Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
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Re:	Call for Comments on contribution C802.16-08/118r1 – the proposed SDD text on frame structure from the Rapporteur's Group
Abstract	Provide detailed rationale for proposed for new IEEE802.16m OFDMA numerology.
Purpose	Discuss and accept the proposed changes to the SDD text contained in contribution C802.16-08/118r1 into the 16m SDD baseline document.
Notice	
Release	
Patent Policy	

Further Considerations on IEEE 802.16m OFDMA Numerology

1. Introduction

This contribution provides some updates and clarifications on the considerations for the set of OFDMA numerology for 16m that was proposed in contribution IEEE C802.16m-08/080r1. Changes to the proposed SDD text on OFDMA numerology contained in IEEE C802.16m-08/118r1 are also provided.

2. Executive Summary

It is critical that the design of 802.16m provide for critical needs in order to enable 802.16 to be a cost-effective, global, and competitive technology well into the future. Meeting these needs will require some balance between how 802.16m will be constrained by the requirement to support legacy MSs while providing for these critical needs as a global IMT-Advanced technology. One of the critical foundations of 802.16m technology will be the configuration of the OFDMA technology that will continue to serve as the base physical layer multiple access and transmission technology for 802.16m. It is proposed that in order for 802.16m to be such a cost-effective, competitive, global technology, it must adopt a different approach to OFDMA configuration in which the subcarrier spacing is fixed to a value that serves well the radio environments in which 16m is intended to operate and which is highly compatible with available and potential future carrier bandwidths. To this end, the physical layer of 16m is proposed to be based on a fixed subcarrier spacing of 12.5 kHz; the rationale for this approach and the selection of this particular spacing and the issues with retaining the current OFDMA parameters are described in detail in the remainder of this document.

Table 1 below provides a summary comparing how the new 12.5-kHz subcarrier spacing compares with the various options of retaining the current subcarrier spacing(s) in meeting key design considerations for 802.16m.

Table 1: Comparison of 12.5-kHz Subcarrier Spacing With Other Solutions

Key Design Considerations	Design Approach for 16m Subcarrier Spacing		
	New 12.5-kHz	Retain Current 16e Subcarrier Spacings	
		Current Spacings 'As Is'	Use 10.9375 kHz
Greenfield (Legacy-free) Considerations			
Lower Hardware Cost	√	X	√
Simplified Global Roaming	√	X	√
Maximize usable bandwidth within carrier adjacent multi-carrier scenarios	√ (1)	X	X (2)
Enable efficient adjacent multicarrier operation with different bandwidths	√	X	X (2)
Enable multicarrier overlay scenarios of different bandwidths	√	X	X
Simplified adaptation to new carrier bandwidths (e.g. 6/12 MHz)	√	X	√-- (3)

Legacy Support Considerations			
Legacy support via TDM multiplexing between 16e and 16m	√	√	√
Legacy support via FDM multiplexing between 16e and 16m	√-- (4)	√- (5)	√-- (6)
16e and 16m sharing of same freq/time area	X	√- (7)	√-- (8)
Less hardware re-design	X (9)	√- (10)	x (10)
Inter-RAT Co-existence Considerations			
Ease of co-existence with other IMT-Advanced Technologies (e.g. LTE) with Frame Slot Time Alignment	√	x (11)	x (11)

NOTES

√ indicates is able to satisfy
√- indicates is able to satisfy but with some undesirable constraints
√-- indicates is able to satisfy but not preferred due to significant drawbacks
X indicates is not feasible or not practical

(1) Alignment of subcarrier spacings between adjacent subcarriers allow full carrier bandwidth to be utilized if adjacent carriers are 16m … resulting in >8% improvement in available used bandwidth.

(2) Could be possible with a change in carrier centering from current assignments based on 250-kHz raster to new centers based on new raster (e.g. 175 kHz) that is divisible evenly by 10.9375 kHz. Also results in additional loss due to gaps required between edges of adjacent carriers since carrier bandwidths are not divisible evenly by the raster.

(3) Some efficiency loss since raster based on this subcarrier spacing does not center available carrier(s) within spectrum band/block.

(4) Can be done with additional hardware for parallel FFTs for different subcarrier spacings, coordinated subcarrier assignment for 16m & 16e, and sufficient guard subcarriers between 16e and 16m used subcarriers. Also, same constraints as (5).

(5) Can be done but can constrain subcarrier arrangement options on 16m subcarriers for 16e distributed subcarrier permutations (e.g. PUSC)

(6) Same constraints as (5) and when legacy operation is on 7/14 or 8.75-MHz bandwidths, then same constraint as (4).

