Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Title	**Variable-Sized Resource Blocks for 802.16m OFDMA Systems**
Date Submitted	**2008-03-10**
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Re:	IEEE 802.16m-08/005 - Call for Contributions on Project 802.16m System Description Document (SDD).
Abstract	This document describes a proposal for 802.16m DL Physical-Layer Resource Blocks.
Purpose	To review and adopt the proposed text in the next revision of the SDD.
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Variable-Sized Resource Blocks for 802.16m OFDMA Systems

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1 Problem Statement

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 needed to simplify a base station's scheduling task and to help minimize associated overhead and signaling.

2 Proposed Problem Solution

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 this contribution we call these time-frequency allocation units Resource Blocks. 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.

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 the following: (1) select the best RB size for a subframe, (2) specify the number of subframe RBs allocated to each user, (3) specify the location of these RBs within a subframe's time-frequency plane, and (4) 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 number of data bits per RB depends on the coding and modulation specified for an RB and on the RB size.

In the following sections we describe the details of an RB structure that supports the numerous channel bandwidths defined in the 802.16m Requirements Document and the numerous radio environments defined in the 802.16m Evaluation Methodology Document [9]. We describe the problem of baseband RB construction, RB design issues of concern that should be addressed, proposed RB sizes that support 802.16m channels, RB allocation modes that better support the various 802.16m channels, and the problem of adapting RB bandwidth to better support the various 802.16m channels. The contribution concludes with text for the 802.16m System Description Document.

3 System Model for Resource Block Construction

Figure 1 shows a conceptual block diagram of an OFDMA subsystem for mapping user data bits to RBs that comprise a downlink (DL) subframe. For the description that follows each constructed downlink RB is comprised of Data Channel symbols and Pilot Channel symbols. As an option an RB may also contain Dedicated Control Channel symbols. However, this contribution does not discuss this option, it only describes RB construction using a Data and Pilot Channel.

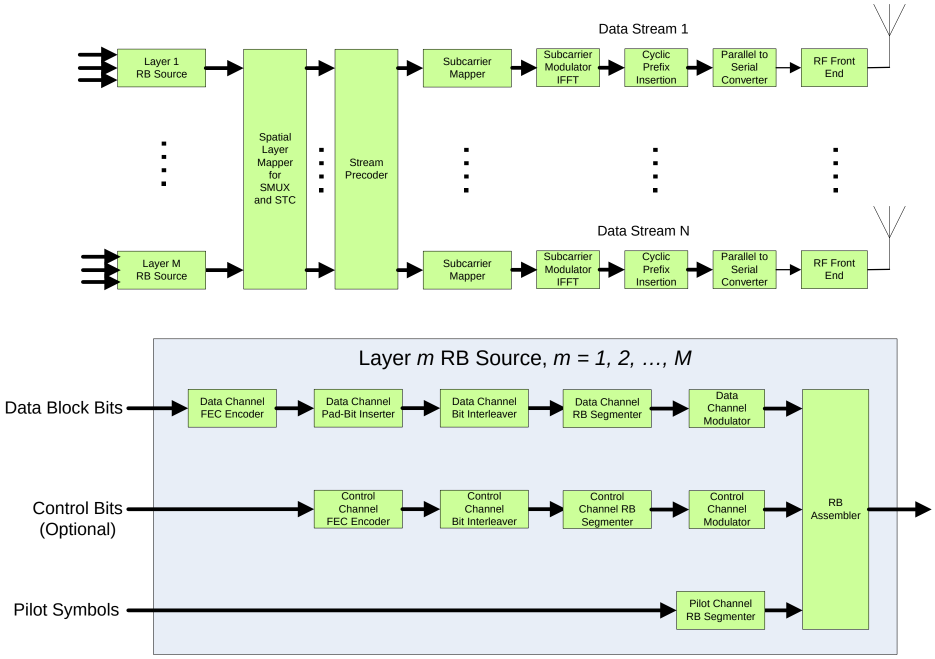


Figure 1: Conceptual block diagram of OFDMA subsystem for mapping bit to Resource Blocks.

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

1. The coding and modulation of each of a user's allocated RBs is matched to the RB's channel conditions. Based on a user's channel conditions each RB is encoded and modulated separately.
   - Advantages:
     (a) Finer granularity RB link adaptation is possible.
   - Disadvantages:
     (a) Coding gain is limited by RB size. A small RB size may not support a long DBTC or LDPC codeword. An increased error rate may result if an RB's SINR is low and its size is small.
     (b) The number of data bits supported per fixed-sized RB 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 RB size.
     (d) Multiple RB encodings are required when a user is allocated multiple RBs, hence a potential for an increase in implementation complexity and power consumption.
     (e) HARQ must support multiple codewords when a user is allocated multiple RBs with different encodings. Hence the potential for an increase in overhead and signaling.
2. The modulation of each of a user's allocated RBs is matched to the RB's channel conditions. The coding of a user's allocated RBs is matched to the channel conditions of all of its allocated RBs. Each user codeword is segmented, the segments are then mapped to all of the user's allocated RBs. 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 user's RBs is modulated separately but the RBs transmit segments of the same user codeword.

