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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. The task of multi-user subcarrier/subchannel allocation by a BS scheduler 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 units to solve the above stated problem. 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 fixed-size 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 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. We describe the problem of RB construction, RB design issues of concern that should be addressed, proposed RB sizes that support 802.16m channel bandwidths, RB allocation modes that better support the various 802.16m channel conditions, and the problem of adapting RB bandwidth to better support the numerous channels conditions. The contribution concludes with text for the 802.16m System Description Document that is based on the proposed solution.

3 System Model for Resource Block Construction

Figure 1 shows a conceptual block diagram an OFDMA subsystem for mapping user data streams 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 to minimize feedback delay. However, this contribution does not discuss this option, it only describes RB construction using a Data and Pilot Channel.

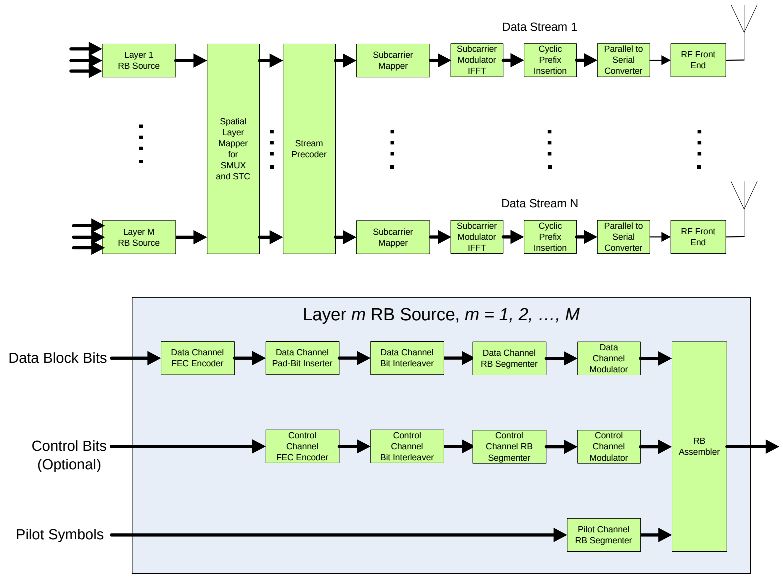

Figure 1: Conceptual block diagram of OFDMA subsystem for mapping data streams to Resource Blocks.

In the conceptual block diagram the approach for link adaptation is to adapt the M-QAM modulation of each user's RBs within a subframe but keep the code rate fixed [1,2]. That is, a user's code rate may only be changed for each subframe, a user's modulation can be different for each subframe and each allocated RB within a subframe. The encoded blocks of equal code rate may be mapped to one or more RBs where each RB modulation is matched to channel conditions. As described in [1,2] this approach for link adaptation is motivated by the following:

- Subcarrier channel variation associated with RBs belonging to the same user is typically much lower than the variation between different users.
- The codeword length can be large in order to make best use of DBTC or LDPC codes.
- By employing one decoder for all user RBs the decoding complexity is moderate.

An alternative approach of adapting both the modulation and coding scheme per RB has also been investigated in [1,2]. This approach may result in increased complexity and limited coding gain due to the shorter codeword lengths.

In the following paragraphs we describe the basic operations performed for RB construction. 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 M-QAM modulation symbols within an RB.

In accordance with the 802.16m traffic models a data channel source produces randomized binary-valued data blocks of various lengths κ_{Data}. For example, a data channel source may produce a length-κ_{Data} data block by buffering n_p randomized data packets of n_{pbits} bits into a length $\kappa_{Data} = n_p n_{pbits}$ data block.

The 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. Some code options for the encoder are Convolutional Codes, Duo-Binary Turbo-Codes (also called convolutional turbo codes) and Low Density Parity Check codes.

The code and/or code rate $R_{Data} = \kappa_{Data}/\eta_{Data}$ of the Data Channel FEC encoder may be adapted to channel and interference conditions.

