Variable-sized Resource Blocks for 802.16m OFDMA Systems

IEEE 802.16 Presentation Submission (Rev. 9)
Document Number: S80216m-08/202r1

Date Submitted: 2008-03-19

Source:

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Venue:

IEEE 802.16 Session #54, Orlando, Florida, USA

Base Contribution: IEEE C802.16m-08/202r1

Purpose: To summarize the contents of the base contribution.

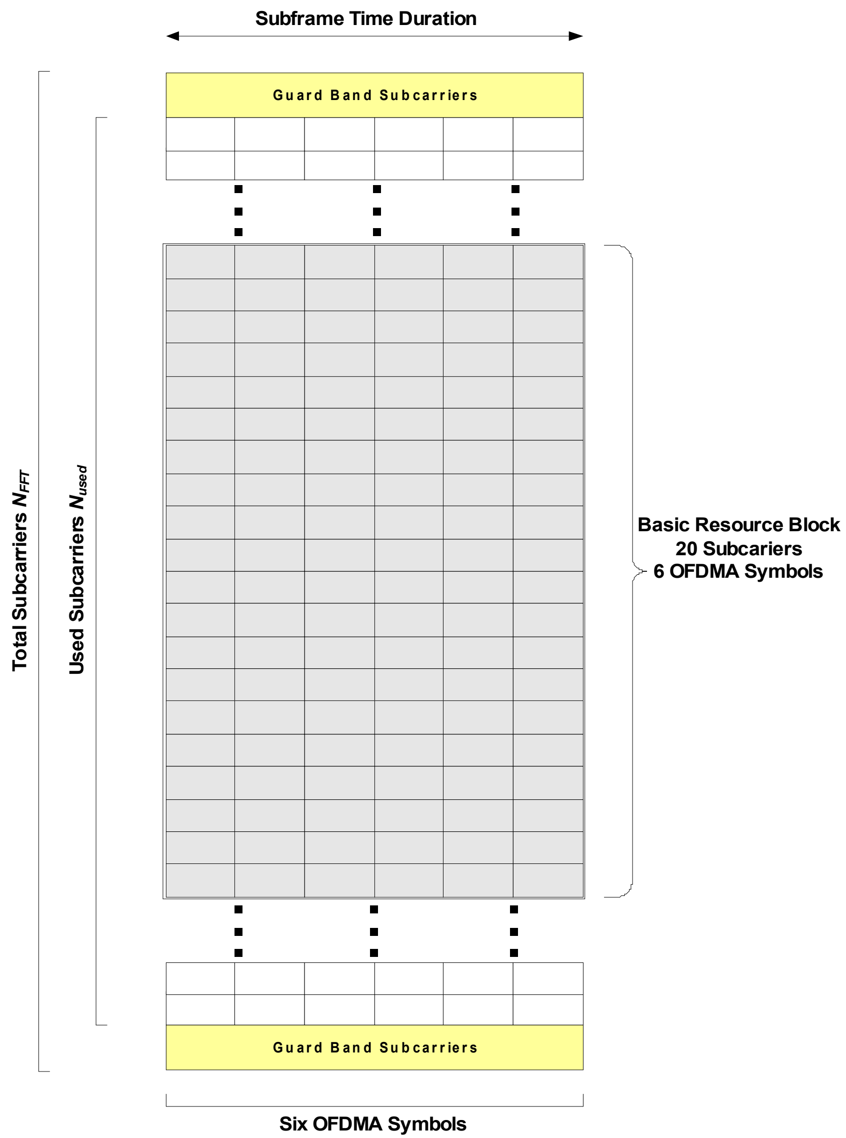
Problem Statement

- To maximize spectral efficiency a base station (BS) scheduler must optimally allocate OFDMA subchannels to users within its cell.
- This task can be computationally complex and time consuming, especially when the number of subchannels is large.
- In addition, associated overhead and signalling may substantially degrade spectral efficiency gains associated with multi-user diversity.
- An improved 802.16m physical layer resource unit is needed to simplify a base station's scheduling task and to help minimize associated overhead and signalling.
- The gain and phase of a channel's transfer function are typically correlated over a number of adjacent OFDMA subcarrier frequencies. This channel characteristic motivates the usage of rectangular time-frequency allocation units.
- Spectral efficiency and data throughput will not degrade significantly if rectangular time-frequency allocation units are allocated per subframe and channel quality is nearly constant within the units.
- In this contribution we call these time-frequency allocation units Resource Blocks.