(7) Maximizes resource sharing between 16e and 16m but 16m MSs need to operate in a combined 16e/16m mode (tight coupling to 16e)

(8) Same constraints as (7) and when legacy operation is on 7/14 or 8.75-MHz bandwidths, then same constraint to support multiple subcarrier spacings simultaneously (i.e. same as for 12.5 kHz)

(9) Complexity of change depends heavily on current design … designs for multiple subcarrier spacing/sampling freq. are well understood and not complex.

(10) It is unclear that there won't be hardware changes/upgrades required due to other PHY and/or MAC changes for 16m - most likely there will

(11) Zone and subframe boundaries based on current numerology do not line up well with LTE frame element timings

3. Problem Statement

As we all know, IEEE 802.16m SRD requires that IEEE 802.16m shall meet the IMT-Advanced requirements. And all enhancements included as part of IEEE 802.16m should promote the concept of continued evolution, allowing IEEE 802.16 to maintain competitive performance as technology advances beyond 802.16m.

On the other hand, IEEE 802.16m SRD requires that IEEE 802.16m shall provide continuing support and interoperability for WirelessMAN-OFDMA Reference System which is defined as system compliant with the capabilities set specified by WiMAX Forum Mobile System Profile Release 1.0. For example, based on the backward compatibility requirements, 802.16m BS shall support 802.16m and legacy MSs when both are operating on the same RF carrier.

But actually there are a lot of problems existing in current legacy system design. Some of them have an unfavorable impact of system implementation, network deployment and equipment cost. So the inheritance of legacy system's drawbacks shall be prevented when we design 802.16m system.

3.1 Subcarrier Spacing

OFDMA numerology is the base of OFDM technology and directly affects the frame structure design which is one of the basic elements of the Physical Layer. Now we will describe some problems caused by OFDMA numerology which is used by legacy system and their effect on current legacy system. The following table describes the basic OFDMA numerology defined by current legacy system.

Table 2: OFDMA Parameters for IEEE 802.16m → Proposal-1

<table>
<tr><td colspan="2">Nominal Channel Bandwidth (MHz)</td><td>5</td><td>7</td><td>8.75</td><td>10</td><td>20</td></tr>
<tr><td colspan="2">Over-sampling Factor</td><td>28/25</td><td>8/7</td><td>8/7</td><td>28/25</td><td>28/25</td></tr>
<tr><td colspan="2">Sampling Frequency (MHz)</td><td>5.6</td><td>8</td><td>10</td><td>11.2</td><td>22.4</td></tr>
<tr><td colspan="2">FFT Size</td><td>512</td><td>1024</td><td>1024</td><td>1024</td><td>2048</td></tr>
<tr><td colspan="2">Sub-Carrier Spacing (kHz)</td><td>10.9375</td><td>7.8125</td><td>9.765625</td><td>10.9375</td><td>10.9375</td></tr>
<tr><td colspan="2">Tu (us)</td><td>91.4</td><td>128</td><td>102.4</td><td>91.4</td><td>91.4</td></tr>
<tr><td>Cyclic Prefix (CP)</td><td>Ts (us)</td><td colspan="4">Number of OFDM Symbols per Frame</td><td>Idle Time (us)</td></tr>
<tr><td rowspan="3">Tg=1/8 Tu</td><td>91.4 + 11.42=102.82 (for 5, 10, 20 MHz)</td><td colspan="4">48 (for 5, 10, 20 MHz)</td><td>64.64</td></tr>
<tr><td>128+16=144 (for 7 MHz)</td><td colspan="4">34 (for 7 MHz)</td><td>104</td></tr>
<tr><td>102.4+12.8=115.2 (for 8.75 MHz)</td><td colspan="4">43 (for 8.75 MHz)</td><td>46.40</td></tr>
</table>

Legacy Numerology Problem# 1: Legacy Numerology Cannot Ease the Pain of Legacy Support!

The legacy systems with 5/10/20MHz, 3.5/7MHz and 8.75MHz have different subcarrier spacing values which are derived based on different series bandwidths, and therefore different sets of sampling frequencies. Such incompatible sampling frequency sets impose unnecessary complexity for equipment to support the various bandwidths. Based on the legacy support requirements, 802.16m BS shall support 802.16m and legacy MSs when both are operating on the same RF carrier. However, there are three sets of legacy numerology in the 16e (or WiMAX) deployment, namely 5/10, 7/14, and 8.75. It is extremely crucial to support them all - we need to ensure global roaming compatibility with common equipment and devices. However, these legacy systems not only have different numerology parameters such as subcarrier spacing, they are often located in different frequency bands. These are tremendous challenges in the 16m design to support legacy systems, and there is NO easy way out!

