Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Title	**OFDMA PHY Enhancements using Hybrid ARQ**
Date Submitted	**[2004-03-13]**
Source(s)	John Liebetreu, Jeff Foerster, Jose Puthenkulam Randall Schwartz, David Johnston, Hassan Yaghoobi, Intel Corporation Panyuh Joo, Seungjoo Maeng, Jaeho Jeon, Soonyoung Yoon, Jeong-Heon Kim, Jaehyok Lee, Myungkwang Byun, JeongTae Oh, Wonil Roh, Inseok Hwang, Jaehee Cho, Sanghoon Sung, Hun Huh, Jiho Jang, Ikbeom Lee, HeeSang Seo, Sijun Cho, Chiwoo Lim, Youngbin Chang, Jaeweon Cho, Jaeyoel Kim, Sung-Eun Park, Samsung Electronics Co. Ltd. Naftali Chayat, Tal Kaitz, Mohammed Shakouri, Alvarion Ltd. Shawn Taylor, Wi-LAN Inc. J. Pierre Lamoureux, Frank Draper, Wavesat Inc Martin Lysejko, Airspan Raja Banerjea, Don Leimer, Proxim Inc Phil Barber, Broadband Mobile Technologies Dale Branlund, Lalit Kotecha, Mike Webb, BeamReach Networks
Re:	Working Group Review of P802.16-REVd_D3
Abstract	
Purpose	To propose enhancements to the OFDMA PHY in 802.16REVd_D3 draft for better mobility performance.
Notice	This document has been prepared to assist IEEE 802.16. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.
Release	The contributor grants a free, irrevocable license to the IEEE to incorporate material contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE's name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE's sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.16.
Patent Policy and Procedures	The contributor is familiar with the IEEE 802.16 Patent Policy and Procedures <http://ieee802.org/16/ipr/patents/policy.html>, including the statement "IEEE standards may include the known use of patent(s), including patent applications, provided the IEEE receives assurance from the patent holder or applicant with

s	respect to patents essential for compliance with both mandatory and optional portions of the standard." Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <mailto:chair@wirelessman.org> as early as possible, in written or electronic form, if patented technology (or technology under patent application) might be incorporated into a draft standard being developed within the IEEE 802.16 Working Group. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>.