- Advantages:
  (a) 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.
  (b) Interleaver length is not limited by RB size. Interleaving is performed over the number of RBs allocated to a user, hence interleaver length is increased when the number of allocated RBs is greater than one.
  (c) 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.
  (d) Potential reduction in overhead since coding is specified for all of a user's RBs rather than each of its RBs.
  (e) Potential reduction in implementation complexity and power consumption since a single encoding operation is required for all of a user's allocated RBs.
- Disadvantages
  (a) Coarser granularity in RB link adaptation since RB adaptation is based on a metric derived from the channel conditions associated with all of a users's allocated RBs.

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 RBs where each RB modulation is matched to channel conditions. This approach and the alternative approach of adapting both the modulation and coding scheme per RB have been analyzed in [1, 3, 5]. As show in [1, 3, 5] the second approach performs excellently.

In the following paragraphs we use the Layer m RB source in the bottom of Figure 1 as a reference to describe the basic baseband signal operations for RB construction. We only describe the operations for the Data Channel since the operations for the other channels are similar.

For each subframe a BS scheduler may allocate a set of $n_B \geq 1$ fixed-sized RBs for a user. The fixed-sized RBs are parametrized by their heights n_{sc}^{RB} and their widths N_{sym}^{RB} (these dimensions are defined in a subsequent section). RB heights are in units of OFDMA subcarriers and RB widths in units of OFDMA symbols (see Figure 2). A user's n_B RBs may be located anywhere within a subframe's time-frequency plane. The area of an RB is $n_{sc}^{RB} \times N_{sym}^{RB}$; this area also equals the number of complex-valued symbols within an RB.

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 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 RB.

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 RB Segmenter. The Data Channel RB 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 RBs. Each of the n_B sub-blocks will be mapped to a single RB, each RB 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 RB size and the modulation specified for their RBs.

The n_B encoded data sub-blocks output by the Data Channel RB 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 RB'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 RB. 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 RB to its time-varying channel and interference conditions.

For a specified code rate R_{Data} the number of data bits mapped to the kth RB 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 RBs is then

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

The kth RB 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. This contribution is only concerned with resource block size it does not propose: (1) pilot symbol sequences (e.g. Constant Amplitude Zero Autocorrelation codes, Zadoff-Chu sequences, complementary Golay codes, etc.), (2) pilot symbol RB patterns for improved pilot-aided channel estimation and MIMO signal processing (e.g. regular or periodic pilot patterns, scattered pilot patterns, Costas array patterns), or (3) methods to reduce pilot overhead.

For each modulation symbol vector input, the RB Assembler combines the RB's pilot symbols with the modulation symbol vector to construct an RB. The scheduler specifies their RB element locations. The total number of data bits plus pilot bits contained within all of a user's n_B allocated RBs 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 RBs of size $n_{sc}^{RB} \times N_{sym}^{RB}$. The total number of data channel bits plus pilot channel bits that can be transmitted by all n_B RBs of size $n_{sc}^{RB} \times N_{sym}^{RB}$ is

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

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

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

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

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

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 RB elements but this requires additional overhead.

4 Resource Block Design Issues

For equal-sized RBs the key design problem is specifying their dimensions in time (number of OFDMA symbols) and frequency (number of OFDMA subcarriers). Two possible design approaches are as follows: (1) specify RB sizes to best match the sizes of data blocks produced by the information source models within the EMD [9], (2) specify RB sizes to best match the characteristics of the physical channel models within the EMD. As described above the construction of RBs can be decoupled from the size of data blocks output by an information source. We therefore take the second approach in this contribution and now list some important RB design issues:

- **RB Size 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 cover or 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 above.
    - 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].
- **RB Overhead Issues**
  - RB sizes should minimize pilot overhead, configuration and control overhead (e.g. power control), and RB addressing overhead. This implies large-sized RBs. RB addressing overhead can be minimized using brick-tessellated subframes as described in IEEE C802.16m-08/069.
  - RB sizes should minimize data feedback overhead for operations such as MIMO precoding and adaptive coding and modulation. This implies large-sized RBs.

5 Resource Block Size Estimation for 802.16m Radio Environments

In this section we address the resource block size issues just described, RB overhead issues are left to other contributions or future study. We first give definitions of channel coherence time and channel coherence bandwidth and then use these definitions to define RB dimensions that support the channel conditions associated with 802.16m radio environments defined in the Evaluation Methodology Document [9]. Note, in the described approach RB size is not specified to the match the data channel source models defined in the Evaluation Methodology Document [9]. Instead, RB size is specified to match the characteristics of the 802.16m physical channels defined in [9].

For a SISO channel the time-variant channel impulse response $h(\tau, t)$ is by definition the channel output when the channel input is an impulse $\delta(t)$. It may be written as

$$h(\tau, t) = \sum_{n=0}^{L-1} h_n(t)\delta(\tau - \tau_n(t)) = \sum_{n=0}^{L-1} \alpha_n(t) e^{-j2\pi f_C \tau_n(t)} \delta(\tau - \tau_n(t)) \tag{6}$$

where integer $L \geq 1$ is the finite number of resolvable propagation paths, $\tau_n(t)$ is the propagation time delay of the nth propagation path as function of time, $\alpha_n(t)$ is the gain of the nth propagation path as function of time and f_C the carrier frequency.