Let's take the traditional argument that we adopt the existing legacy numerology so that the 16m system can support the 16e system without much pain. Without even considering the compromise of 16m performance, is the argument true?

Assuming that we wish to base our 16m OFDMA design on the numerology that already exists in 802.16e, there are two ways we can attempt to do this:

Option 1: Let's take the different sets of numerology as they are. THE 16M MS WILL SUPPORT ALL LEGACY SAMPLING RATES AND SUBCARRIER SPACINGS EVEN IN GREEN FIELD DEPLOYMENT (WHERE LEGACY SUPPORT IS TURNED OFF), This also means needing to support different bandwidths and different numerology sets for global roaming. It can be done. It should be the easiest way to achieve legacy support. However, the existing LTE and UMB designs have each already adopted a single set of numerology, but the 16m design is going to remain with 3 sets of numerology for 5/7/8.75Mhz system bandwidths. In order to resolve future 16m devices roaming, how could you reduce the costs of 16m with multiple sets of numerology? Not to mention there are quite a few problems in today's 16e numerology (stated in the problem statements to follow). How will 16m handle 6-MHz and 12-MHz system bandwidths which have been defined in 700MHz and other bands – by creating a 4^{th} set of numerology for them? It is also very hard for us to predict what other bandwidths will be allocated for the IMT-Advanced Bands. Are we going to continue adding new sets of numerology? This will continue to require more costly and complex designs for future 16m. Other competing technologies are using single sets of numerology and design to support different system bandwidths in different bands to achieve global roaming. What will be the competitive edge of 16m? This is clearly not a good option.

Option 2: Let's take ONE of the legacy sets of numerology (say the popular 5/10MHz). THE MS WILL STILL NEED TO SUPPORT DIFFERENT SETS OF NUMEROLOGY FOR LEGACY SUPPORT - namely 7/14MHz and 8.75MHz. The argument of sharing only one set of numerology between 16m and 16e design will no longer be true. At least we cannot have one set of numerology for 16m design for global roaming. Since a 16m MS design would need to support multiple sampling base frequencies for legacy support anyway, such as providing support for both 16m (2.5GHz, 10.9375kHz) and 16e (3.5Ghz, 7.8125kHz) using a rate change filter with one crystal or via separate crystals, THEN THERE IS NO DIFFERENCE IN DESIGN COMPLEXITY REGARDLESS OF THE SUBCARRIER SPACING USED BY 16M - EITHER 10.9375 KHZ OR OTHER SUBCARRIER SPACING SUCH AS 12.5KHZ. The question becomes if there are any problems with using the existing 10.9375kHz subcarrier spacing and as will be shown in problem statements that follow, there are further issues with using the 10.9375kHz, subcarrier spacing.

Legacy Numerology Problem# 2: Lower Spectral Efficiency Due to Unused Guard Subcarriers

The numerology based on a typical legacy 16e design can be found in Table 310a of IEEE 802.15e 2005. Out of 914 subcarriers that fall into the 10MHz bandwidth, there are only 840 subcarriers that can be used to transmit information - 8.8% of the bandwidth is wasted. Furthermore, the bandwidth occupied by the 914 subcarriers does not fully fill the 10-Mhz carrier bandwidth. The following is the formula on how to calculate the maximum frequency efficiency:

$$n_{Efficiency} = \frac{R_{Modulation} \times n_{UsedSubcarriers}}{T_{symobol} \times BW_{System}} \qquad \text{(Eq. 2-1)}$$

where $R_{Modulation}$ is modulation rate (e.g. 4 for 16QAM), $n_{UsedSubcarriers}$ is number of used subcarriers within the nominal system bandwidth, $T_{symobol}$ is symbol period, and BW_{System} is the nominal system bandwidth

Let's set CP=0 to calculate the maximum $n_{Efficiency}$ of the system

$$T_{symobol} = \frac{1}{f_{\Delta}} \qquad \text{(Eq. 2-2)}$$

where f_{Δ} is subcarrier spacing.

$$BW_{System} \geq n_{MaximumSubcarriers} \times f_{\Delta} \qquad \text{(Eq. 2-3)}$$

where $n_{MaximumSubcarriers}$ is the maximum number of subcarriers that a nominal system bandwidth can have.