OFDMA PHY Enhancements to support Hybrid ARQ

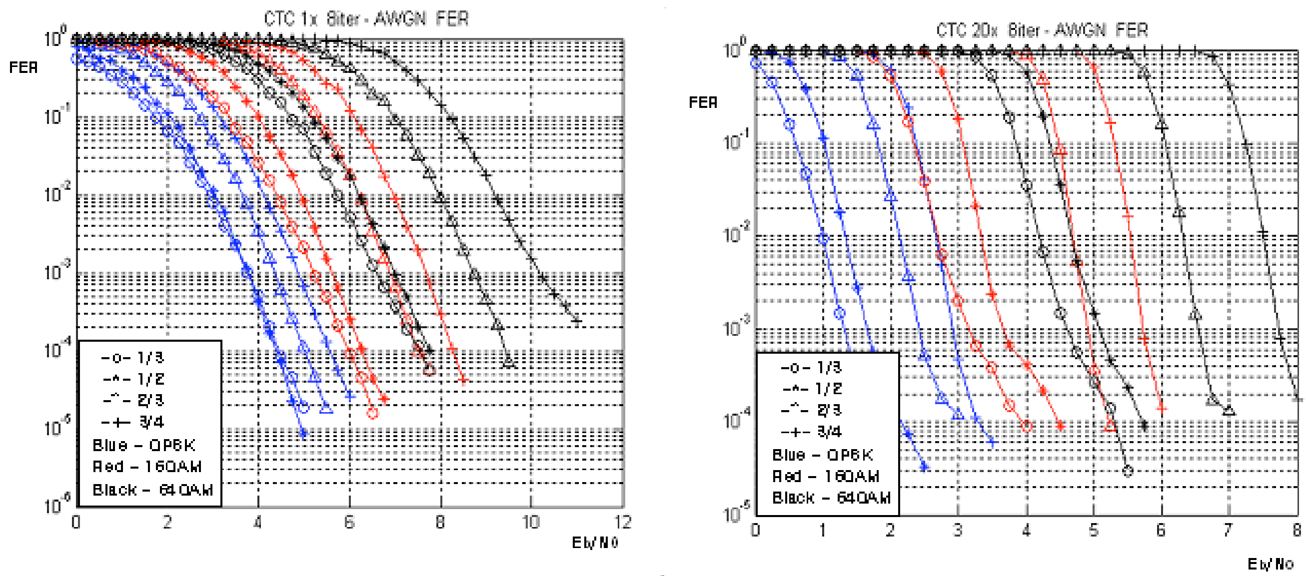
Introduction

In this contribution we propose enhancements to the WirelessMAN OFDMA PHY for better mobile performance by using Hybrid ARQ using CTC.

1 Requirements for the FEC structure

Like other Turbo code families, the convolutional Turbo code (CTC) shows that its link performance is very sensitive to the codeword length. Figure 1 shows the BER performance of various combinations of CTC rate and modulation in AWGN. The number of iteration is eight. Figure 1 (a) and (b) show BER performances when the allocated subchannel(s) are one and 20, respectively. The graphs show that the BER performance for large codeword is superior to the short codeword at most 2.5 dB in Eb/No.

In 802.16, it is assumed that the information bit size for a physical burst varies in large range (from 48 to thousands bits). Thus, it happens to have very short codeword. However, it should be guaranteed that the whole information bits for a burst are to be encoded as one codeword. It makes the coding gain for a long information bits to be maximized.



(A) (B)

Figure1. BER performance of CTC with different codeword size.

In 802.16 OFDMA mode, adaptive modulation and coding (AMC) is exploited against the long and short term fading and path loss. In mobile cellular operation, the difference between channel conditions when it is reported (feedbacked) and it is applied for AMC is inevitable. Thus, any mobile system should provide some countermeasures against the difference. For example, the margin for SNR threshold for each AMC level is possible solution.

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 sited 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 against the mobility.

For the implementation of IR scheme, the generation of subpackets 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. The whole information bits for a burst are to be encoded as one codeword
2. FEC structure should support IR type HARQ scheme.
3. For the support of IR type HARQ scheme, the subpacket should show complementary property.

2 Proposed DL/UL FEC structure for OFDMA mode

Generation of CTC encoded codeword

The mother code is rate 1/3 convolution Turbo code (CTC) and 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 $1 + D^3$

The 1/3 CTC shows better BER performance over 1/2 CTC. Figure 2 compares BER performance of the two codes. The more coding gain will be reflected on the HARQ performance too. The increase of coding gain is minimal with the lower code rate CTC.

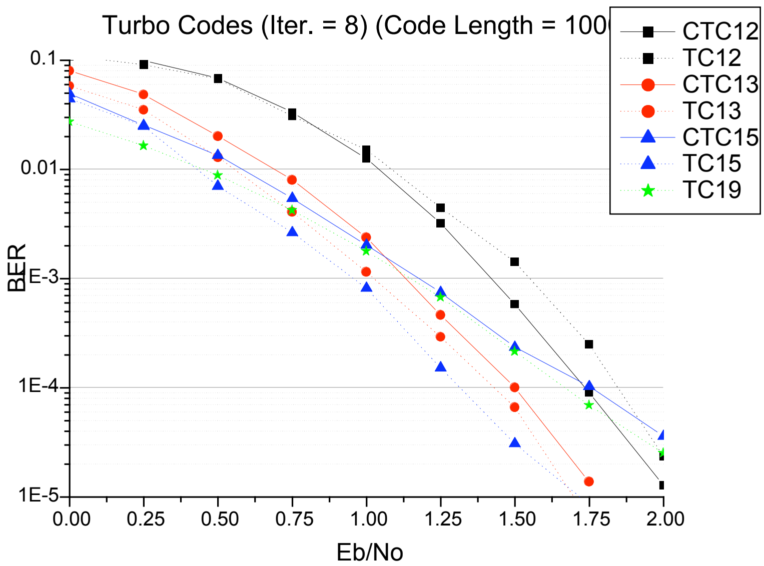


Figure 2. BER performance of 1/2 CTC and 1/3 CTC

The whole information bit sequence of length Nep is encoded into a codeword of length 3*Nep. Nep is limited to the allowable number of {48, 96, 144, 192, 288, 384, 480, 960, 1920, 2880, 3840, 4800}. Because the increase of CTC coding gain is saturated when the length of input is larger than 5000 bits the maximum of Nep is 4800. Figure 3 shows block diagram of CTC encoder. The output sequence is represented as follows.

