HARQ using coding-block-based CRC

IEEE 802.16 Presentation Submission Template (Rev. 9)

Document Number:
IEEE C802.16m-08/395
Date Submitted:
2008-05-05
Source:
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Venue:
IEEE 802.16m-08/016r1, “Call for Contributions on Project 802.16m System Description Document (SDD)”.
Target topic: “Hybrid ARQ (protocol and timing)”.
Base Contribution:
This is the base contribution.
Purpose:
To be discussed and adopted by TGm for the 802.16m SDD

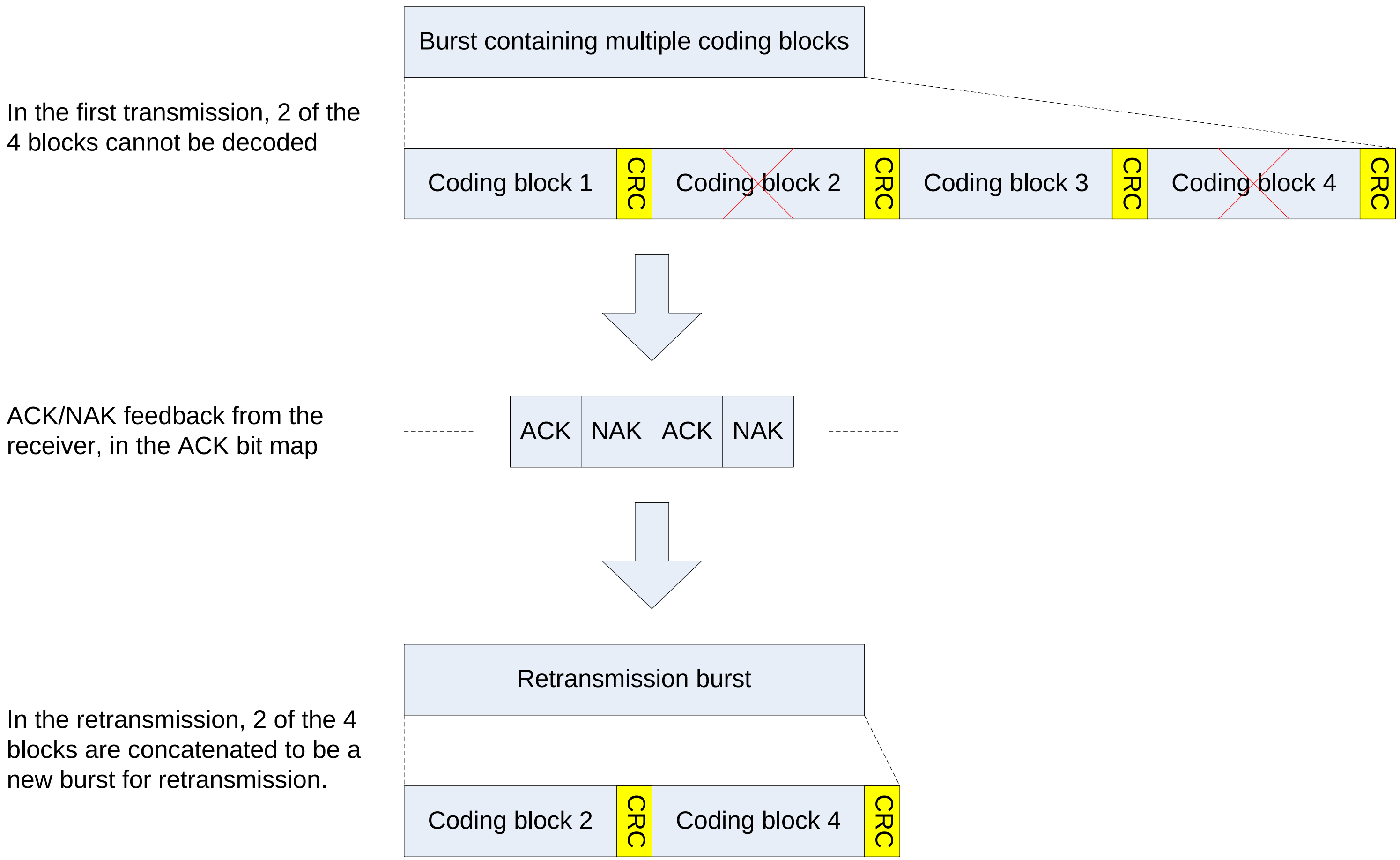
Motivation

- In HARQ enabled channel encoding process, at the transmitter (BS or MS) side
  - The information bits (allocated in a PHY burst) are firstly appended with a 16-bit CRC at the tail.
  - After that, information bits (plus CRC) of the burst are fragmented into coding blocks according to certain rules, if the length of information bits (plus CRC) exceeds the maximum possible length for encoding in a single coding block.
  - Each coding block is encoded independently.
- At the receiver (MS or BS) side,
  - The coding blocks are decoded independently, and then information bits of all coding blocks are concatenated.
  - If the CRC check succeeds, ACK will be sent to the receiver. Otherwise, NAK will be sent to the transmitter to request the retransmission of the burst.
  - One ACK/NAK corresponds to one HARQ-enabled burst.
- When one or multiple coding blocks are not decoded successfully, the CRC check for the burst will fail and the whole burst (including all the coding blocks) has to be retransmitted. Thus, PHY bandwidth is wasted since all the blocks are retransmitted even if some of them could be decoded successfully.

