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Re:	IEEE 802.16m-08/024 - Call for Comments and Contributions on Project 802.16m System Description Document (SDD). Topic: Link Adaptation
Abstract	This document describes a proposal for 802.16m link adaptation.
Purpose	To review and adopt the proposed text in the next revision of the SDD.
Notice	
Release	
Patent Policy	

Joint PRU Coding and Independent PRU Modulation for Link Adaptation

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1 Introduction

Spectral efficiency and data throughput are key requirements that a base station (BS) scheduler needs to address within a 802.16m system implementation. To maximize efficiency and throughput a base station scheduler should optimally allocate OFDMA subcarriers/subchannels to users within its cell. This task can be computationally complex and time consuming especially when the number of subcarriers/subchannels is large. In addition, associated overhead and signaling may substantially degrade spectral efficiency gains associated with multi-user diversity. An improved 802.16m physical layer resource unit is used in 802.16m systems to simplify a base station's scheduling task and to help minimize associated overhead and signaling.

The gain and phase of a channel's transfer function are typically correlated between a number of adjacent OFDMA subcarrier frequencies. This channel characteristic motivates the usage of equal-sized physical layer allocation units. Spectral efficiency and data throughput will not degrade significantly if time-frequency allocation units are allocated per subframe and channel quality is nearly constant within the units.

In the 802.16m system these equal-sized time-frequency allocation units are called Physical Resource Units. A Physical Resource Unit (PRU) is defined as a rectangular area within a subframe comprised of a specified number of subcarriers (frequencies) and a specified number of OFDMA symbols (time slots). An PRU is the smallest fundamental time-frequency unit that may be allocated to an 802.16m user.

PRU scheduling may depend on input such as an uplink channel quality reports sent to a BS by users within is cell. Based on this input a BS scheduler can dynamically perform the following: (1) specify the number of subframe PRUs allocated to each user, (2) specify the location of these PRUs within a subframe's time-frequency plane, and (3) specify the channel coding and modulation to be used for these PRUs. The scheduler may map a user's encoded and modulated data block to a single PRU or to multiple PRUs. The number of data bits per PRU depends on the coding and modulation specified for an PRU and on the PRU size.

Two approaches for PRU-based channel coding and modulation and link adaptation are as follows: (1) Independent PRU Coding and Independent PRU Modulation, and (2) Joint PRU Coding and Independent PRU Modulation. In the following sections we describe these two approaches. This contribution then proposes the second approach for PRU-based link adaptation.

Link adaptation may be implemented using a mode selection technique in which a mode is associated with an FEC type and rate, modulation signal constellation, HARQ type, and MIMO technique. Link adaptation may also be implemented by a simple rate adaptation in which only coding and modulation are adapted. The proposed approach can be used for both of these approaches.

2 System Model for Baseband Link Adaptation

Figure 1 shows a conceptual block diagram of an OFDMA subsystem for mapping user data bits to PRUs that comprise a downlink (DL) subframe. For the description that follows each constructed downlink PRU is comprised of Data Channel symbols and Pilot Channel symbols.

For each subframe a BS scheduler may allocate one or more fixed-sized PRUs to a user. A scheduler may disperse a user's PRUs in time, frequency and/or space. Two approaches in which a BS scheduler may match a user's allocated PRUs to channel conditions are as follows [1, 3, 4, 5]:

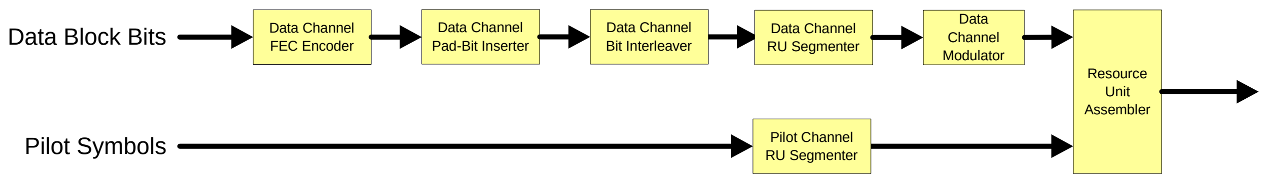

Figure 1: Conceptual block diagram of subsystem for mapping bits to Physical Resource Units.

1. **Independent PRU Coding and Independent PRU Modulation.** The coding and modulation of each of a user's allocated PRUs is matched to the PRU's channel conditions. Based on a user's channel conditions each PRU is encoded and modulated separately.