Let's substitute Eq. 2-2, and Eq. 2-3 into Eq. 2-1, we can conclude as following:

$$n_{Efficiency} \leq \frac{R_{Modulation} \times n_{UsedSubcarriers}}{n_{MaximumSubcarriers}} \qquad \text{(Eq. 2-4)}$$

THE FREQUENCY EFFICIENCY IS PROPORTIONAL TO THE NUMBER OF USED SUBCARRIERS NUMBER OVER THE MAXIMUM NUMBER OF SUBCARRIERS WITHIN THE SYSTEM BANDWIDTH. We can see if we can use the 73 Guard Subcarriers ($n_{MaximumSubcarriers}$ - $n_{UsedSubcarriers}$ =914-841=73) and 1 DC subcarrier to transmit data and divided it by the maximum number of subcarriers of 914, the new 16m system can be immediately 8.8% more efficient. The proposed 16m numerology described in the Section 3 of this contribution allows all subcarriers to be used for data transmission without Guard Subcarriers since the subcarrier spacings between adjacent abutting carriers are aligned. This makes operation with the proposed 16m numerology to be 8.8% more efficient by design when compared to PUSC operation with the existing 16e numerology. When the operator bandwidth has sufficient guard band around a carrier, then the 8.8% need not be wasted.

Table 3: Legacy 1024-FFT OFDMA downlink carrier allocation-PUSC

Parameter	Value	Comments
Number of DC Subcarriers	1	Index 512
Number of Guard Subcarriers, Left	~~91~~ 92	—
Number of Guard Subcarriers, Right	~~92~~ 91	—
Number of Used Subcarriers (N_{used}) including all possible allocated pilots and the DC subcarrier.	841	Number of all subcarriers used within a symbol.
renumbering sequence	6, 48, 37, 21, 31, 40, 42, 56, 32, 47, 30, 33, 54, 18, 10, 15, 50, 51, 58, 46, 23, 45, 16, 57, 39, 35, 7, 55, 25, 59, 53, 11, 22, 38, 28, 19, 17, 3, 27, 12, 29, 26, 5, 41, 49, 44, 9, 8, 1, 13, 36, 14, 43, 2, 20, 24, 52, 4, 34, 0	Used to renumber clusters before allocation to subchannels.
Number of carriers per cluster	14	—
Number of clusters	60	—
Number of data subcarriers in each symbol per subchannel	24	—
Number of subchannels	30	—
PermutationBase6 (for 6 subchannels)	3,2,0,4,5,1	—
PermutationBase4 (for 4 subchannels)	3,0,2,1	—

Legacy Numerology Problem# 3: Capacity Loss in Multi-Carrier Deployment Due to Non-aligned Subcarriers in Adjacent Carriers

With the current WirelessMAN-OFDMA Reference System, the center frequencies of carriers are located on a 250-kHz raster from the spectrum band edge. The 250-kHz raster is commonly used since it divides evenly into all carrier bandwidths (which are typically set in multiples of 0.5 or 1 MHz), is fine enough to allow flexibility in fine-tuning the location of carriers within spectrum bands or blocks within the band, but yet is somewhat coarse to reduce the number of potential center frequency locations (and thereby limit MS search times for operating carriers). Since the 250-kHz raster can be evenly divided into the available and typical carrier bandwidths, adjacent carriers can be placed abutting to each other and thereby maximize the usage of the available spectrum. An example of this type of RF deployment is illustrated in **Figure 1** for the case of two adjacent 5-Mhz carriers being deployed.