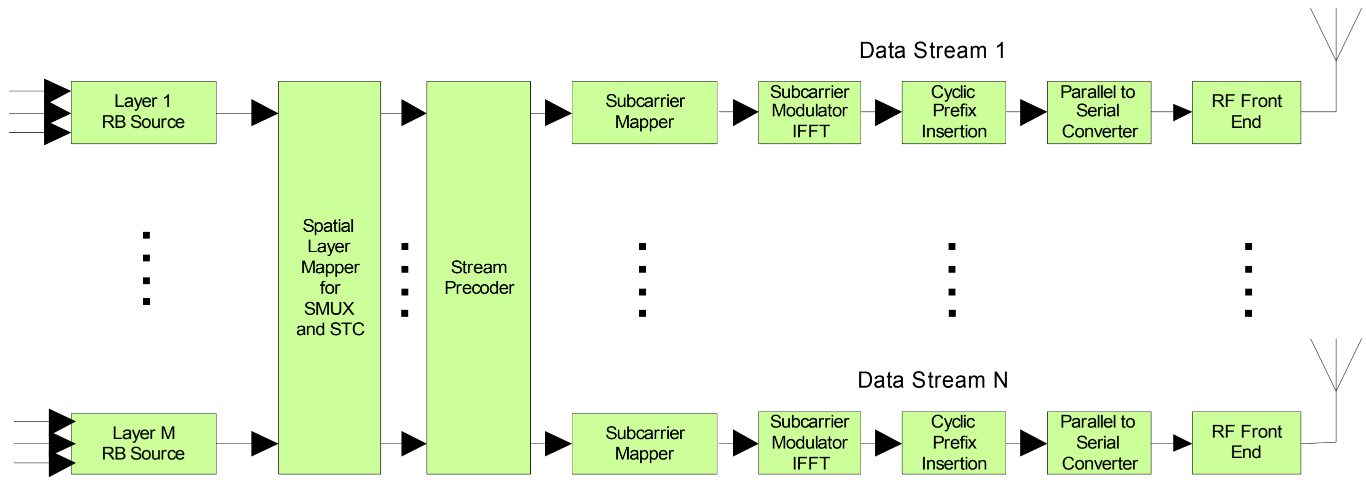
Resource Block Definition

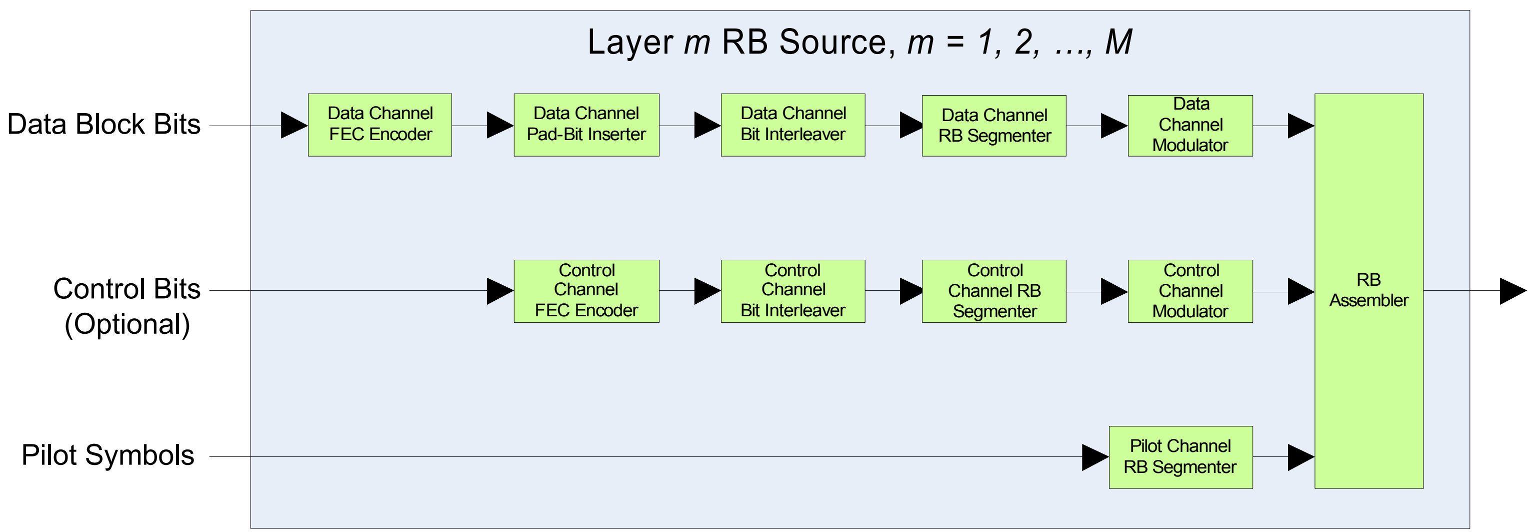
- A Resource Block (RB) is defined as a rectangular area within a subframe comprised of a specified number of subcarriers (frequencies) and a specified number of OFDMA symbols (time slots).
- An RB is the smallest fundamental time-frequency unit that may be allocated to an 802.16m user. A scheduler may disperse a user's allocated RBs in time, frequency and/or space.
- Downlink RB 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 RB tasks such as the following:
  - Select the best RB size for a subframe or other RB allocation period
  - Specify the number of subframe RBs allocated to each user
  - Specify the location of a user's RBs within a subframe's time-frequency plane
  - Specify the channel coding and modulation to be used for these RBs.
- The scheduler may map a user's encoded and modulated data block to a single RB or to multiple RBs
- The scheduler may also map a user's RBs to different transmit antennas.

Example RB within a Subframe's Time-frequency Plane



System Model for Resource Block Construction





Two Approaches for RB Coding and Modulation

- To design physical layer RBs the approaches for encoding and modulating a user's allocated RBs should be evaluated and compared.
- Two approaches to encode and modulate a user's allocated RBs are listed below. Details are in contribution C80216m-08_202r1.pdf and references [1, 3, 4, 5].
- **Approach 1 (Independent RB Coding and Independent RB Modulation):**
  - The coding and modulation of each of a user's allocated RBs is matched to each of the RB's channel conditions.
  - Based on a user's channel conditions each RB is encoded and modulated separately.
- **Approach 2 (Joint RB Coding and Independent RB Modulation):**
  - The modulation of each of a user's allocated RBs is matched to each of the RB's channel conditions.
  - Encoding is applied over all of a user's RBs. The coding of a user's allocated RBs is matched to the aggregate channel conditions of all of its allocated RBs.
  - Each user codeword is segmented, the segments are then individually modulated. The modulated segments are then mapped to all of the user's allocated RBs that may dispersed in time, frequency and space.