Recall that the 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. It describes the similarity or correlation of $h(\tau, t)$ when sampled at different times. The definition of coherence time implies that the channel affects differently two signals arriving with a time separation greater than T_C. For example, given a given initial time slot t_0 the channel coherence time T_C in units of time slots is basically the number of time slots for which $h(\tau, t)$ and $h(\tau, t_0 + T_C)$ are independent.

Fourier transforming $h(\tau, t)$ with respect to the delay variable τ gives the time-variant channel transfer function

$$H(f, t) = \int_{-\infty}^{\infty} h(\tau, t) e^{-j2\pi f \tau} d\tau = \sum_{n=0}^{L-1} h_n(t) e^{-j2\pi f \tau_n} \tag{7}$$

The 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), it describes the similarity or correlation of the time-variant transfer function $H(f, t)$ at different frequencies across a channel bandwidth. Frequency selective fading occurs when signal bandwidth is much greater than the channel coherence bandwidth. RBs separated in frequency by the channel coherence bandwidth have independent fading.

The channel's frequency correlation function may be defined as

$$R_H(f_{\text{offset}}) = \frac{E\left[H(f)H^*(f + f_{\text{offset}})\right]}{E\left[|H(f)|^2\right]} = \frac{1}{1 + (2\pi f_{\text{offset}} \sigma)^2} \tag{8}$$

and the channel's time correlation function as

$$R_h(t_{\text{offset}}) = \frac{E\left[h(t)h^*(t + t_{\text{offset}})\right]}{E\left[|h(t)|^2\right]} = J_0^2\left(2\pi f_D t_{\text{offset}}\right) \tag{9}$$

Here $J_0^2\left(2\pi f_D t_{\text{offset}}\right)$ denotes a squared zero-order Bessel function of the first kind, σ the channel delay spread, f_{offset} a frequency offset, and t_{offset} a time offset. The Bessel function argument $f_D = v/c$ denotes the maximum Doppler frequency shift, v denotes velocity and c the speed of light.

	Proposal 2	**Proposal 1**
Useful Symbol Time	80 μsec	91.4 μsec
Guard Interval Time	10 μsec	11.4 μsec
Total Symbol Time	90 μsec	102.8 μsec
# Symbols per Subframe	6	6
Six-symbol Subframe Duration	0.54 msec	0.617 msec
Subcarrier Spacing	12.5 kHz	10.94 kHz

Table 1: Frame structure values for Resource Block size estimation

The channel coherence bandwidth B_C may be calculated from the frequency correlation function $R_H(f_{\text{offset}})$, it equals the value of f_{offset} where the correlation $R_H(f_{\text{offset}})$ has dropped to a certain threshold. The x% channel coherence bandwidth is that value of f_{offset} such that

$$R_H(f_{\text{offset}}) = \frac{x}{100} \tag{10}$$

The 50% coherence bandwidths is typically estimated as

$$B_C \approxeq \frac{1}{5\sigma} \tag{11}$$

Similarly, the coherence time T_C may be calculated from the time correlation function $R_h(t_{\text{offset}})$, it equals the value of t_{offset} where the correlation $R_h(t_{\text{offset}})$ has dropped to a certain threshold. The x% coherence time is that value of t_{offset} such that

$$R_h(t_{\text{offset}}) = \frac{x}{100} \tag{12}$$

The 50% coherence times is typically estimated as

$$T_C \approxeq \frac{9}{16\pi f_D} \tag{13}$$

Note that the channel impulse response and transfer function decorrelate for time differences $t_{\text{offset}} > T_C$ and frequency differences $f_{\text{offset}} > B_C$.

Table 1 contains proposal-1 and proposal-2 frame structure values from Table 11.3-1 in contribution [6] and values derived from Table 11.3-1. We will use these values in defining our RB sizes. However, it should be emphasized that same approach described my also be applied to the harmonized frame structure values.

The current Evaluation Methodology Document [9] describes a number of 802.16m radio operating environments and contains tables with their channel delay profiles. Using the maximum path delay within each table as the delay spread σ and equation 11 we computed the 50% coherence bandwidth estimates shown in Table 2. Also shown in Table 2 is the number of subchannels that span each estimated channel coherence bandwidth. Estimating the maximum Doppler frequency shift from $f_D = v/c$ and using equation 13 we computed the 50% coherence time estimates shown in Table 3. Also shown in Table 3 is the number of OFDMA symbols that span each estimated channel coherence time.

A resource block is a rectangular area within a subframe's time-frequency plane that is treated as single physical layer allocation unit. An RB is constructed from a set of $n_{sc}^{RB} > 1$ contiguous OFDMA subcarriers (RB frequency dimension) and a set of $N_{sym}^{RB} > 1$ contiguous OFDMA symbols (RB time dimension). As described above a BS scheduler may allocate a set of $n_B \geq 1$ RBs. For each subframe the allocated RBs are fixed in sized. A user's RBs may be located anywhere within a subframe's time-frequency plane (see subsequent section on RB allocation modes).

