference zones may then be used by a neighbor BS to transmit data to SS that are registered with it, which would otherwise suffer from interference from the interfering BS. The BS can create Safety channels by allocating Gap regions in the DL-MAP and UL-MAP.

6 Specific text changes

6.1 AMC sub-channels and band selection

[Update the text in section 8.4.6.3 according to the text below]:

8.4.6.3 Optional permutations for AAS and AMC sub-channels

A BS ~~using the AAS option~~ may change from the “distributed subcarrier permutation” described in 8.4.6.1 and 8.4.6.2 to the “adjacent subcarrier permutation” when changing from non-AAS to AAS-enabled traffic to support AAS adjacent subcarrier user traffic in the cell. Alternatively the adjacent subcarrier permutation can be used to take advantage of the structure of the adjacent subcarrier

permutation in parts of DL sub-frame that are indicated accordingly by the DL-MAP. After this change, the BS shall only transmit / receive ~~AAS-enabled~~ traffic using the adjacent subcarrier permutation ~~until the end of the frame~~ during the allocated period. The BS shall always return to the distributed subcarrier permutation ~~for the broadcast (non-AAS) traffic~~ at the beginning of a new DL sub-frame. While the BS does not have any SSs registered that are not capable of using the ~~AAS~~ adjacent subcarrier permutation selected by the BS, the BS may employ the AAS superframe structure. Otherwise, it shall always return to the distributed subcarrier permutation at the end of each frame and provision broadcast traffic at the start of each frame.
The AAS superframe shall have the following structure:
1) The BS shall start each superframe with no less than 20 consecutive frames, which contain both downlink and uplink broadcast OFDMA symbols. Each of these frames shall provision DCD, UCD, DL-MAP and UL-MAP messages, and at least one initial ranging opportunity. The frame duration code in each frame except the last one shall be set to the actual frame duration used. The frame duration code in the last frame shall be set to 0x00.
2) Subsequently, the BS shall transmit up to 200 ms of AAS only frames, followed by a minimum of one frame containing at least one downlink broadcast OFDMA symbol, which shall provision DCD, UCD and DL-MAP messages. The frame duration code shall be set to 0x00.
3) The BS shall repeat Step 2) of this subclause, up to the AAS superframe duration, which shall be no more than 1s.

With the adjacent subcarrier permutation, symbol data within a subchannel is assigned to adjacent subcarriers and the pilot and data subcarriers are assigned fixed positions in the frequency domain within an OFDMA symbol. This permutation is the same for both uplink and downlink. Within each frame, the BS shall indicate the switch to the optional permutation in the AAS_DL_IE() and AAS_UL_IE() when switching to AAS traffic (see 8.4.5.3 and 8.4.5.4). To define adjacent subcarrier permutation, a bin, which is the set of 9 contiguous subcarriers within an OFDMA symbol, is a basic allocation unit both in downlink and uplink. A bin structure is shown in Figure 226.

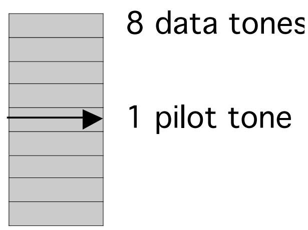


Figure 226 – Bin structure

A group of 4 rows of bins is called a band. AMC subchannel consists of 6 contiguous bins in a same band.

Table 249—OFDMA adjacent subcarrier allocations (2048-FFT)

Parameter	Value
Number of dc subcarriers	1
Number of guard subcarriers, left	160
Number of guard subcarriers, right	159
N_{used} , Number of used subcarriers	1728
Total number of subcarriers	2048
Number of pilots	192
Number of data subcarriers	1536
Number of bands	48
Number of bins per band	4
Number of data subcarriers per subchannel	48

Table 250—OFDMA adjacent subcarrier allocations (1024-FFT)

Parameter	Value
Number of dc subcarriers	1
Number of guard subcarriers, left	80
Number of guard subcarriers, right	79
N_{used} , Number of used subcarriers	864
Total number of subcarriers	1024
Number of pilots	96