Each encoded length-η_{Data} data block output by the Data Channel FEC Encoder is first interleaved by the Data Channel Bit Interleaver and then input to the Data Channel RB Segmenter where it is segmented into $n_B \geq 1$ encoded data sub-blocks of lengths $\eta_{k,Data}$, $k = 0, \ldots, n_B - 1$. Lengths $\eta_{k,Data}$ must be divisors of two, they are specified by the scheduler and are based on the chosen RB size.

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 $m_{k,Data} = \eta_{k,Data}/b_{k,Data}$ where $b_{k,Data} = \log_2(M_{k,Data})$ 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. Signal constellations are specified by the scheduler and are based on channel and interference conditions. For the kth modulation symbol vector all $m_{k,Data}$ data modulation symbols must be from the same signal constellation. However, they may be different for each of the n_B modulation symbol vectors in order to adapt to time-varying channel and interference conditions.

Before continuing with operation description it should be noted that the length $m_{k,Data}$ of a modulation symbol vector is dependent on the pair $(\eta_{k,Data}, b_{k,Data})$. For example, if $\eta_{k,Data} = 640$, and $b_{k,Data} = 2$ the length of the resulting modulation symbol vector is $m_{k,Data} = \eta_{k,Data}/b_{k,Data} = 320$. In current 802.16 systems $\eta_{k,Data}$ and $b_{k,Data}$ are specified so that $m_{k,Data}$ is always a divisor of two. It is assumed that this is also true for 802.16m systems.

For a specified code rate R_{Data} and set of data M-QAM modulations $M_{k,Data}$, $k = 0, \ldots, n_B - 1$, the total number of data channel bits to be mapped by the scheduler to all n_B allocated user RBs is

$$n_{Data\_bits} = n_{sc}^{RB} \cdot N_{sym}^{RB} \cdot \sum_{k=0}^{n_B-1} \frac{\eta_{k,Data}}{m_{k,Data}} \tag{1}$$

For each RB the Pilot Channel produces $n_{k,Pilot}$, $k = 0, \ldots, n_B - 1$, pilot bits, two bits per complex-valued pilot symbol. The RB Assembler combines the complex-valued pilot symbols within the complex-valued modulation symbol vectors output by the Data Channel into an RB. 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.

The total number of data channel bits plus pilot channel bits mapped by the scheduler to all n_B allocated user RBs is

$$n_{total\_user\_bits} = n_{sc}^{RB} \cdot N_{sym}^{RB} \cdot \left(n_{Data\_bits} + \sum_{k=0}^{n_B-1} n_{k,Pilot} \right) \tag{2}$$

It must be emphasized that integer $n_{total\_user\_bits}$ is a variable that may not equal or match 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

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

To completely fill all n_B allocated RBs with a 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 a cyclic repetition of the first n_{pad} bits of the length n_{Data_bits} codeword block. This is more efficient than simple zero-padding [1,2] and incurs hardly any additional complexity. Another option is to multiplex other users data within the unused locations 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). Some important RB design issues are the following:

- **RB Size Issues**
  - RB sizes should support all operating channel bandwidths.
  - 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 allowed data block sizes with minimal performance degradation and with minimal decrease in data throughput due to pad bits as described above.
    - Large-sized RBs better support large data blocks and large bandwidth allocations. However, if a small data block is mapped to a large-sized RB a number of RB elements will not be used resulting in pad bits and a decrease in data throughput.
    - Small-sized RBs better support small data blocks, small bandwidth allocations and power-limited communications (e.g. cell-edge). 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. Minimum coherence time depends on the maximal user velocity limit. Users with high speeds will cause the RB size to be unnecessarily small for other users with better channel conditions.
  - RB bandwidth should be less than the minimum expected channel coherence bandwidth. RBs separated in frequency by the channel coherence bandwidth have independent fading. Minimum coherence bandwidth depends on the multi-path properties of an 802.16m radio environment.
- **RB Overhead Issues**
  - RB sizes should minimize pilot signal overhead, configuration and control overhead (e.g. power control), and RB addressing overhead.
  - RB sizes should minimize data feedback overhead for operations such as MIMO precoding and adaptive coding and modulation. Note that these design objectives imply 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 RBs that support the channel conditions associated with 802.16m radio environments.