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

CTC interleaving scheme is same as described in the current 802.16dr3 specifications except the new parameters for the allowable Nep.

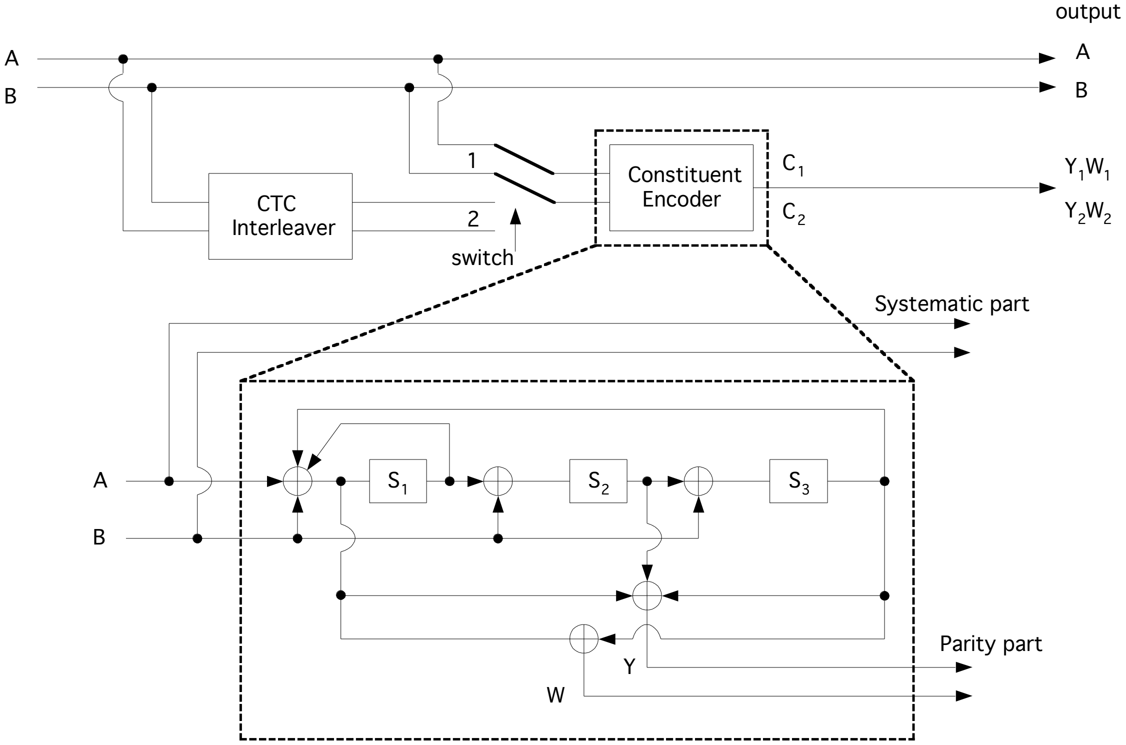


Figure 3. Block diagram of rate 1/3 CTC encoder

Subpacket generation

Proposed FEC structure punctures mother codeword to generate subpacket with various coding rates. The subpacket is also used as HARQ packet transmission. Figure 4 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.

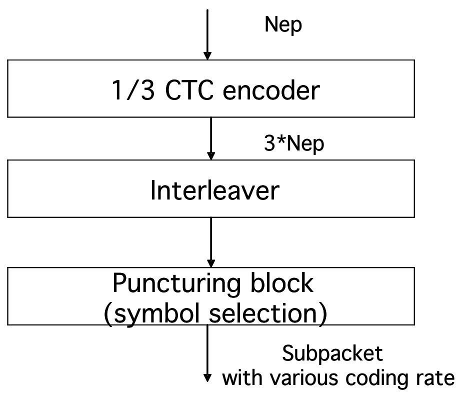


Figure 4. Block diagram of subpacket generation

Interleaving block: QCTC (Quasi Complementary Turbo Code)

A 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. We call such Turbo code as complementary Turbo code. 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 5 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.