Number of data subcarriers	768
Number of bands	24
Number of bins per band	4
Number of data subcarriers per subchannel	48

Table 251—OFDMA adjacent subcarrier allocations (512-FFT)

Parameter	Value
Number of dc subcarriers	1
Number of guard subcarriers, left	40
Number of guard subcarriers, right	39
N_{used} , Number of used subcarriers	432
Total number of subcarriers	512
Number of pilots	48
Number of data subcarriers	384
Number of bands	12
Number of bins per band	4
Number of data subcarriers per subchannel	48

6.2 Hybrid-ARQ

[Update the text in section 8.4.9.2.3.1 according to the text below]:

The Convolutional Turbo Code defined in this section is designed to enable support of hybrid ARQ (HARQ). HARQ implementation is optional. The Convolutional Turbo Code encoder, including its constituent encoder, is depicted in Figure 240. It uses a double binary Circular Recursive Systematic Convolutional code. The bits of the data to be encoded are alternately fed to *A* and B, starting with the MSB of the first byte being fed to A. The encoder is fed by blocks of k bits or N couples (k = 2*N bits). For all the frame sizes k is a multiple of 8 and N is a multiple of 4. Further N shall be limited to: $8 \le N/4 \le 1024$.

The polynomials defining the connections are described in octal and symbol notations as follows:
— For the feedback branch: 0xB, equivalently $1+D+D^3$ (in symbolic notation)
— For the Y parity bit: 0xD, equivalently $1+D^2+D^3$
— For the W parity bit: 0x9, equivalently $1+D^3$

[Replace figure 240 with the figure below]:

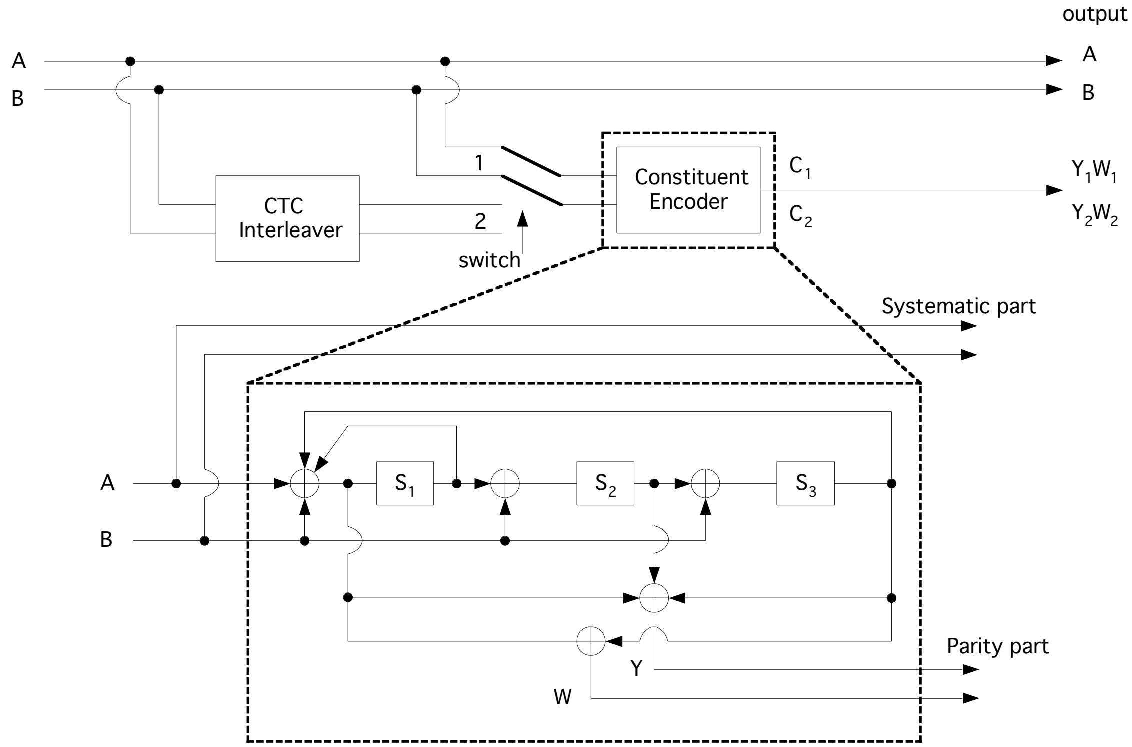


Figure 240—CTC encoder

First, the encoder (after initialization by the circulation state Sc_1, see 8.4.9.2.3.3) is fed the sequence in the natural order (position 1) with the incremental address $i = 0 .. N-1$. This first encoding is called S_{C1} encoding. Then the encoder (after initialization by the circulation state Sc_2, see 8.4.9.2.3.3) is fed by the interleaved sequence (switch in position 2) with incremental address $j = 0, \ldots N-1$. This second encoding is called C_2 encoding.
The order in which the encoded bit shall be fed into the interleaver (8.4.9.3) is:

$$\cancel{A_0, B_0 .. A_{N-1}, B_{N-1}, Y_{1,0}, Y_{1,1} .. Y_{1,M}, Y_{2,0}, Y_{2,1} .. Y_{2,M}}$$

$$A, B, Y_1, W_1, Y_2, W_2 =$$
$$A_1, A_2, \cdots, A_N, B_1, B_2, \cdots, B_N, Y_{11}, Y_{12}, \cdots, Y_{1N}, W_{11}, W_{12}, \cdots, W_{1N}, Y_{21}, Y_{22}, \cdots, Y_{2N}, W_{21}, W_{22}, \cdots, W_{2N}$$

where M is the number of parity bits.

[Delete section 8.4.9.2.3.4 and add the text below instead]:

8.4.9.2.3.4 Subpacket generation

Proposed FEC structure punctures the mother codeword to generate subpacket with various coding rates. The subpacket is also used as HARQ packet transmission. Figure bbb shows block diagram of subpacket generation. 1/3 CTC encoded codeword goes through interleaving block and the puncturing is performed. The puncturing is performed to select the consecutive interleaved bit sequence that starts at any point of whole codeword. For the first transmission, the subpacket is generated to select the consecutive interleaved bit sequence that starts from the first bit of the systematic part of the mother codeword. The length of the subpacket is chosen according to the needed coding rate reflecting the channel condition. The first subpacket can also be used as a codeword with the needed coding rate for a burst where HARQ is not applied.

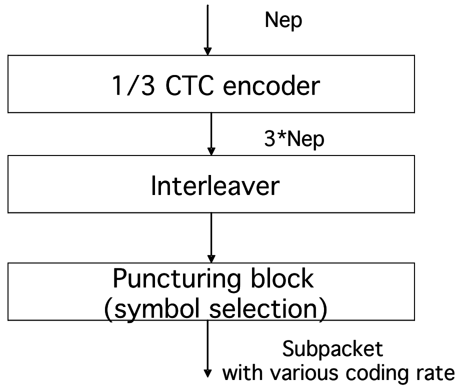


Figure bbb— Block diagram of subpacket generation

8.4.9.2.3.5 Interleaving block

The puncturing process is very common to generate various coding rates with Turbo code families. However, the puncturing should guarantee the complementary characteristics of the punctured codeword. In other words, the parity bits of the punctured codeword should be chosen uniformly from the parity bits of a constituent encoder. The parity bits of the punctured codeword should have even number of parities from the two constituent encoders. Because the puncturing is just a simple process to select the subpacket, the proposed FEC structure rely such complementary property on the interleaving block.
Figure ccc shows block diagram of the interleaving scheme of the proposed FEC structure. At first, the CTC encoder output is separated into a sublock. Then the interleaving is applied for the bit sequence within the sublock. It guarantees the uniformity of the interleaved codeword. Next, Symbol grouping is performed such that the parity bits from the two constituent encoders are interlaced bit by bit. The systematic part of the 1/3 CTC encoder is located at the head of the interleaved codeword. In this way, the proposed FEC structure ensures the quasi complementary characteristics of the interleaved codeword and thus, complementary characteristics of the subpacket. We just say “quasi complementary” for the case of breaking the complementariness of few bits after puncturing.