   - Advantages:
     (a) Finer granularity PRU link adaptation is possible.
   - Disadvantages:
     (a) Coding gain is limited by PRU size. A single PRU may not support a long DBTC or LDPC codeword. An increased error rate may result if a PRU's SINR is low and its size is small.
     (b) The number of data bits supported per fixed-sized PRU and the number of data bits per encoded source data block may be difficult to match, hence a throughput reduction due to encoder pad bits.
     (c) Interleaver length is limited by PRU size.
     (d) Multiple PRU encodings are required when a user is allocated multiple PRUs, hence a potential for an increase in implementation complexity and power consumption.
     (e) HARQ must support multiple codewords when a user is allocated multiple PRUs with different encodings. Hence the potential for an increase in overhead and signaling.

2. **Joint PRU Coding and Independent PRU Modulation.** The modulation of each of a user's allocated PRUs is matched to the PRU's channel conditions. The coding of a user's allocated PRUs is matched to the channel conditions of all of its allocated PRUs. Each user codeword is segmented, the segments are then mapped to all of the user's allocated PRUs. Code adaptation may be based on a metric (e.g. Mutual Information Based Effective SNR [1, 3, 6]) derived from the channel conditions associated with all of a users's allocated PRUs. Hence, based on a user's channel conditions each of user's PRUs is modulated separately but the PRUs transmit segments of the same user codeword.

   - Advantages:
     (a) Coding gain is not limited by PRU size. The mapping of an information source's data block to a user's PRUs is decoupled from the length of the data block. Data blocks may be encoded using long DBTC or LDPC codewords that are mapped to multiple PRUs, codeword segments may be dispersed in time, frequency and space over multiple user PRUs. Small data blocks may be encoded and mapped to a single PRU.
     (b) Interleaver length is not limited by PRU size. Interleaving is performed over the number of PRUs allocated to a user, hence interleaver length is increased when the number of allocated PRUs is greater than one.
     (c) HARQ must support only one codeword when a user's data block is allocated multiple PRUs. Hence the potential for a decrease in overhead and signaling.
     (d) Potential reduction in overhead since coding is specified for all of a user's PRUs rather than each of its PRUs.

(e) Potential reduction in implementation complexity and power consumption since a single encoding operation is required for all of a user's allocated PRUs.

- Disadvantages

  (a) Coarser granularity in PRU link adaptation since PRU adaptation is based on a metric derived from the channel conditions associated with all of a users's allocated PRUs.

In the conceptual block diagram the second approach is used [1, 3, 4, 5]. In this approach encoded data blocks may be mapped to one or more PRUs where each PRU modulation is matched to channel conditions. This approach and the alternative approach of adapting both the modulation and coding scheme per PRU have been analyzed in [1, 3, 5]. As show in [1, 3, 5] the second approach performs excellently.

In the following paragraphs we use Figure 1 as a reference to describe the basic baseband signal operations for PRU construction. We only describe the operations for the Data Channel.

For each subframe a BS scheduler may allocate a set of $n_B \geq 1$ fixed-sized PRUs for a user. The fixed-sized PRUs are parametrized by their heights n_{sc}^{PRU} and their widths N_{sym}^{PRU} (these dimensions are defined in the SDD draft). PRU heights are in units of OFDMA subcarriers and PRU widths in units of OFDMA symbols. A user's n_B PRUs may be located anywhere within a subframe's time-frequency plane. The area of an PRU is $n_{sc}^{PRU} \times N_{sym}^{PRU}$; this area also equals the number of complex-valued symbols within an PRU.

In accordance with the 802.16m traffic models, a data channel source (not shown in Figure 1) produces randomized binary-valued data blocks or MAC PDUs of various lengths κ_{Data}. A MAC PDU may be comprised of components such as a MAC header, traffic model SDU and CRC fields. MAC SDUs may be fragmented into multiple PDUs or aggregated into a single PDU. MAC PDUs may also be concatenated to construct a length-κ_{Data} data block.

The adaptive Data Channel FEC Encoder is parametrized by the pair $(\eta_{Data}, \kappa_{Data})$ where κ_{Data} denotes the number of bits of an encoder input data block and η_{Data} the number of encoded bits output by the encoder. Values for η_{Data} must be divisors of two or equivalently an integer number of 8-bit bytes. Some code options for the adaptive encoder are Convolutional Codes, Duo-Binary Turbo-Codes (also called convolutional turbo codes) and Low Density Parity Check codes. The used code and/or code rate $R_{Data} = \kappa_{Data}/\eta_{Data}$ is determined by a link-adaptation algorithm based on channel and interference conditions, it is not determined by an upper-layer algorithm in order to fit an encoded MAC PDU into a fixed-size PRU.

Each encoded length-η_{Data} data block output by the Data Channel FEC Encoder is bit-padded (only if needed) by the Data Channel Pad-Bit Inserter (description is below), interleaved by the Data Channel Bit Interleaver, and then input to the Data Channel PRU Segmenter. The Data Channel PRU Segmenter segments its length-η_{Data} input into $n_B \geq 1$ encoded data sub-blocks of lengths $\eta_{k,Data}$, $k = 0, \ldots, n_B - 1$. The sub-blocks will be subsequently mapped to a user's n_B allocated PRUs. Each of the n_B sub-blocks will be mapped to a single PRU, each PRU may be modulated differently. Lengths $\eta_{k,Data}$ must be divisors of two, they are specified by the scheduler and are based on the chosen PRU size and the modulation specified for their PRUs.