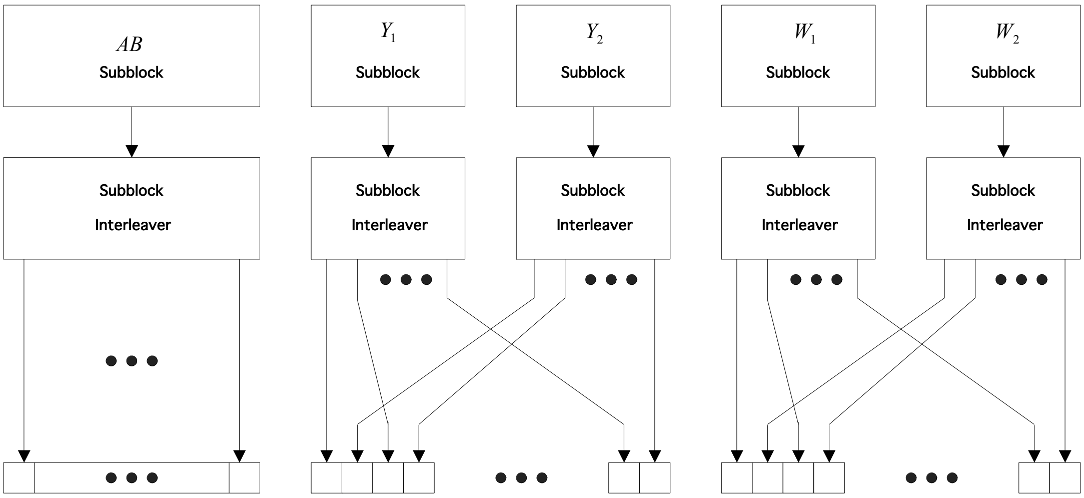


Figure 5. Block diagram of the interleaving scheme

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_{EP} = 48, 96, 144, 192, 288, 384, 480, 960, 1920, 2880, 3840, 4800);

N_{SCHk} be the number of subchannel(s) allocated for the k-th subpacket (1~480);

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 $i = 0\ to\ L_K - 1$,

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

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

The N_{EP}, N_{SCHk} , and SPID values are determined by the access point and are provided to the access terminal through the MAP bursts. 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.

Selection of Modulation order

Modulation order (m_k) is determined by the number of bits per subcarriers. For the same Nep, smaller number of the allocated subchannels (Nsch) means low coding rate and low modulation order, the larger number of the allocated subchannels (Nsch) means higher coding rate and higher modulation order. For DL, the modulation order (2 for QPSK, 4 for 16QAM, and 6 for 64QAM) shall be set for all the allowed transmission formats. For UL, only QPSK and 16 QAM are allowed.
The current 802.16d OFDMA mode, modulation order is determined by the channel condition. So the above description looks different. However, the modulation order determined also reflects the channel condition. Once the modulation order is determined for each Nep and Nsch combination, one can determine SNR threshold for each combination. Then the channel conditions reported from each user terminal can decide the possible combinations of Nep and Nsch for the current channel condition for each user terminal. Then, the selection of Nep and Nsch is a task of a system scheduler.

3 Suitability of the proposed FEC structure for CTC and mobility

As described above, the proposed FEC structure is suitable for CTC and mobile operation of cellular operation.

1. Full exploitation of CTC coding gain:
   - A. The proposed structure encodes the whole information bit sequence of length Nep as one codeword.
   - B. The proposed structure can generate the punctured codeword with various coding rate. The punctured codeword shows the property of QCTC which guarantees its CTC coding gain.
2. Efficient HARQ support:
   - A. The proposed structure generates subpackets for HARQ transmission.
     - i. The subpackets show the property of QCTC which guarantees its CTC coding gain.
     - ii. IR scheme is possible (The subpacket can be different from the previous subpacket).
     - iii. The location of each subpacket is independent of the previous subpacket.