For 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 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

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

and the channel's time correlation function as

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

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

The channel coherence bandwidth B_C may be calculated from the frequency correlation function $R_H(\Delta f)$, it equals the value of Δf where the correlation $R_H(\Delta f)$ has dropped to a certain threshold. The $X\%$ channel coherence bandwidth is that value of Δf such that

Useful Symbol Time:	80 μsec
Guard Interval:	10 μsec
Total Symbol Time:	90 μsec
# Symbols per subframe:	6
Six-Symbol Subframe Duration:	0.54 msec
Subcarrier Spacing:	12.5 kHz

Table 1: Frame structure values for Resource Block size estimation

$$R_H(\Delta f) = \frac{x}{100} \tag{10}$$

The 50% coherence bandwidths is typically approximated as

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

Similarly, the coherence time T_C may be calculated from the temporal correlation function $R_H(\Delta t)$, it equals the value of Δt where the correlation $R_H(\Delta t)$ has dropped to a certain threshold. The $X\%$ coherence time is that value of Δt such that

$$R_H(\Delta t) = \frac{x}{100} \tag{12}$$

The 50% coherence times is typically approximated 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 $\Delta t > T_C$ and frequency differences $\Delta f > B_C$.

Table 1 contains proposal-2 frame structure values from Table 11.3-1 in contribution [6] and values derived from Table11.3-1. We will use these values in defining our RB sizes. However, it should be emphasized that same approach described my also be applied using the proposal-2 frame structure values from Table 11.3-1.

The current Evaluation Methodology Document [5] 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 17 we computed the 50% coherence bandwidth estimates shown in Table 2. Also shown in Table 2 is the number of 12.5 kHz subchannels that spans each estimated channel coherence bandwidth. Estimating the maximum Doppler frequency shift from $f_D = v/c$ and using equation 19 we computed the 50% coherence time estimates shown in Table 3. Also shown in Table 3 is the number of 90 μsec OFDMA symbols that spans 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).

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

802.16m Radio Environment	Delay Spread σ (nsec)	Estimated 50 % Coherence BW B_C (kHz)	# of 12.5 kHz Subcarriers
Indoor Hot Spot	215	930	75
Indoor Small Office	250	800	64
Rural Macrocell	420	476	39
Outdoor to Indoor	585	342	28
Urban Microcell	615	325	26
Suburban Macrocell	770	260	21
Urban Macrocell	1845	108	9
Modified Vehicular A	2620	76	7
Bad Urban Microcell	2800	71	6
Modified Pedestrian B	3870	5	5
Bad Urban Macrocell	7100	3	3
Median: 21 subcarriers (12.5 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
3	6.6672	63.466	706
10	22.224	19.040	212
20	44.448	9.520	106
50	111.12	3.810	43
100	222.24	1.904	22
150	333.36	1.269	15
200	444.48	0.952	11
250	555.6	0.762	9
Six 90 μsec OFDMA symbols per 0.54 msec subframe			

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

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

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

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

Each RB element $x(f_k, t_m)$ is produced via a length-N_{FFT} IFFT operation on an 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 M-QAM modulation and pilot symbols within an RB.

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: Table Caption

The symbol dimension N_{sym}^{RB} is fixed but the subcarrier dimension n_{sc}^{RB} is variable. From Table 3 it is seen that the worst-case coherence time estimate is 0.762 msec and that nine 90 μsec OFDMA symbols span this time interval. From Table 1 it is seen that each subframe is comprised of six OFDMA symbols which span a time duration of 0.54 msec. The worst-case coherence time estimate is greater than the number of symbols per subframe so we set the OFDMA symbol dimension $N_{sc}^{RB} = 6$. The variable 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 $B_C = 63.466$ msec (Doppler of 6.6672 Hz) and a coherence bandwidth of $B_C = 108$ kHz remains approximately constant or flat for RBs with a subcarrier dimension of $n_{sc}^{RB} = 10$ but not for a subcarrier dimension of $n_{sc}^{RB} = 20$.