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)				

Table 2: Channel coherence bandwidth estimates for various 802.16m radio operating environments. Channel delay spread values were obtained from the current Evaluation Methodology Document

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				

Table 3: Channel coherence time at 2.4 GHz with respect to Doppler

More formally an RB is defined as an n_{sc}^{RB}-by-N_{sym}^{RB} block matrix located within a subframe's time-frequency plane. RB elements are defined as

$$\begin{aligned} x(f_k, t_m) &= \frac{1}{\sqrt{N_{FFT}}} \sum_{n=0}^{N_{FFT}-1} s(n, t_m) e^{j2\pi kn/N_{FFT}} \\ k &= 0, 1, \ldots, n_{sc}^{RB} - 1 \\ m &= 0, 1, \ldots, N_{sym}^{RB} - 1 \end{aligned} \tag{14}$$

Integers f_k and real-values t_m respectively denote OFDMA subcarrier indices and OFDMA symbol start times, they are contiguous and ordered as follows:

$$\begin{aligned} f_0 &< f_1 < f_2 < \cdots < f_{n_{sc}^{RB}-1} \leq N_{FFT} - 1 \\ 0 &\leq t_0 < t_1 < t_2 < \cdots < t_{N_{sym}^{RB}-1} \end{aligned} \tag{15}$$

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}			

Table 4: Number of RBs per subframe as a function of channel bandwidth and the number of used subcarriers

Each RB element $x(f_k, t_m)$ is produced via a length-N_{FFT} IFFT operation on a complex-valued symbol sequence $\{s(n, t_m)\}_{n=0}^{N_{FFT}-1}$. The product $n_{sc}^{RB} \times N_{sym}^{RB}$ equals the number of complex-valued RB elements within an RB.

From Table 1 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 3 it is seen that the worst-case coherence time estimate is greater than the number of OFDMA symbols per subframe. Hence for a time duration of six OFDMA symbols the physical subchannel associated with an OFDMA subcarrier is flat. We therefore set the RB's OFDMA symbol dimension to $N_{sc}^{RB} = 6$ OFDMA symbols.

The variable RB bandwidth or subcarrier dimension n_{sc}^{RB} is defined as

$$n_{sc}^{RB} = m \cdot N_{sc}^{RB},\ m = \frac{1}{2}, 1, 2, 4 \tag{16}$$

It can be adapted to different channel coherence bandwidth variations such as those associated with the 802.16m radio environments shown in Table 2. For example, a channel with coherence time of $T_C = 63.466$ msec (Doppler of 6.6672 Hz) and a coherence bandwidth of $B_C = 108$ kHz (Urban Macrocell) remains approximately flat for a time duration of $N_{sym}^{RB} = 6$ OFDMA symbols and a subcarrier dimension of $n_{sc}^{RB} = 10$ but not for $n_{sc}^{RB} = 20$.

Variable m is a scaling factor that scales the subcarrier dimension N_{sc}^{RB} of an N_{sc}^{RB}-by-N_{sym}^{RB} *base* resource block. The use of the RB scaling factor m is similar in concept to that of scaling OFDMA symbol time durations to specify cyclic prefix lengths. From Table 2 it is seen that the median coherence bandwidth estimate is 21 subcarriers (proposal 2) or 24 subcarriers (proposal 1). We round these numbers to 20 and set the subcarrier dimension for the base RB to $N_{sc}^{RB} = 20$. Hence, an N_{sc}^{RB}-by-N_{sym}^{RB} base resource block is comprised of $N_{sc}^{RB} = 20$ subcarriers and $N_{sym}^{RB} = 6$ OFDMA symbols. Figure 2 illustrates a base RB within a subframe's time-frequency plane.

Table 4 shows the number of RBs per subframe as a function of channel bandwidth and the number of used subcarriers. 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 $N_{\text{used}}^{5\text{ MHz}}$, $N_{\text{used}}^{10\text{ MHz}}$ and $N_{\text{used}}^{10\text{ MHz}}$ must be a multiple of $n_{sc}^{RB} = m \cdot N_{sc}^{RB}$, $m = 1/2, 1, 2, 4$.

6 Resource Block Allocation Modes

The allocation of RBs to OFDMA users should based on time-varying channel conditions. From Table 2 it is seen that a single RB allocation method or mode will not support all possible 802.16m channel conditions. Figure 3 shows two basic RB allocation modes that are proposed to address this problem, they are summarized as follows:

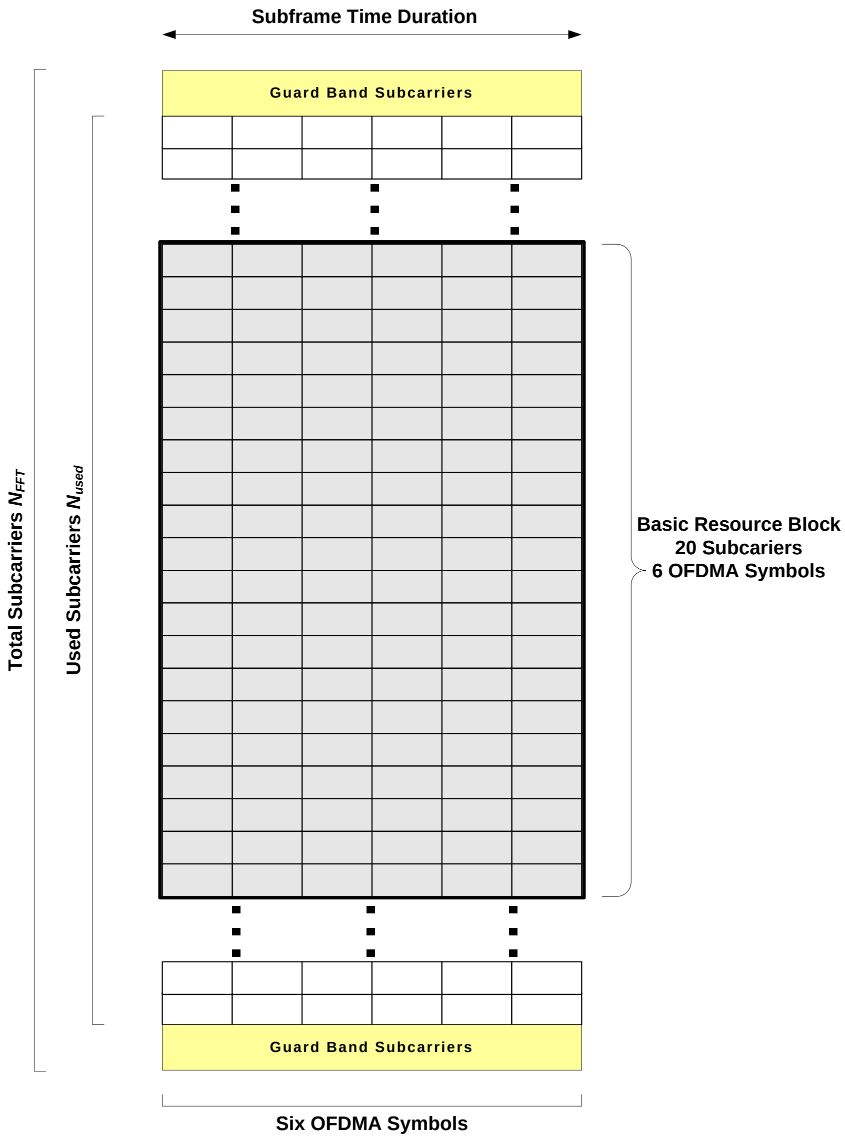


Figure 2: Base RB dimensions are N_{sc}^{RB}= 20 subcarriers and N_{sym}^{RB}= 6 OFDMA symbols. Variable RB dimensions are $n_{sc}^{RB} = m \cdot N_{sc}^{RB}$subcarriers and N_{sym}^{RB} OFDMA symbols where $m = \frac{1}{2}, 1, 2, 4$.

1. Contiguous RB Allocation. For contiguous allocation a user's RBs are allocated contiguously within an area of a subframe's time-frequency plane. Contiguous RB allocation transmission is beneficial for frequency selective channels [1,2]. Estimates of channel coherence bandwidth may be used for specifying a contiguous RB allocation.

2. 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:

   (a) 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.

   (b) Delay critical data transmission without channel feedback reporting. For this case data transmissions may be made more reliable by implementing subcarrier frequency hopping or diversity via a non-contiguous mode.

   (c) 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.