  - 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 RBs.
  - Hence, based on a user's channel conditions each of the user's RBs is modulated separately but the RBs transmit segments of the same user codeword.

Some Characteristics of Approach 1 (Independent RB Coding/Modulation)

- Independent RB link adaptation is possible.
- Coding gain is limited by RB size. A small RB size may not support a long DBTC or LDPC codeword. Hence, an increased error rate may result if an RB's SINR is low and its size is small.
- The number of data bits supported by an RB and the number of data bits per encoded source data block may be difficult to match, hence a throughput reduction.
- Interleaver length is limited by RB size.
- Multiple RB encodings are required when a user is allocated multiple RBs, hence a potential for an increase in implementation complexity and power consumption.
- HARQ must support multiple codewords when a user is allocated multiple RBs with different encodings. Hence the potential for an increase in overhead and signalling.

Some Characteristics of Approach 2 (Joint RB Coding/Independent RB Modulation)

- Coding gain is not limited by RB size.
- The mapping of an information source's data block to a user's RBs is decoupled from the size of the data block.
- Data blocks may be encoded using long DBTC or LDPC codewords that are mapped to multiple RBs, codeword segments may be dispersed in time, frequency and space over multiple user RBs.
- Small data blocks may be encoded and mapped to a single RB.
- Interleaver length is not limited by RB size. Interleaving is performed over the number of RBs allocated to a user.
- HARQ must support only one codeword when a user's data block is allocated multiple RBs. Hence the potential for a decrease in overhead and signaling.
- Potential reduction in overhead since coding is specified for all of a user's RBs rather than each of its RBs.
- Potential reduction in implementation complexity and power consumption since a single encoding operation is required for all of a user's allocated RBs.
- RB code adaptation is based on a metric derived from the channel conditions associated with all of a users's allocated RBs.