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. From Table 2 it is seen that the median coherence bandwidth estimate is 21 subcarriers. We round this number 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 (250 kHz in frequency) and $N_{sym}^{RB} = 6$ OFDMA symbols (0.54 msec in time). 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. An N_{sc}^{RB}-by-N_{sym}^{RB} base resource block is comprised of $N_{sc}^{RB} = 20$ subcarriers (250 kHz in frequency) and $N_{sym}^{RB} = 6$ OFDMA symbols (0.54 msec in time). In order for n_{RB} 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 will not support all possible channel conditions. Figure 3 shows two basic RB allocation methods that are proposed to address this problem, 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 [1,2]. Channel coherence bandwidth may be used for specifying a contiguous RB allocation.

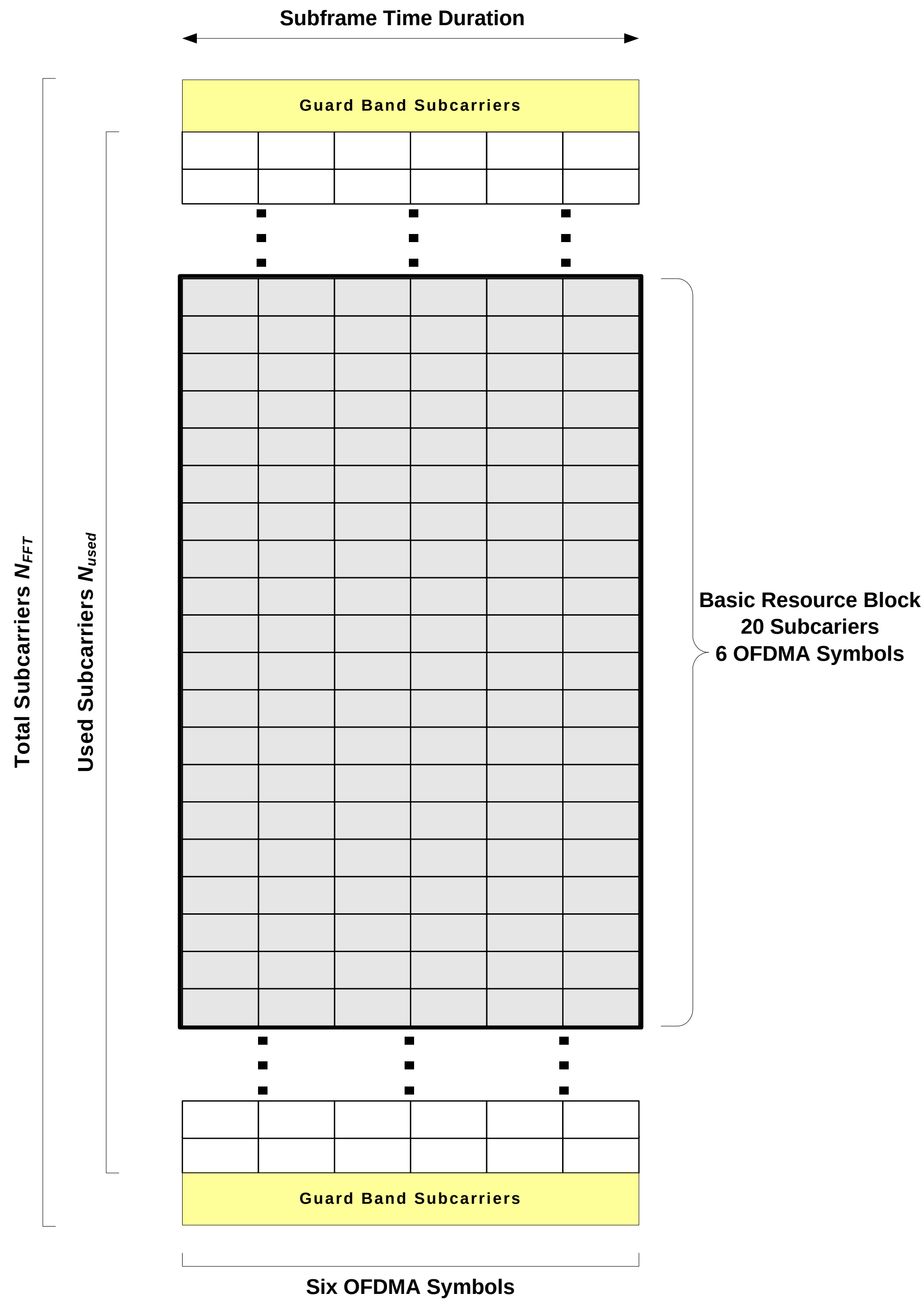

Figure 2: Base RB dimensions are N_{sc}^{RB}= 20 subcarriers and N_{sym}^{RB}= 6 OFDMA symbols. Variable RB dimensions are $n_{sc}^{RB} = m \cdot N_{sc}^{RB}$subcarriers and N_{sym}^{RB} OFDMA symbols where $m = \frac{1}{2}, 1, 2, 4$.

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 frequency hopping or diversity via a non-contiguous mode.

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

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.