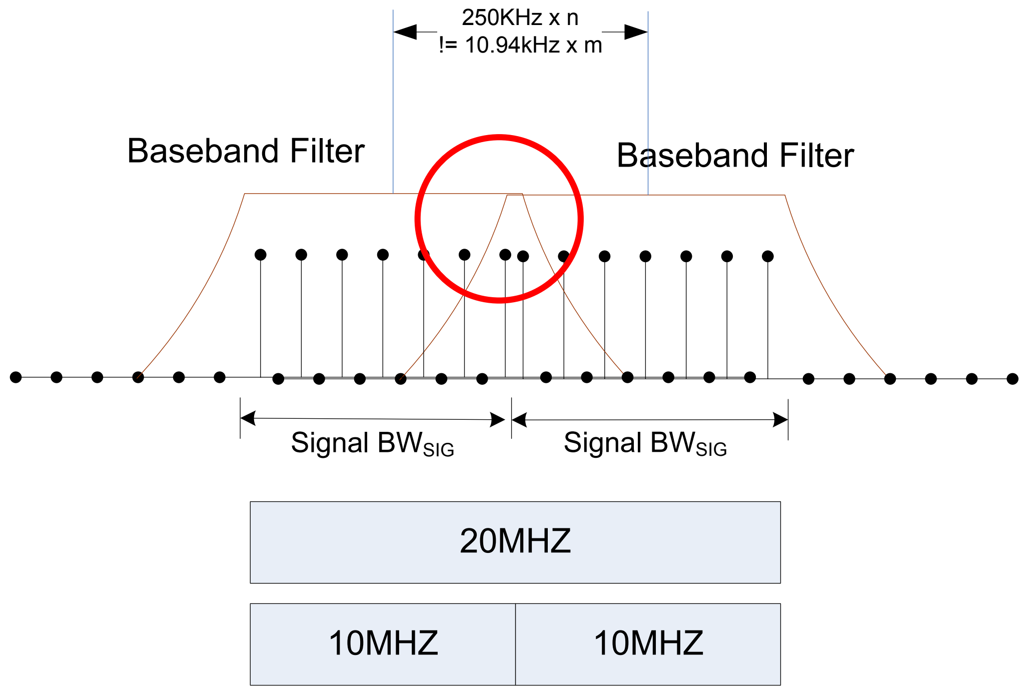


Figure 1: Illustration of Adjacent Carrier and Overlay Carrier Deployments with Legacy Subcarrier Spacing

Also shown in **Figure 1** is the issue with using the legacy subcarrier spacing of 10.9375 kHz for the 5 and 10-MHz bandwidths with this scenario – since there is not an integer number of subcarriers from the carrier center frequency to the carrier edge, the subcarriers are not aligned between the adjacent carriers. The nature of OFDM operation is such that transmissions on a subcarrier do not introduce interference power at points that are an integer number of subcarrier spacings from the transmitting subcarrier but do cause interference power between these points. Therefore, with subcarriers not being aligned between adjacent carriers means that interference from transmissions near the edge of one carrier causes excessive interference to subcarriers near the edge of the adjacent carrier if not properly addressed. In the design of the legacy WirelessOFDMA-MAN Reference System, this issue was addressed via the combination of two approaches: 1) the reservation of a number of subcarriers at the carrier edge as unused guard subcarriers so that some interference reduction is achieved by natural decay of the transmitted signal power with increasing frequency separation, and 2) the use of a transmit filter to further reduce the interference power to the adjacent carrier to an acceptable level. Both of these approaches incur overhead: 1) loss of capacity of between 5% to more than 8% due to guard subcarriers, and 2) implementation cost/complexity due to requirement of transmit filter. Both of these overheads of the legacy system can be eliminated by simply aligning the subcarriers between the adjacent carriers.

Legacy Numerology Problem # 4: Lack of Multi-Carrier Scalability for Multi-Carrier Deployment

The service providers often prefer a solution such as scalable deployment plan, launching more carriers as the business grows. The incompatible subcarrier spacing makes it unnecessarily restrict the efficiency and flexibility for 1.25MHz series (5, 8.75, 10, 20MHz) and 3.5MHz series (3.5, 7, 14MHz) to work in multi-carrier mode with the carriers being of the same or a mixture of different system bandwidths. If the carriers are operated as adjacent carriers as illustrated in Figures 2 and 3, inter-carrier interference due to the imcompatible subcarrier spacings necessitates the presence of guard subcarriers as was discussed in 'Legacy Numerology Problem #3'. In addition, the multiple carriers cannot be operated as an overlay of several multiple bandwidths onto a common aggregate bandwidth (common FFT) in order to support devices of different bandwidth capabilities at the same time – this feature is important to be able to support devices with very different cost, complexity and throughput requirements on a common air interface (e.g. from low-rate, low-cost remote data collection/monitoring devices to high-end multimedia devices). This multi-carrier mode is illustrated in Figure 4.