Coding-block-based CRC

- We propose that CRC shall be added to each of the coding blocks.
  - At the receiver, the error of each coding block are detected separately.
  - Each coding block has a corresponding ACK/NAK feedback.
  - After the transmitter receives NAK feedbacks of some coding blocks in the burst, it shall only retransmit these NAKed blocks in the retransmission burst.
  - The ACKed blocks shall not be transmitted again.
- According to the fragmentation rules of coding blocks in IEEE 802.16 channel coding scheme, the last two coding blocks of a burst could be smaller than the maximum possible size of a codling block.
  - To reduce the unnecessary CRC overhead, we propose that the last two coding blocks are combined together and then with one CRC appended, if they are not of the maximum possible size of two codling block.
  - E.g. when 16QAM and ½ CTC is selected as the MCS scheme, every coding block could contain at most 60 bytes of information bits (including CRC). If 150 bytes are allocated to be transmitted in one burst, there will be 3 coding blocks. The 1st one contains 60 bytes, and the 2nd and 3rd one contains the other 90 bytes. In this case, two CRCs will be appended to the 3 coding blocks. The 1st CRC is appended to the 1st coding block, and the 2nd CRC is appended to the 2nd and 3rd blocks as a whole.

An example of the proposed method



Overhead analysis

- When the proposed method is used, two parts of extra overhead are added.
  - Multiple CRCs are added to a burst, instead of one CRC for a burst in 802.16e HARQ.
  - Multiple ACK/NAK feedbacks are needed corresponding to multiple CRCs, instead of one feedback per PHY burst.

Benefit of the proposal considering the multiple-CRC overhead

- The throughput improvement mainly comes from first retransmission, since the probability of "retransmission more than once" is much smaller.
- To show the benefit of the method, we assume:
  - The target burst error rate of the first transmission is p_e.
  - The burst is fragmented into n coding blocks.
  - The maximum coding block size is M information bytes.
- The target "coding block error rate" should be

$$p_{e1} = 1 - (1 - p_e)^{\frac{1}{n}}$$

- In this proposal, we append n CRCs to the information bits, while in current IEEE 802.16, only 1 CRC is appended to the information bits. Each CRC contains 2 bytes.
- Therefore, relative improvement of throughput for the overall throughput (including the 1st transmission and 1st retransmission) should be

$$a \approx \frac{n \cdot (1 + p_e)}{n \cdot (1 + p_{e1})} \left(\frac{n \cdot M - 2 \cdot n}{n \cdot M - 2} \right) - 1$$

Relative throughput improvement using the proposed method with 16e CTC being used

MCS	**M (bytes)**	p_e	**Improvement (%), n=2**	**Improvement (%), n=3**	**Improvement (%), n=4**	**Improvement (%), n=5**	**Improvement (%), n=10**
QPSK 1/2 16QAM 1/2 64QAM 5/6	60	0.2	6.70	9.46	10.95	11.89	13.88
QPSK 3/4 16QAM 3/4 64QAM 1/2 64QAM 3/4	54	0.2	6.49	9.17	10.63	11.55	13.48
64QAM 2/3	48	0.2	6.23	8.82	10.23	11.12	12.99
QPSK 1/2 16QAM 1/2 64QAM 5/6	60	0.1	2.86	3.94	4.51	4.86	5.58
QPSK 3/4 16QAM 3/4 64QAM 1/2 64QAM 3/4	54	0.1	2.66	3.67	4.21	4.54	5.22
64QAM 2/3	48	0.1	2.40	3.34	3.83	4.13	4.76

UL ACK/NAK feedback Aggregation

- Consider the overhead of Multiple ACK/NAK feedback.
  - In UL HARQ process, the feedback from BS is just one bit per each coding block, which is minor bandwidth consumption and could not affect the benefit of the proposed method.
  - In DL HARQ, the feedback from MS in UL could be large bandwidth consumption.
    - In 16e, one UL ACK/NAK channel occupies half a PUSC/OPUSC slot and could be used to transmit only one bit.
    - If multiple ACK/NAKs are transmitted in UL for one burst, BS will allocate multiple UL ACK channel to the MS. This is a bandwidth inefficient scheme.
- To solve the problem in UL feedback, two types of UL ACK/NAK channel are proposed
  - A basic ACK/NAK channel to transmit 1-bit feedback.
  - An enhanced ACK/NAK channel to transmit combined *m*-bit feedback, e.g. *m*=3.
    - The PHY resource for transmitting one enhanced ACK/NAK channel should be much smaller than *m* times of the PHY resource for a basic ACK/NAK channel.
      - This is a reasonable requirement. The transmission of a single bit is usually most bandwidth-inefficient.
    - When multiple CRCs are added to the coding blocks of a DL PHY burst, the corresponding UL ACK/NAK feedbacks should use the enhanced ACK/NAK channel to lower the bandwidth consumption.
    - The enhanced ACK/NAK channel could also be used in the case when BS transmits multiple HARQ PHY bursts to same MS in DL, where one enhanced ACK/NAK channel could be used to feedback ACK/NAK information for *m* bursts.

Proposed text changes for 802.16m SDD

- Section 11.x.x: HARQ

  HARQ mechanism is enhanced for providing increased throughput.

  When a HARQ-enabled PHY burst contains multiple independent coding blocks, a CRC shall be added to each coding block. At the receiver, the decoding error of each coding block is detected separately based on the corresponding CRC check. Each coding block has a corresponding ACK/NAK feedback. After the transmitter receives NAK feedbacks for some coding blocks in the burst, it shall only retransmit those NAKed blocks in the retransmission burst.

- Section 11.x.x.x: UL ACK/NAK channel

  Two types of UL ACK/NAK channel shall be supported:

  - A basic ACK/NAK channel to transmit 1-bit feedback.
  - An enhanced ACK/NAK channel to transmit combined *m*-bit ACK/NAK feedback, where *m* is an integer. The value of *m* is TBD.