Resource Block	802.16m Radio Environment	50 % Coherence BW B_{C,RB_i} (kHz)	# of 12.5 kHz Subcarriers	RB Size $n_{sc}^{RB} \times N_{sym}^{RB}$
RB_4^{BW}	Indoor Hot Spot	930	75	$4N_{sc}^{RB}$-by-N_{sym}^{RB}
RB_3^{BW}	Indoor Small Office	800	64	$2N_{sc}^{RB}$-by-N_{sym}^{RB}
RB_3^{BW}	Rural Macrocell	476	39	$2N_{sc}^{RB}$-by-N_{sym}^{RB}
RB_2	Outdoor to Indoor	342	28	N_{sc}^{RB}-by-N_{sym}^{RB}
RB_2	Urban Microcell	325	26	N_{sc}^{RB}-by-N_{sym}^{RB}
RB_2	Suburban Macrocell	260	21	N_{sc}^{RB}-by-N_{sym}^{RB}
RB_1	Urban Macrocell	108	9	$\frac{1}{2}N_{sc}^{RB}$-by-N_{sym}^{RB}
RB_1	Modified Vehicular A	76	7	$\frac{1}{2}N_{sc}^{RB}$-by-N_{sym}^{RB}
RB_1	Bad Urban Microcell	71	6	$\frac{1}{2}N_{sc}^{RB}$-by-N_{sym}^{RB}
RB_1	Modified Pedestrian B	5	5	$\frac{1}{2}N_{sc}^{RB}$-by-N_{sym}^{RB}
RB_1	Bad Urban Macrocell	3	3	$\frac{1}{2}N_{sc}^{RB}$-by-N_{sym}^{RB}

Table 5: Channel coherence bandwidth estimates and RB candidate set elements for various 802.16m radio operating environments.

A statistical ranking and selection algorithm may be used to adapt RB bandwidth dimension n_{sc}^{RB} to channel conditions. For a statistical ranking and selection algorithm we first define a candidate RB set

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

that contains N_{RB} resource blocks sizes with distinct bandwidths n_{sc}^{RB}. For example, radio operating environments were used to derive the 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