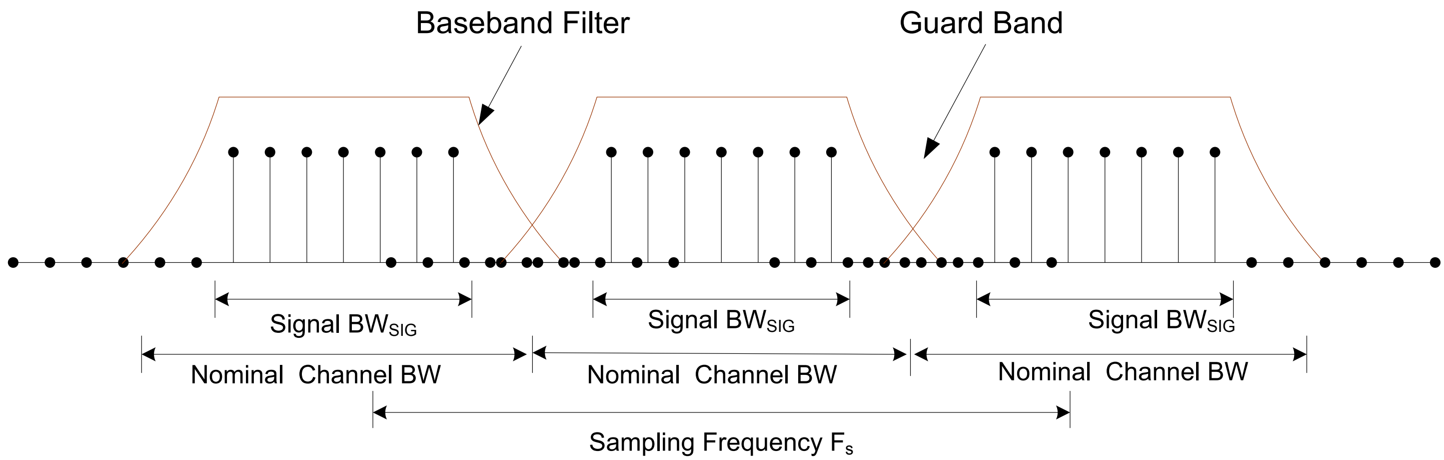


Figure 2: Illustration of Multi-Carrier Deployment with Guard Bands

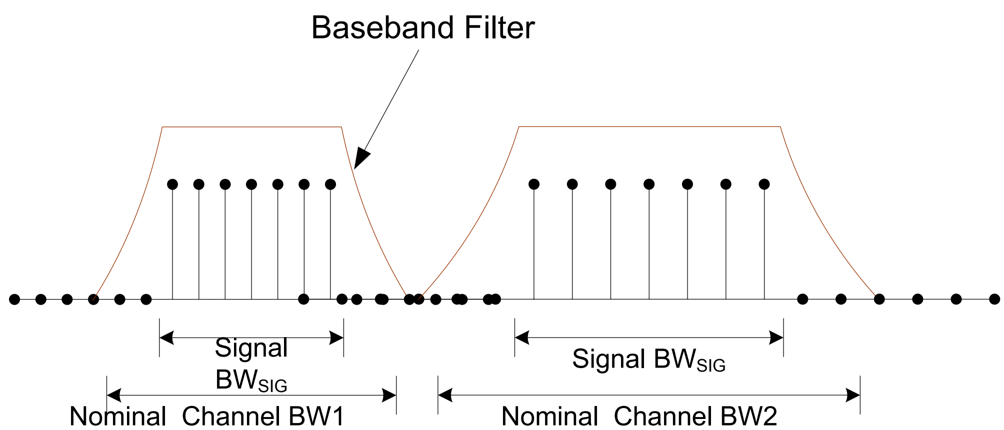


Figure 3: Illustration of Mixed System Bandwidths Multi-Carrier Deployment

Using 12.5 kHz as the subcarrier spacing, 16m will line up with different rasters in different frequency bands and the subcarrier spacings between adjacent carriers will be aligned. Therefore, this subcarrier spacing will allow multi-carrier deployment with the same or mixed of different system bandwidths to be readily supported. This capability provides 16m a competitive advantage over UMB and LTE which cannot support multi-carrier deployment without guard subcarriers between neighboring carriers., as shown in Figure 4. It demonstrates great advantages in multi-carrier deployment and the easiest way to ACHIEVE GLOBAL ROAMING FOR DIFFERENT 16M DEVICES.