Joint RB Coding/Independent RB Modulation for 802.16m Systems

- Approach 2 has many benefits for 802.16m systems
- Propose that joint RB coding and independent RB modulation be used for 802.16m systems.
- In the engineering literature [1, 3, 4, 5] it is shown by simulation that this approach performs excellently.
- The previous system model slide shows a conceptual implementation for RB construction using approach 2.
- In this approach RBs design size can be decoupled from the information source models as defined in EMD.
- RB sizes do not need to match data block sizes produced from information source model, they can be matched to physical channel characteristics defined in EMD.

Some Resource Block Design Issues

- RB sizes should support all 802.16m operating channel bandwidths (e.g. 5, 10 and 20 MHz).
- For optimal spectral efficiency and data throughput an integer number of RBs should tessellate the time-frequency plane of all 802.16m subframe sizes.
- RB sizes should support all 802.16m user bandwidth allocations with minimal performance degradation and with minimal decrease in data throughput due to encoder pad bits as described in C80216m-08_202r1.pdf.
  - Large-sized RBs better support large user bandwidth allocations. However, if a small data block is mapped to a large-sized RB a number of the available RB bits will not be used resulting in a decrease in data throughput.
  - Small-sized RBs better support small user bandwidth allocations and power-limited communications (e.g. cell-edge for interference reduction). However, small-sized RBs may require increased overhead resulting in a decreased data throughput.
- **RB time duration should be less than the minimum expected channel coherence time.** RBs separated in time by the channel coherence time have independent fading. The minimum expected coherence time can be estimated from the maximum expected 802.16m user velocity.
- **RB bandwidth should be less than the minimum expected channel coherence bandwidth.** RBs separated in frequency by the channel coherence bandwidth have independent fading. The minimum expected coherence bandwidth can be estimated from the multi-path properties 802.16m channels defined within Evaluation Methodology Document [9].

Table 1: Coherence Bandwidth Estimates for 802.16m Radio Operating Environments

802.16m Radio Environment	Delay Spread σ (nsec)	Estimated 50 % Coherence BW B_C (kHz)	# of 12.5 kHz Subcarriers	# of 10.94 kHz Subcarriers
Indoor Hot Spot	215	930	75	86
Indoor Small Office	250	800	64	74
Rural Macrocell	420	476	39	44
Outdoor to Indoor	585	342	28	32
Urban Microcell	615	325	26	30
Suburban Macrocell	770	260	21	24
Urban Macrocell	1845	108	9	10
Modified Vehicular A	2620	76	7	7
Bad Urban Microcell	2800	71	6	7
Modified Pedestrian B	3870	5	1	1
Bad Urban Macrocell	7100	3	1	1
Median: 21 subcarriers (12.5 kHz), 24 subcarriers (10.95 kHz)				

Coherence bandwidth B_C of a channel is a statistical measure of the range of frequencies over which the channel transfer function $H(f,t)$ can be considered flat (equal gain and linear phase).

Table 2: Coherence Time Estimates for Various Doppler Values and Carrier of 2.4 GHz

Velocity v (kmph)	Doppler f_D (Hz)	Estimated 50 % Coherence Time T_C (msec)	# of 90 μsec OFDM Symbols	# of 102.8 μsec OFDM Symbols
3	6.6672	63.466	705	618
10	22.224	19.040	212	186
20	44.448	9.520	106	93
50	111.12	3.810	43	34
100	222.24	1.904	22	19
150	333.36	1.269	15	13
200	444.48	0.952	11	10
250	555.6	0.762	9	7
Six OFDMA symbols per subframe				

Channel coherence time T_C is a statistical measure of the time interval over which a channel's impulse response $h(\tau,t)$ is essentially invariant.