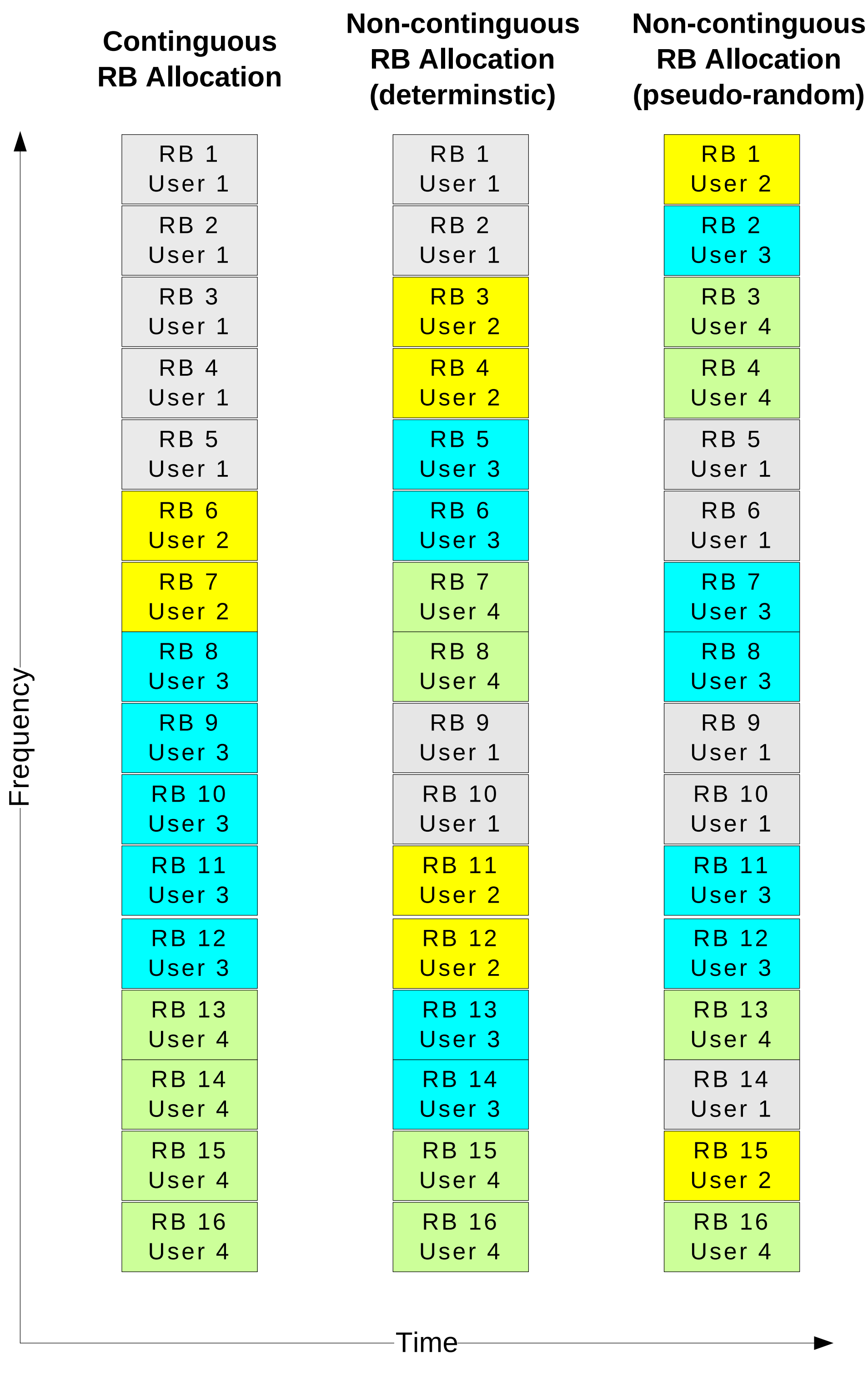

Figure 3: The allocation of RBs to OFDMA users should based on channel conditions. A single RB allocation mode will not support all possible channel conditions. Two basic RB allocation modes that may be implemented to address this problem are continguous and non-continguous.