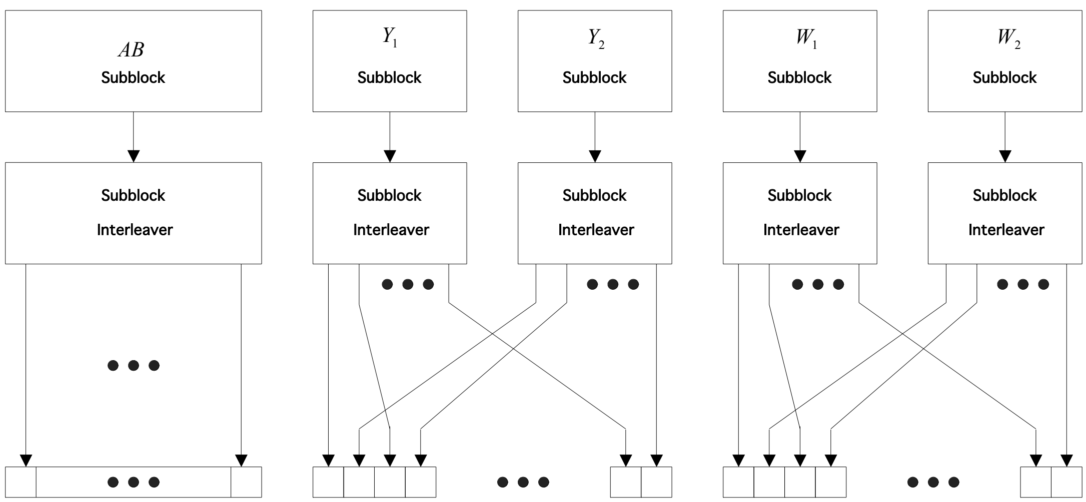


Figure ccc— Block diagram of the interleaving scheme

8.4.9.2.3.6 Symbol selection

Lastly, symbol selection is performed to generate the subpacket. We call the puncturing block as the symbol selection in the viewpoint of subpacket generation.
Mother code is transmitted with one of subpackets. The symbols in a subpacket are formed by selecting specific sequences of symbols from the interleaved CTC encoder output sequence. The resulting subpacket sequence is a binary sequence of symbols for the modulator.

Let

k be the subpacket index when HARQ is enabled. k=0 for the first transmission and increases by one for the next subpacket;
N_{EP} be the number of bits in the encoder packet
N_{SCHk} be the number of subchannel(s) allocated for the k-th subpacket
m_k be the modulation order for the k th subpacket ($m_{k=0}$ = 2 for QPSK, 4 for 16QAM, and 6 for 64-QAM); and
$SPID_k$ be the subpacket ID for the k-th subpacket, (for the first subpacket, $SPID_{k=0}$ = 0).

Also, let the scrambled and selected symbols be numbered from zero with the 0-th symbol being the first symbol in the sequence. Then, the index of the i-th symbol for the k-th subpacket shall be

$$S_{k,i} = (F_k + i) \bmod (3 * N_{EP})$$

where $i = 0 \text{ to } L_K - 1$,

$$L_k = 48 * N_{SCHk} * m_k \text{, and}$$

$$F_k = (SPID_k * L_k) \bmod (3 * N_{EP}).$$

The N_{EP}, N_{SCHk}, and SPID values are determined by the BS and can be inferred by the SS through the allocation size in the DL-MAP and UL-MAP. The m_k parameter is determined in the next subsection. The above symbol selection makes the followings possible.
1. The first transmission includes the systematic part of the mother code. Thus, it can be used as the codeword for a burst where the HARQ is not applied.
2. The location of the subpacket can be determined by the SPID itself without the knowledge of previous subpacket. It is very important property for HARQ retransmission.

[Add the text below to a new section after 6.4.15]:

6.4.16 MAC support for HARQ

Hybrid automatic repeat request (H-ARQ) scheme is an optional part of the MAC and can be enabled on a per-terminal basis. The per-terminal H-ARQ and associated parameters shall be specified and negotiated during initialization procedure. A terminal cannot have a mixture of H-ARQ and non-H-ARQ traffic.
One or more MAC PDUs can be concatenated and an H-ARQ packet formed by adding a CRC to the PHY burst. Figure eee shows how the H-ARQ encoder packet is constructed.