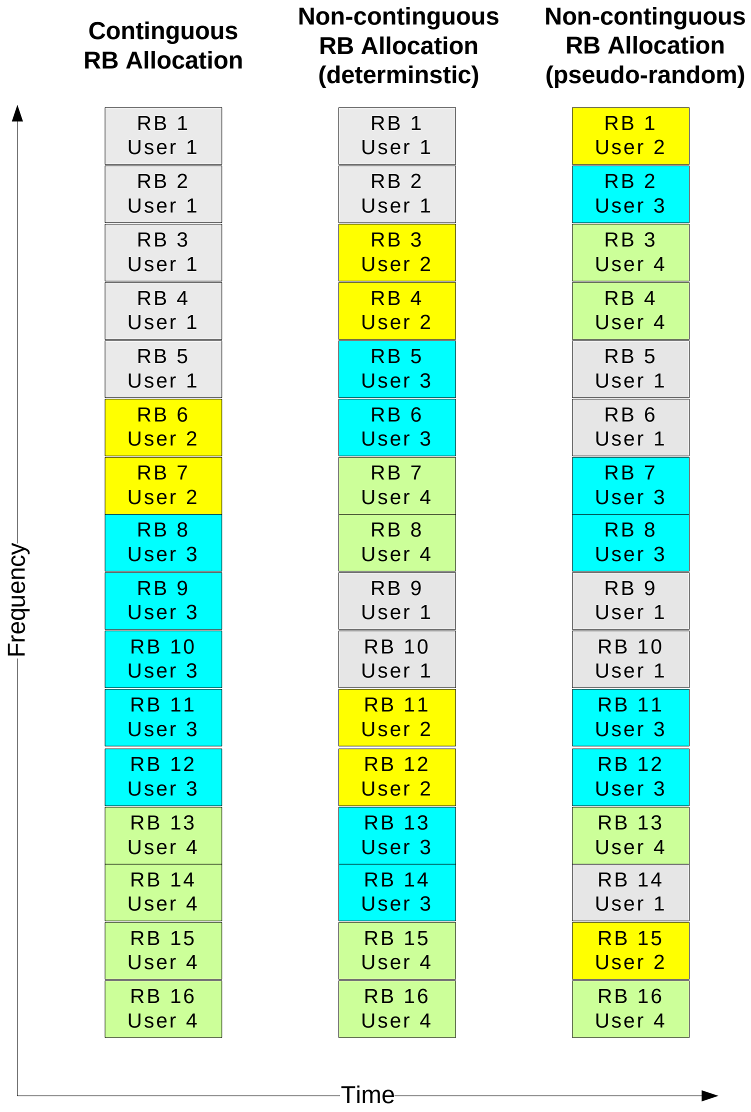
7 Resource Block Size Adaptation

The number of subcarriers n_{sc}^{RB} comprising an 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, the RB bandwidth may be selected by using estimates of the channel coherence bandwidth provided by one or more OFDMA users.

802.16m Radio Environment	50 % Coherence BW B_{C,RB_i} (kHz)	# of 10.94 kHz Subcarriers	# of 12.5 kHz Subcarriers	RB Candidate	Candidate Size $n_{sc}^{RB} \times N_{sym}^{RB}$
Indoor Hot Spot	930	86	75	RB_4^{BW}	$4N_{sc}^{RB}$-by-N_{sym}^{RB}
Indoor Small Office	800	74	64	RB_3^{BW}	$2N_{sc}^{RB}$-by-N_{sym}^{RB}
Rural Macrocell	476	44	39	RB_3^{BW}	$2N_{sc}^{RB}$-by-N_{sym}^{RB}
Outdoor to Indoor	342	32	28	RB_2^{BW}	N_{sc}^{RB}-by-N_{sym}^{RB}
Urban Microcell	325	30	26	RB_2^{BW}	N_{sc}^{RB}-by-N_{sym}^{RB}
Suburban Macrocell	260	24	21	RB_2^{BW}	N_{sc}^{RB}-by-N_{sym}^{RB}
Urban Macrocell	108	10	9	RB_1^{BW}	$\frac{1}{2}N_{sc}^{RB}$-by-N_{sym}^{RB}
Modified Vehicular A	76	7	7	RB_1^{BW}	$\frac{1}{2}N_{sc}^{RB}$-by-N_{sym}^{RB}
Bad Urban Microcell	71	7	6	RB_1^{BW}	$\frac{1}{2}N_{sc}^{RB}$-by-N_{sym}^{RB}
Modified Pedestrian B	5	1	1	RB_1^{BW}	$\frac{1}{2}N_{sc}^{RB}$-by-N_{sym}^{RB}
Bad Urban Macrocell	3	1	1	RB_1^{BW}	$\frac{1}{2}N_{sc}^{RB}$-by-N_{sym}^{RB}
N_{sc}^{RB}-by-N_{sym}^{RB} base RB is comprised of N_{sc}^{RB}= 20 subcarriers and N_{sym}^{RB}= 6 OFDMA symbols					

Table 5: Example of channel coherence bandwidth values and RB candidate set elements that may be used in a statistical ranking and selection algorithm for adapting RB size to time-varying channel condidions. Different candidate sets may be defined for other 802.16m bandwidths such as 5, 10 and 20 MHz.

A statistical ranking and selection algorithm may be used to adapt RB sizes to channel conditions. For a statistical ranking and selection algorithm we first define an RB candidate set



Contingguous RB Allocation	Non-contingguous RB Allocation (determinstic)	Non-contingguous RB Allocation (pseudo-random)
RB 1 User 1	RB 1 User 1	RB 1 User 2
RB 2 User 1	RB 2 User 1	RB 2 User 3
RB 3 User 1	RB 3 User 2	RB 3 User 4
RB 4 User 1	RB 4 User 2	RB 4 User 4
RB 5 User 1	RB 5 User 3	RB 5 User 1
RB 6 User 2	RB 6 User 3	RB 6 User 1
RB 7 User 2	RB 7 User 4	RB 7 User 3
RB 8 User 3	RB 8 User 4	RB 8 User 3
RB 9 User 3	RB 9 User 1	RB 9 User 1
RB 10 User 3	RB 10 User 1	RB 10 User 1
RB 11 User 3	RB 11 User 2	RB 11 User 3
RB 12 User 3	RB 12 User 2	RB 12 User 3
RB 13 User 4	RB 13 User 3	RB 13 User 4
RB 14 User 4	RB 14 User 3	RB 14 User 1
RB 15 User 4	RB 15 User 4	RB 15 User 2
RB 16 User 4	RB 16 User 4	RB 16 User 4