The n_B encoded data sub-blocks output by the Data Channel PRU Segmenter are then sequentially input to the M-QAM Data Channel Modulator. For the kth encoded data sub-block, the modulator outputs a modulation symbol vector of length $m_{k,Data} = \eta_{k,Data}/b_{k,Data}$. Integer $b_{k,Data} = \log_2(M_{k,Data})$ denotes the number of bits per $M_{k,Data}$-QAM modulation symbol. Modulation symbols may be from an $M_{k,Data} = 4$ (QPSK), an $M_{k,Data} = 16$ (16-QAM) or an $M_{k,Data} = 64$ (64-QAM) signal constellation. Hence $b_{k,Data} = 2$, 4 or 6 so $m_{k,Data}$ is a factor of 2. Signal constellations are specified by the scheduler and are based on PRU's channel and interference conditions. For the kth modulation symbol vector all $m_{k,Data}$ data modulation symbols must be from the same signal constellation, they are associated with a single PRU. However, the data modulation symbols may be different for each of the n_B modulation symbol vectors in order to adapt or match the modulation of each PRU to its time-varying channel and interference conditions.

For a specified code rate R_{Data} the number of data bits mapped to the kth PRU equals the product $R_{Data} \cdot \eta_{k,Data}$. The total number of Data Channel bits mapped by the scheduler to all n_B allocated user PRUs is then

$$n_{Data\_bits} = R_{Data} \cdot \sum_{k=0}^{n_B-1} \eta_{k,Data} \tag{1}$$

The kth PRU also contains $n_{k,Pilot} \geq 0$ pilot bits (e.g. two bits per complex-valued pilot symbol). Pilot symbol sequences are generally chosen to have flat power spectral densities and constant envelopes.

For each modulation symbol vector input, the PRU Assembler combines the PRU's pilot symbols with the modulation symbol vector to construct an PRU. The scheduler specifies their PRU element locations. The total number of data bits plus pilot bits contained within all of a user's n_B allocated PRUs is

$$n_{total\_user\_bits} = n_{Data\_bits} + \sum_{k=0}^{n_B-1} n_{k,Pilot} \tag{2}$$

The number of data bits will vary and the number of pilot bits may also vary so integer $n_{total\_user\_bits}$ is a variable. This variable may not equal the total number of bits that can be transmitted by all n_B allocated PRUs of size $n_{sc}^{PRU} \times N_{sym}^{PRU}$. The total number of data channel bits plus pilot channel bits that can be transmitted by all n_B PRUs of size $n_{sc}^{PRU} \times N_{sym}^{PRU}$ is

$$n_{total\_PRU\_bits} = \left(n_{sc}^{PRU} \cdot N_{sym}^{PRU} \cdot \sum_{k=0}^{n_B-1} b_{k,Data} \right) + \sum_{k=0}^{n_B-1} n_{k,Pilot} \tag{3}$$

To completely fill all n_B allocated PRUs with data and pilot bits we require that

$$n_{total\_PRU\_bits} - n_{total\_user\_bits} = 0 \tag{4}$$

To meet this requirement the $n_{total\_user\_bits}$ bits output by the Data Channel encoder may be extended using $n_{pad} \geq 0$ pad bits. The Data Channel Pad-Bit Inserter performs this function. The required number of pad bits is simply the difference

$$n_{pad} = n_{total\_PRU\_bits} - n_{total\_user\_bits} \tag{5}$$

The n_{pad} bits may be zeros, a cyclic repetition of the first n_{pad} bits of the length n_{Data_bits} codeword block [3], etc. This is an implementer's decision. Another option is to multiplex other users data within the unused PRU elements but this requires additional overhead.

3 References

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4 Proposed Text for the SDD

Link Adaptation - Baseband Coding and Modulation

Baseband link adaptation will employ joint Physical Resource Unit (PRU) coding and independent PRU modulation. In this approach the modulation of each of a user's allocated PRUs is adapted to the PRU's channel conditions. The coding of a user's allocated PRUs is adapted to the channel conditions of all of its allocated PRUs. Each user codeword is segmented, the segments are then mapped to all of the user's allocated PRUs. Modulation adaptation is based on SINR measurements for each PRU. Code adaptation is based on an effective SINR metric (e.g. Mutual Information Based Effective SNR) derived from the channel conditions associated with all of a users's allocated PRUs. Hence, based on a user's channel conditions each of user's PRUs is modulated separately but the PRUs transmit segments of the same user codeword.