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

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

$$RB_{i_1}^{BW} \prec RB_{i_2}^{BW} \prec \cdots \prec RB_{i_{N_{RB}}}^{BW} \quad (19)$$

where $\{i_1, i_2, \ldots, i_{N_{RB}}\}$ is a distinct permutation of $\{1, 2, \ldots, N_{RB}\}$. A ranking of $\mathcal{B}^{BW}$ will be consistent with a ranking of the elements in $\mathcal{R}^{BW}$. The scheduler then selects the number of subcarriers n_{sc}^{RB} comprising the highest ranked candidate $RB_{i_1}^{BW}$ as the resource subcarrier dimension to use for an RB 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 $\mathcal{B}^{BW}$. Some example design considerations for specifying candidate elements within $\mathcal{R}^{BW}$ are as follows: (1) small RB sizes may require extensive signaling and overhead, (2) a lower RB bandwidth limit may be set to best support the minimal used encoded and modulated data block size, (3) the size of the RBs bandwidth may be multiples of each other.

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

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

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

4. Select the highest ranked candidate $RB_{i_1}^{BW}$ as the resource block size to use for an RB allocation period.

5. Schedule data in accordance with the selected RB size RB_1^{BW} 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. An unbiased sample estimate of the frequency correlation function $R_H(\Delta f)$ may then be computed as

$$\begin{aligned} \hat{R}_H(p) &= \frac{1}{N_{FFT} - p} \sum_{k=0}^{(N_{FFT}-1)-p} \hat{H}(\frac{k}{T_S}) \hat{H}(\frac{k+p}{T_S}) \\ p &= 0, 1, \ldots, N_{FFT} - 1 \end{aligned} \quad (21)$$

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

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

Real value $0 < \alpha \leq 1$ is a smoothing factor and n an index for the pilot symbol period. The coherence bandwidth may then be estimated by measuring the width of the smoothed frequency correlation estimate $\tilde{R}_{H,n}(p)$. Specifically, the estimated coherence bandwidth may be defined as

$$\hat{B}_C = \frac{L_C + 1}{T_S} = (L_C + 1)\,\Delta f \cdot N_{FFT} \tag{23}$$

where L_C is the maximum value of p for which

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

Here β a decision threshold value between 0 and 1.

8 References

1. S. Stiglmayr, M. Bossert, E. Costa, "Adaptive coding and modulation in OFDM systems using BICM and rate-compatible punctured codes," European Wireless, Paris, Apr. 2007.

2. Sternad, M. Svensson, T. Ottosson, T. Ahlen, A. Svensson, A. Brunstrom, A., Towards Systems Beyond 3G Based on Adaptive OFDMA Transmission, Proceedings of the IEEE, Volume 95, Issue 12, Dec. 2007 Page(s):2432 - 2455.

3. T.S. Rappaport, Wireless Communications Principles and Practice. Prentice-Hall, January 1996.

4. W C Jakes, Microwave Mobile Communications, IEEE Press Piscataway, NJ.

5. IEEE C802.16m-08/080r4, Draft IEEE 802.16m Evaluation Methodology Document, 2007-03-4.

6. IEEE C802.16m-08/118r1, Proposed 802.16m Frame Structure Baseline Content Suitable for Use in the 802.16m SDD.

9 Proposed Text for the SDD

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).

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 subframe allocation period or it may vary adaptively as the 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. Hence, an N_{sc}^{RB}-by-N_{sym}^{RB} base resource block is comprised of $N_{sc}^{RB} = 20$ subcarriers (250 kHz in frequency) and $N_{sym}^{RB} = 6$ OFDMA symbols (0.54 msec in time). Figure 4 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.