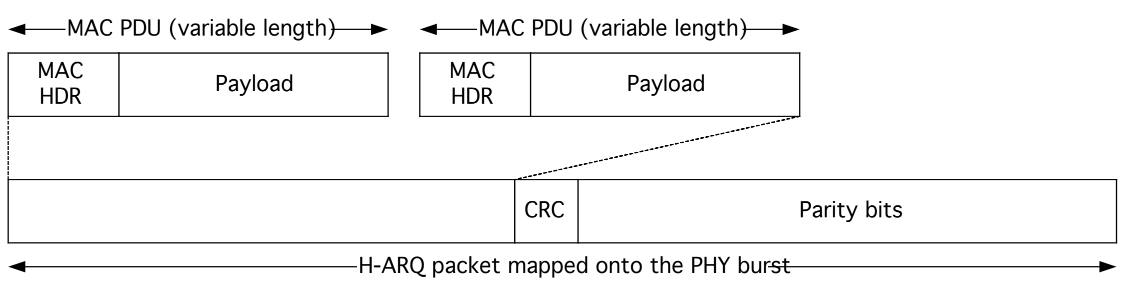


Figure eee—Construction of H-ARQ encoder packet

Each H-ARQ packet is encoded according to the PHY specification, and four subpackets are generated from the encoded result. A subpacket identifier (SPID) is used to distinguish the four subpackets. In case of downlink communication, a BS can send one of the subpackets in a burst transmission. Because of the redundancy among the subpackets, SS can correctly decode the original encoder packet even before it receives all four subpackets. Whenever receiving the first subpacket, the SS attempts to decode the original encoder packet from it. If it succeeds, the SS sends an ACK to the BS, so that the BS stops sending additional subpackets of the encoder packet. Otherwise, the SS sends a NAK, which causes the BS to transmit one subpacket selected from the four. These procedures go on until the SS successfully decodes the encoder packet. When the SS receives more than one subpacket, it tries to decode the encoder packet from ever-received subpackets.
The rule of subpacket transmission is as follows,

1. At the first transmission, BS shall send the subpacket labeled ‘00’.

2. BS may send one among subpackets labeled '00', '01', '10', or '11' in any order, as long as the total number of transmitted subpackets does not exceed the maximum number of H-ARQ retransmission specified in CD message .
3. BS can send more than one copy of any subpacket, and can omit any subpacket except the subpacket labeled '00' .

In order to specify the start of a new transmission, one-bit H-ARQ identifier sequence number (AI_SN) is toggled on every successful transmission of an encoder packet on the same H-ARQ channel. If the AI_SN changes, the receiver treats the corresponding subpacket as a subpacket belongs to a new encoder packet, and discards ever-received subpackets with the same ARQ identifier.
The H-ARQ scheme is basically a stop-and-wait protocol. The ACK is sent by the SS after a fixed delay (synchronous ACK) defined by H-ARQ_ACK_DELAY which is specified in CD message. Timing of retransmission is, however, flexible and corresponds to the asynchronous part of the H-ARQ.
The H-ARQ scheme supports multiple H-ARQ channels per a connection, each of which may have an encoder packet transaction pending. The number of H-ARQ channels in use is determined by BS. These ARQ channels are distinguished by an H-ARQ channel identifier (ACID). The ACID for any subpackets can be uniquely identified by the control information carried in the MAPs.
H-ARQ (Hybrid Automatic Repeat reQuest) can be used to mitigate the effect of channel and interference fluctuation. H-ARQ renders performance improvement due to SNR gain and time diversity achieved by combining previously erroneously decoded packet and retransmitted packet, and due to additional coding gain by IR (Incremental Redundancy).

6.4.16.2 DL/UL ACK/NAK signaling

For DL/UL H-ARQ, fast ACK/NAK signaling is necessary. For the fast ACK/NAK signaling of DL H-ARQ channel, a dedicated PHY layer ACK/NAK channel is designed in UL. For the fast ACK/NAK signaling of UL H-ARQ channel, H-ARQ ACK message is designed.