Figure 3: The allocation of RBs to OFDMA users should based on channel conditions. A single RB allocation mode will not support all possible channel conditions. Two basic RB allocation modes that may be implemented to address this problem are continguous and non-continguous.

$$\mathcal{R}^{BW} = \left\{RB_1^{BW}, RB_2^{BW}, \ldots, RB_{N_{RB}}^{BW}\right\} \tag{17}$$

that contains N_{RB} resource blocks sizes with distinct RB bandwidths n_{sc}^{RB}. For example, the 802.16m radio operating environments of Table 2 were used to derive the example candidate set shown in Table 5. Different candidate sets may be used for different channel bandwidths, this is denoted by the superscript BW (e.g. $BW = 5, 10$ and 20 MHz). Coherence bandwidths associated with the N_{RB} resource blocks sizes in $\mathcal{R}^{BW}$ are contained within the following set

$$\mathcal{B}^{BW} = \left\{B_{C,RB_1}, B_{C,RB_2}, \ldots, B_{C,RB_{N_{RB}}}\right\} \tag{18}$$

By comparing a coherence bandwidth estimate $\hat{B}_C$ with all coherence bandwidths in $\mathcal{B}^{BW}$ a scheduler may rank or order the elements in $\mathcal{B}^{BW}$. This will give a ranking that is consistent with an RB ranking such as

$$RB_{i_1}^{BW} \prec RB_{i_2}^{BW} \prec \cdots \prec RB_{i_{N_{RB}}}^{BW} \tag{19}$$

where $\{i_1, i_2, \ldots, i_{N_{RB}}\}$ is a distinct permutation of $\{1, 2, \ldots, N_{RB}\}$. A scheduler may then select the highest ranked RB candidate and use this RB for a subframe or other desired allocation period.

Given sets $\mathcal{R}^{BW}$ and $\mathcal{B}^{BW}$ the process for adapting RB sizes based on time-varying channel conditions is summarized by the following five steps:

1. Define a candidate RB set $\mathcal{R}^{BW}$ and a corresponding coherence bandwidth set $\mathcal{B}^{BW}$ as in the Table 5 example.

2. Obtain a coherence estimate $\hat{B}_C$ for an RB allocation period (e.g. subframe). For example $\hat{B}_C$ 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.

3. Rank the candidate RBs contained in $\mathcal{R}^{BW}$ by comparing $\hat{B}_C$ with the values in $\mathcal{B}^{BW}$. For example, RBs in $\mathcal{R}^{BW}$ can be ranked according to an L_p-norm

   $$\left\|\hat{B}_C - B_{C,RB_i}^{BW}\right\|_p, \; p = 1, 2, \infty \tag{20}$$

   which quantifies the distance between a coherence bandwidth B_{C,RB_i}^{BW} in $\mathcal{B}^{BW}$ and an estimated channel coherence bandwidth $\hat{B}_C$.

4. Select the highest ranked candidate in $\mathcal{R}^{BW}$ as the resource block size to use for an RB allocation period.

5. Schedule subframe data in accordance with the selected RB size and signal the RB size to OFDMA users.

Estimates $\hat{B}_C$ may be derived from estimates of the channel transfer function $H(f, t)$. In OFDMA system the receiver samples the received signal at time intervals T_S, removes the cyclic prefix, and computes the FFT of a received OFDMA symbol. For the kth subcarrier a frequency-domain channel estimate $\hat{H}(k/T_S)$ can be easily computed using pilot symbols. An unbiased sample estimate of the frequency correlation function $R_H(k_{\text{offset}})$ may then be computed as

$$\begin{aligned} \hat{R}_H(k_{\text{offset}}) &= \frac{1}{N_{FFT} - k_{\text{offset}}} \sum_{k=0}^{(N_{FFT}-1)-k_{\text{offset}}} \hat{H}\left(\frac{k}{T_S}\right) \hat{H}\left(\frac{k + k_{\text{offset}}}{T_S}\right) \\ k_{\text{offset}} &= 0, 1, \ldots, N_{FFT} - 1 \end{aligned} \tag{21}$$

where N_{FFT} is the dimension of the FFT and k_{offset} a subcarrier frequency offset. This estimate may smoothed by applying an exponentially weighted moving average filter defined by the equation

$$\tilde{R}_{H,n}(k_{\text{offset}}) = \alpha \hat{R}_{H,n}(k_{\text{offset}}) + (1-\alpha)\tilde{R}_{H,n-1}(k_{\text{offset}}) \tag{22}$$

Real value $0 < \alpha \leq 1$ is a smoothing or filter memory factor and n an index for the pilot symbol period. The coherence bandwidth may then be estimated by measuring the width of smoothed frequency correlation estimates. Specifically, the estimated coherence bandwidth may be defined as

$$\hat{B}_C = \frac{k_{\max}+1}{T_S} \tag{23}$$

where $k_{\max}$ is the maximum value of k_{offset} for which

$$\left|\tilde{R}_{H,n}(k_{\text{offset}})\right| \leq \beta \tilde{R}_{H,n}(0) \tag{24}$$

Here β a decision threshold value between 0 and 1.