Proposed Variable-Sized RB

Base RB Size:	N_{sc}^{RB}-by-N_{sym}^{RB}
Number of OFDMA Subcarriers per Base RB:	$N_{sc}^{RB} = 20$
Number of OFDMA Symbols per Base RB:	$N_{sym}^{RB} = 6$
Variable RB Size:	n_{sc}^{RB}-by-N_{sym}^{RB}
Number of OFDMA Subcarriers per Variable RB:	$n_{sc}^{RB} = m \cdot N_{sc}^{RB}$
Variable Scaling Factor:	$m = \frac{1}{2}, 1, 2, 4$

RB Size Justification Based on Tables 1 and 2

- From C802.16m-08/118r1 it is seen that each subframe is comprised of six OFDMA symbols which span a time duration of 0.54 msec (proposal 2) or 0.617 msec (proposal 1).
- From Table 2 it is seen that the worst-case coherence time estimate for 802.16m channels is greater than six OFDMA symbols.
- Hence for a time duration of six OFDMA symbols the physical subchannel associated with an OFDMA subcarrier is flat.
- Hence, the OFDMA symbol dimension of the base RB is 6 OFDMA symbols.
- From Table 1 it is seen that the median coherence bandwidth estimate is 21 subcarriers (proposal 2) or 24 subcarriers (proposal 1). We rounded these numbers to 20 and set the subcarrier dimension for the base RB equal to 20.
- The RB bandwidth dimension can be adapted to different channel coherence bandwidth variations such as those associated with the 802.16m radio environments shown in Table 1.
- Variable m is a scaling factor that scales the subcarrier dimension of the base resource block. The use of the RB scaling factor is similar in concept to that of scaling OFDMA symbol time durations to specify cyclic prefix lengths.

Table 3: Number of RBs per Subframe

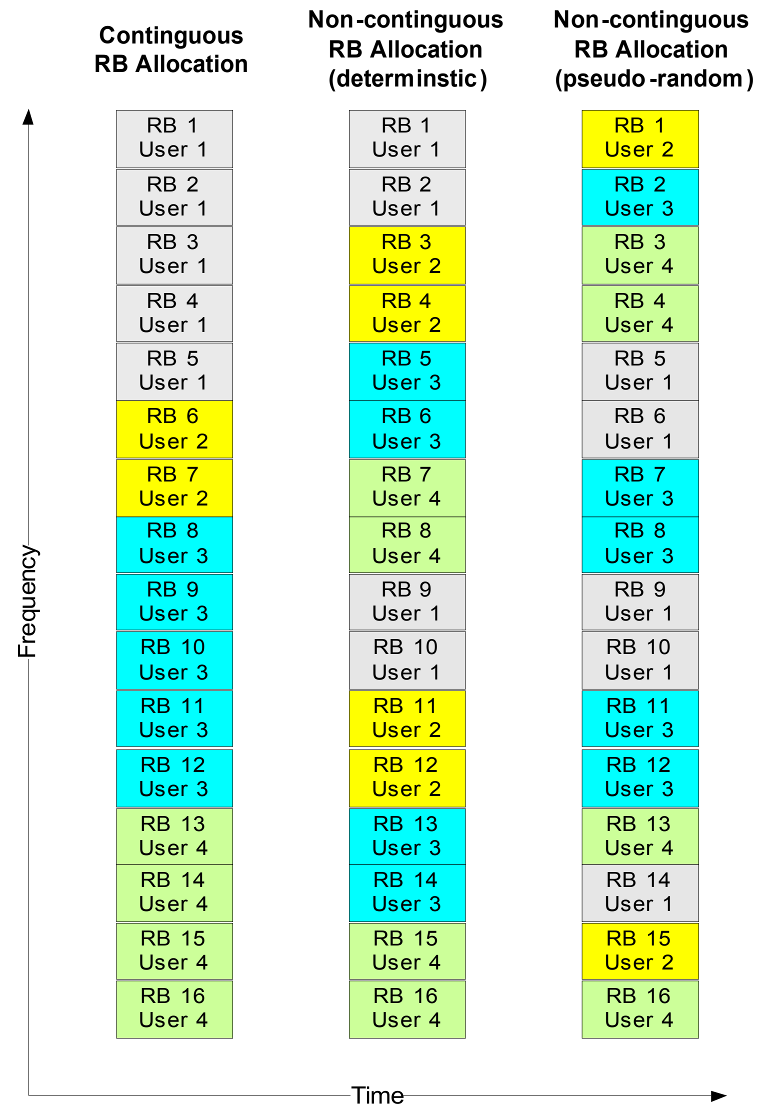
Channel Bandwidth	FFT Size N_{FFT}	# of Used Subcarriers N_{used} (Data plus pilots only)	Number of RBs Per Subframe n_B
5 MHz	512	$N_{\text{used}}^{5\text{ MHz}}$	$N_{\text{used}}^{5\text{ MHz}}/n_{sc}^{RB}$
10 MHz	1024	$N_{\text{used}}^{10\text{ MHz}}$	$N_{\text{used}}^{10\text{ MHz}}/n_{sc}^{RB}$
20 MHz	2048	$N_{\text{used}}^{20\text{ MHz}}$	$N_{\text{used}}^{20\text{ MHz}}/n_{sc}^{RB}$
Note 1: Number of subcarriers per base RB is $N_{sc}^{RB} = 20$			
Note 2: Number of OFDMA symbols per base RB is $N_{sym}^{RB} = 6$			
Note 3: Number of subcarriers per RB is $n_{sc}^{RB} = m \cdot N_{sc}^{RB},\ m = 1/2, 1, 2, 4$			
Note 4: $N_{\text{used}}^{5\text{ MHz}}$, $N_{\text{used}}^{10\text{ MHz}}$ and $N_{\text{used}}^{10\text{ MHz}}$ must be multiples of n_{sc}^{RB}			