6.3 High-efficiency uplink sub-channel

[Add a new section after section 8.4.6.2.3]:

8.4.6.2.4 Additional optional Symbol Structure for PUSC

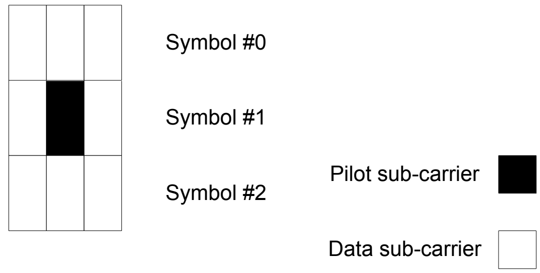
The additional optional subchannel structure uplink supports 92 subchannels where each transmission uses 48 data carriers symbols as their minimal block of processing.

Table ggg— OFDMA uplink subcarrier allocations

Parameter	**Value**	**Comments**
Number of DC Subcarriers	1	index 1024
Number of Guard Subcarriers, Left	183	
Number of Guard Subcarriers, Right	184	
Number of Used Subcarriers (Nused) including all possible allocated pilots and the DC carrier.	1681	Number of all subcarriers used within a symbol
PermutationBase0	12, 71, 62, 42, 73, 88, 89, 5, 77, 43, 86, 63, 55, 48, 54, 35, 79, 69, 36, 44, 2, 38, 21, 91, 31, 27, 72, 75, 17, 39, 34, 66, 70, 49, 67, 10, 45, 15, 13, 84, 37, 8, 19, 65, 81, 83, 24, 33, 53, 22, 7, 6, 90, 18, 52, 9, 32, 40, 47, 41, 60, 16, 26, 59, 3, 51, 57, 74, 4, 64, 68, 23, 20, 78, 56, 61, 29, 1, 25, 46, 28, 85, 50, 80, 82, 11, 58, 87, 76, 30, 14, 0	used to allocate tiles to subchannels
Number of carriers per tile	3	Number of all subcarriers used within a tile
Number of tiles	552	
Number of tiles per subchannel	6	
Number of subchannels	92	

A burst in the uplink is composed of 3 time symbols and 1 subchannel, within each burst, there are 48 data subcarriers and 6 fixed-location pilot subcarrier. Tile configuration is illustrated in Figure 223.

Figure hhh—Description of an uplink tile



The allocated frequency band shall be divided into 552 tiles, the allocation of tiles to subchannels is performed in the following manner:
1). Divide the tiles space into 6 groups, containing 92 tiles each
2). Choose 6 tiles per subchannel using the following formula:

tile(n) = 92*n + (Pt[(s+n) mod 92] + UL_IDCell) mod 92

n - tile index 0..5
Pt - tiles permutation
s - is the subchannel number
UL_IDCell - is an integer valued 0..69 set by the MAC

After allocating the tiles for each subchannel the data subcarriers per subchannel are enumerated by the following process:
1) Starting from the first symbol at the lowest subcarrier from the lowest tile and continuing in an ascending manner through the subcarriers in the same symbol and going to next symbol at the lowest data subcarrier, and so on, data subcarriers shall be indexed from 1 to 48.
2). The enumeration of the subcarriers will follow the following formula:

subcarrier(n,s) = (n+13*s) mod Nsubcarriers

n - is a runing index 1..48
s - is the subchannel number
Nsubcarriers - the number of subcarriers per subchannel

This enumaration sets the order to which the mapping of the data onto the subcarriers shall be performed

6.4 Coverage enhancing safety channels

[Add the following text in the end of section 8.4.5.3.1]:

The Gap DIUC (DIUC=13) may be used by the BS to create coverage enhancing safety zones. This is intended to provide reduced interference zones within the coverage area of the BS. The reduced interference zones are useful when the BS interfere with other BS. In such situations the reduced interference zones may be used by the interfered BS to transmit data to SS that are registered with it, which would otherwise suffer from interference.