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9 Proposed Text for the SDD

Resource Blocks and Resource Block Allocation Modes

A resource block (RB) is a rectangular area within a subframe's time-frequency plane that is treated as single physical layer allocation unit. An RB is constructed from a set of $n_{sc}^{RB} > 1$ contiguous OFDMA subcarriers (RB frequency dimension) and a set of $N_{sym}^{RB} > 1$ contiguous OFDMA symbols (RB time dimension). A BS scheduler may allocate a set of RBs to each user for each subframe. A user's RBs may be located anywhere within a subframe's time-frequency plane (see below text on RB allocation modes). A scheduler may disperse a user's allocated RBs in time, frequency and/or space. Figure 4 shows a conceptual block diagram of an OFDMA subsystem for mapping user data bits to RBs that comprise a downlink (DL) subframe.

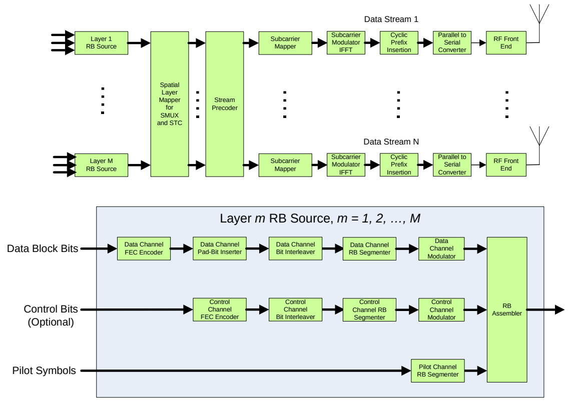


Figure 4: Conceptual block diagram of OFDMA subsystem for mapping bits to Resource Blocks.

The RB symbol dimension N_{sym}^{RB} is fixed at six OFDMA symbols. The number of subcarriers n_{sc}^{RB} comprising an RB bandwidth may either be fixed for a allocation period or it may vary adaptively as a channel changes. In the fixed case, the selected RB bandwidth dimension n_{sc}^{RB} may be less than or equal to the smallest expected channel coherence bandwidth. In the variable or adaptive case, n_{sc}^{RB} is defined as

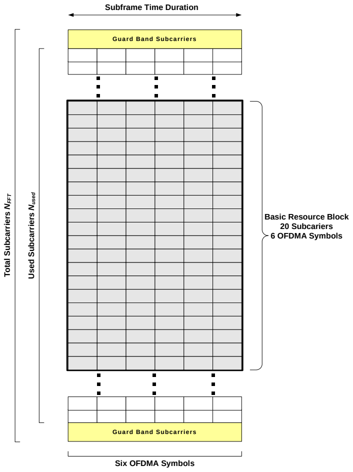
$$n_{sc}^{RB} = m \cdot N_{sc}^{RB},\ \ m = \frac{1}{2}, 1, 2, 4$$

Variable m is a scaling factor that scales the subcarrier dimension N_{sc}^{RB} of an N_{sc}^{RB}-by-N_{sym}^{RB} base resource block with $N_{sc}^{RB} = 20$ subcarriers and $N_{sym}^{RB} = 6$ OFDMA symbols. Figure 5 illustrates a base RB within a subframe's time-frequency plane. By changing the scaling factor the RB bandwidth dimension n_{sc}^{RB} can be adapted to different channel coherence bandwidth variations associated with various radio operating environments. In the adaptive case, the used RB dimension n_{sc}^{RB} shall be selected by using estimates of the channel coherence bandwidth provided by one or more OFDMA users.

Two basic RB allocation methods that may be implemented are shown in Figure 6, they are summarized as follows:

1. Contiguous RB Allocation. For contiguous allocation a user's RBs are allocated contiguously within an area of a subframe's time-frequency plane. Contiguous RB allocation transmission is beneficial for frequency selective channels. Channel coherence bandwidth may be used for specifying a contiguous RB allocation.

2. 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



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deterministic or pseudo-random manner. A non-contiguous RB allocation may be beneficial for the following:

(a) 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.

(b) Delay critical data transmission without channel feedback reporting. For this case data transmissions may be made more reliable by implementing subcarrier frequency hopping or diversity via a non-contiguous mode.

(c) Broadcasting and multicasting the same data to a number of users.

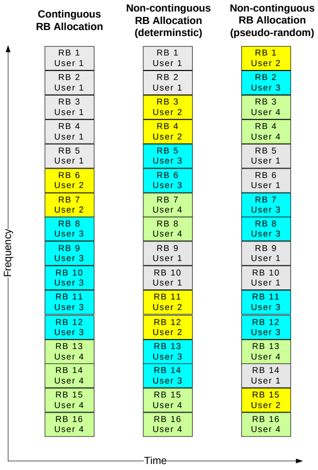

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Figure 6: The allocation of RBs to OFDMA users should based on channel conditions. A single RB allocation mode will not support all possible channel conditions. Two basic RB allocation modes that may be implemented to address this problem are continguous and non-continguous.