4 Conclusions

The proposed FEC structure satisfies the CTC and mobile cellular operation of 802.16d OFDMA mode.

5 H-ARQ operation

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.

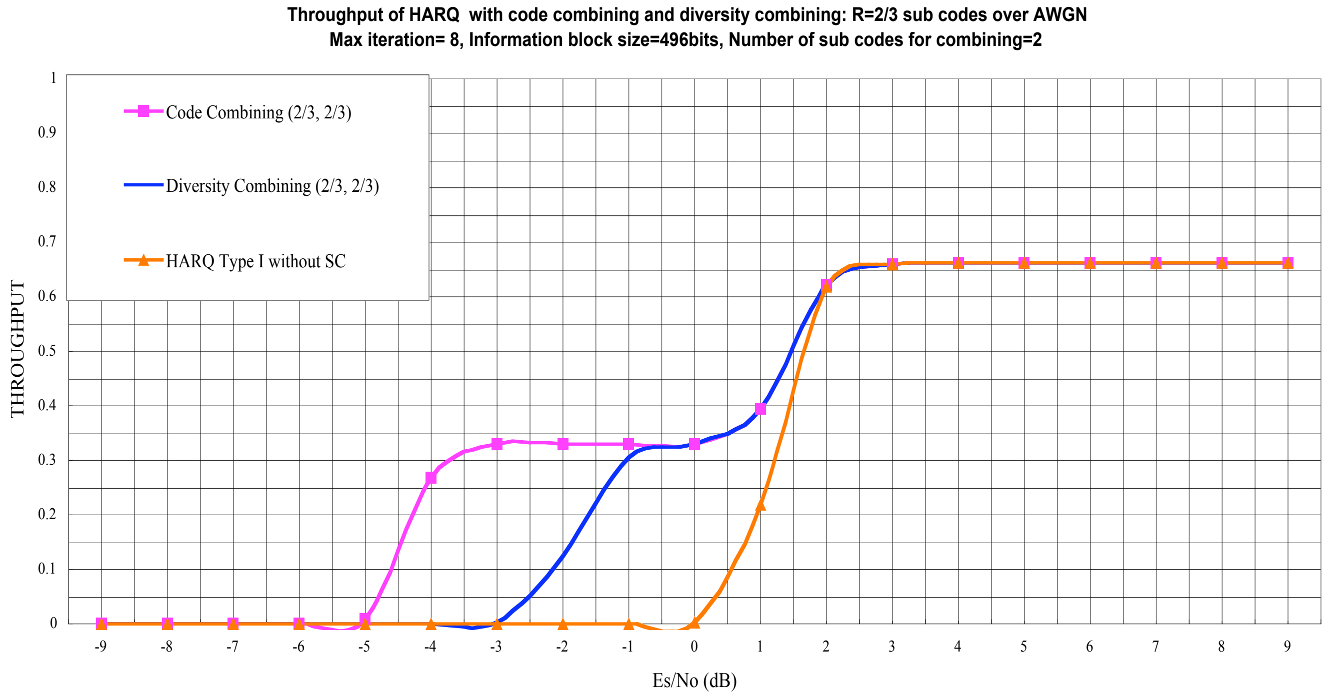


Figure 1. Soft combining gain in H-ARQ

6 PHY and MAC support for HARQ

Subpacket generation

The proposed FEC provides quasi complementary Turbo code (QCTC) structure. Due to QCTC structure, the subpackets for H-ARQ can be efficiently generated.

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 bit-map IE is designed and the IE will be inserted in MAP.

H-ARQ parameter signaling

The parameters for each subpacket should be signaled independent of the subpacket burst itself. The parameters for each subpacket include SPID (Subpacket Identifier. The BS shall set this field to the subpacket identifier for the subpacket transmission.), ACID (ARQ Channel Identifier. The BS shall set this field to the ARQ channel identifier for the subpacket transmission.), and AI_SN (ARQ identifier sequence number. This toggles between '0' and '1' on successfully transmitting each encoder packet with the same ARQ channel.). For the signaling of those parameters, new H-ARQ Control IE is defined and the IE is to be placed in a MAP IE for a burst where H-ARQ is enabled.