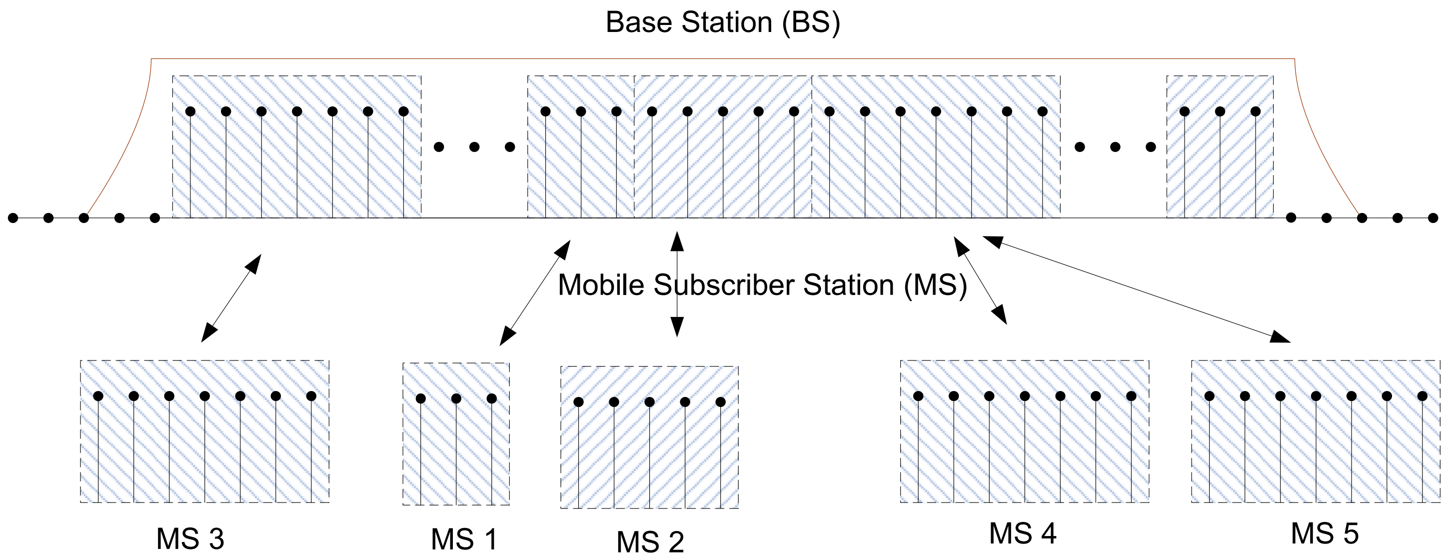


Figure 4: Illustration of Mixed Bandwidths Multi-Carrier Deployment without Guard Bands

Legacy Numerology Problem # 5: Changing Raster to Address Problem #3 Causes Other Problems

A sufficient requirement to achieve the alignment of subcarriers between adjacent carriers is to define the raster as an integer number of subcarrier spacings and to separate the center frequencies of adjacent carriers by an integer number of raster spacings. There are two design approaches that can be taken to meet this requirement:

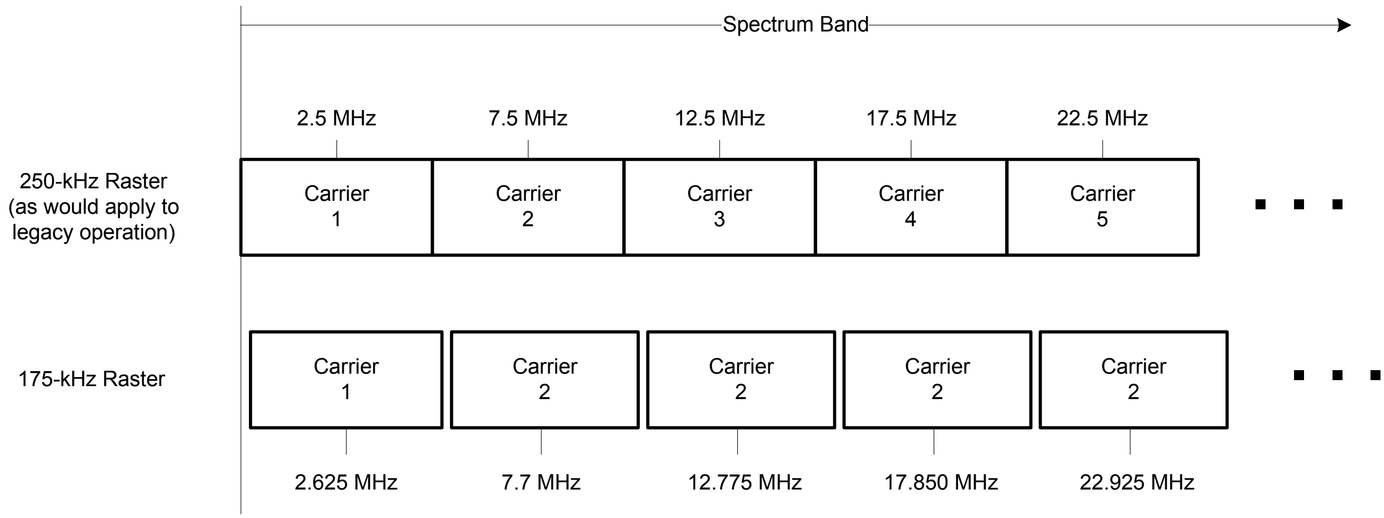
a. Retain subcarrier spacing from the legacy WirelessOFDMA-MAN Reference System and define a new raster based on it
b. Retain the existing 250-kHz raster and define a new subcarrier spacing for 802.16m.