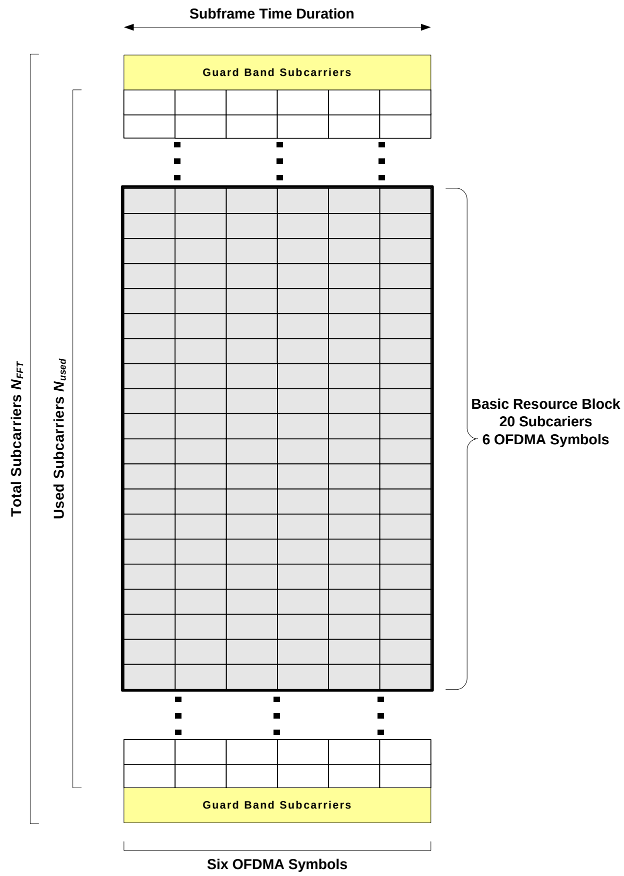

Figure 4: Base RB dimensions are $N_{sc}^{RB}= 20$ subcarriers and $N_{sym}^{RB}= 6$ OFDMA symbols. Variable RB dimensions are $n_{sc}^{RB}= m \cdot N_{sc}^{RB}$subcarriers and N_{sym}^{RB} OFDMA symbols where $m = \frac{1}{2}, 1, 2, 4$.

Two basic RB allocation methods that may be implemented are shown in Figure 5, 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 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 frequency hopping or diversity via a non-contiguous mode.

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

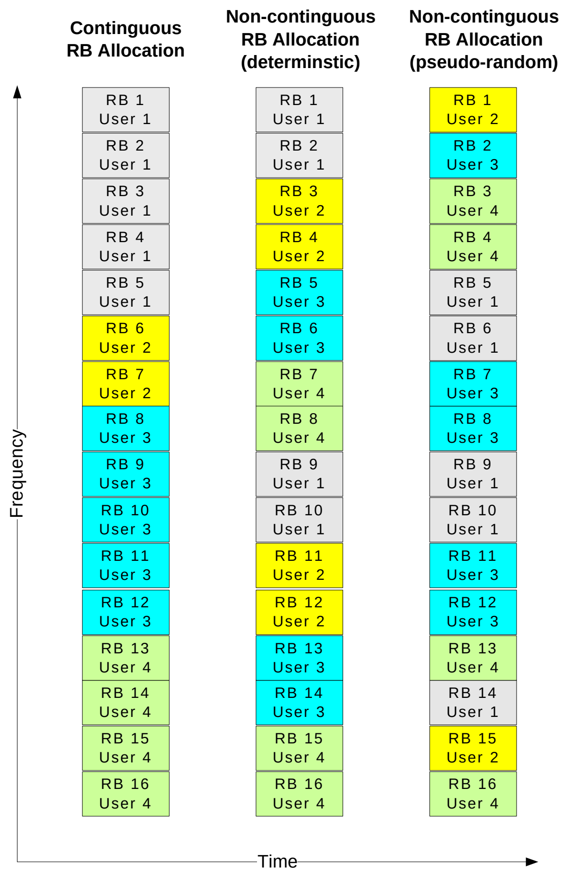

Figure 5: Example showing RB allocation modes. A single RB allocation mode will not support all possible channel conditions. Two basic RB allocation modes that may be implemented to address this problem are continguous and non-continguous.