The number of used subcarriers has not yet been defined for 802.16m so these table values are parameters to be defined later. However, in order for an integer number of RBs to tessellate the used part of a subframe (guard band subcarriers and DC subcarrier are not used), the number of used subcarriers must must be a multiple of the number of RB subcarriers.

Resource Block Allocation Modes

- The allocation of RBs to OFDMA users should based on time-varying channel conditions. From Table 1 it is seen that a single RB allocation method or mode will not support all possible 802.16m channel conditions.
- Two basic RB allocation modes that are proposed to address this problem are Contiguous RB Allocation and Non-Contiguous RB Allocation.
- **Contiguous RB Allocation**
  - For contiguous allocation a user's RBs are allocated contiguously within an area of a subframe's time-frequency plane. A contiguous RB allocation is beneficial for frequency selective channels [1,2].
  - Estimates of channel coherence bandwidth may be used for dynamically specifying a contiguous RB size and contiguous RB allocation.
- **Non-Contiguous RB Allocation**. Within a subframe's time-frequency plane a user's RBs are spaced or distributed in subcarrier frequency. A non-contiguous RB allocation may be implemented in a deterministic or pseudo-random manner. A non-contiguous RB allocation may be beneficial for the following:
  - At a base station channel quality for one or more user's RBs may not be known or may be inaccurate due to poor channel quality feedback or high Doppler rates.
  - Delay critical data transmission without channel feedback reporting. For this case data transmissions may be made more reliable by implementing subcarrier frequency hopping via a pseudo-random non-contiguous mode.
  - Broadcasting and multicasting the same data to a number of users; for these cases accurate individual user channel estimates may be difficult to acquire so subcarrier frequency hopping may be beneficial.

RB Allocation Modes



Resource Block Size Adaptation

- The number of subcarriers comprising a RB bandwidth may either be fixed for an allocation period or it may vary adaptively as the channel changes.
- In the fixed case, the selected RB bandwidth may be less than or equal to the smallest expected channel coherence bandwidth.
- In the variable or adaptive case as proposed, the RB bandwidth may be selected by using estimates of the channel coherence bandwidth provided by one or more OFDMA users.
- For example the used coherence bandwidth may be the smallest channel coherence bandwidth of a number of OFDMA users, the average coherence bandwidth of a number of users, or the channel coherence bandwidth of a high-priority user, etc.
- Estimates of coherence bandwidth may be derived easily from estimates of the channel transfer function computed from pilot symbols.
- An example algorithm is shown in contribution C80216m-08_202r1.pdf

References

See contribution IEEE C802.16m-08/202r1 for references and proposed SDD text.