There are issues with taking approach 'a' above as follows:

- Legacy support is adversely affected since the centering of carriers for 802.16m will be different from that for the WirelessOFDMA-MAN Reference System. This mis-alignment of carriers is illustrated in **Figure** 5. An important characteristic to note from Figure 5 is that the offsets between the two sets of carriers are not constant, which complicates the design and engineering of legacy support significantly. The offset in center frequencies resulting from the different rasters causes mis-alignment of the operating carrier bandwidth and of the subcarriers between the legacy zones and the new 16m zones when they occupy overlapping frequency spaces – an example of which is illustrated in Figure 6. Having a separate set of carrier center frequencies for 802.16m operation due to a different raster also adversely affects the time required for 802.16m MSs to search for available 16m or legacy service due to a doubling of the number of possible center frequencies that need to be searched.
- Especially for the 10.9375-kHz subcarrier spacing that applies to 5/10/20-MHz bandwidth operation, a raster cannot be defined consisting of an integer number of subcarrier spacings that also divide evenly into the 5, 10 or 20 MHz bandwidths. For this case, there is only one raster value of 175 kHz that exists in the same raster value range as 250 kHz in which the raster can be defined in units of kHz (others are in much finer units such as in Hz or fractions of Hz); and it can be easily seen that 175 kHz does not divide evenly into 5, 10, nor 20 Mhz. Given this situation, there are only two ways in which the center frequencies of adjacent carriers can be aligned to a multiple of rasters from the spectrum band edge: 1) introduce a gap between adjacent carriers as shown in Figure 7 and Figure 8, and 2) eliminate the need for a gap between adjacent carriers by

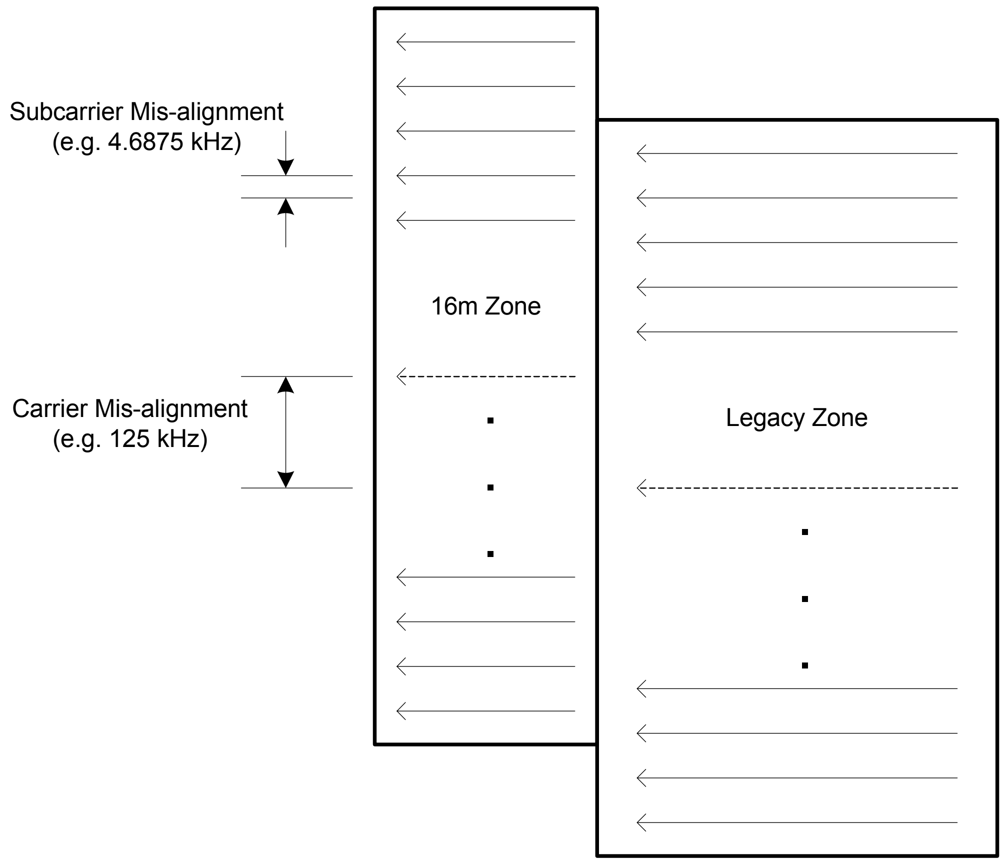
truncating the effective bandwidth of the carrier as shown in Figure 9. In both these cases, some spectrum wastage is necessary.

- Implementations are affected since a consistent centering of a carrier or a set of adjacent carriers within the same relative position within a spectrum band or block within a band cannot be defined – this may impact the availability of low-cost generic parts in designs.



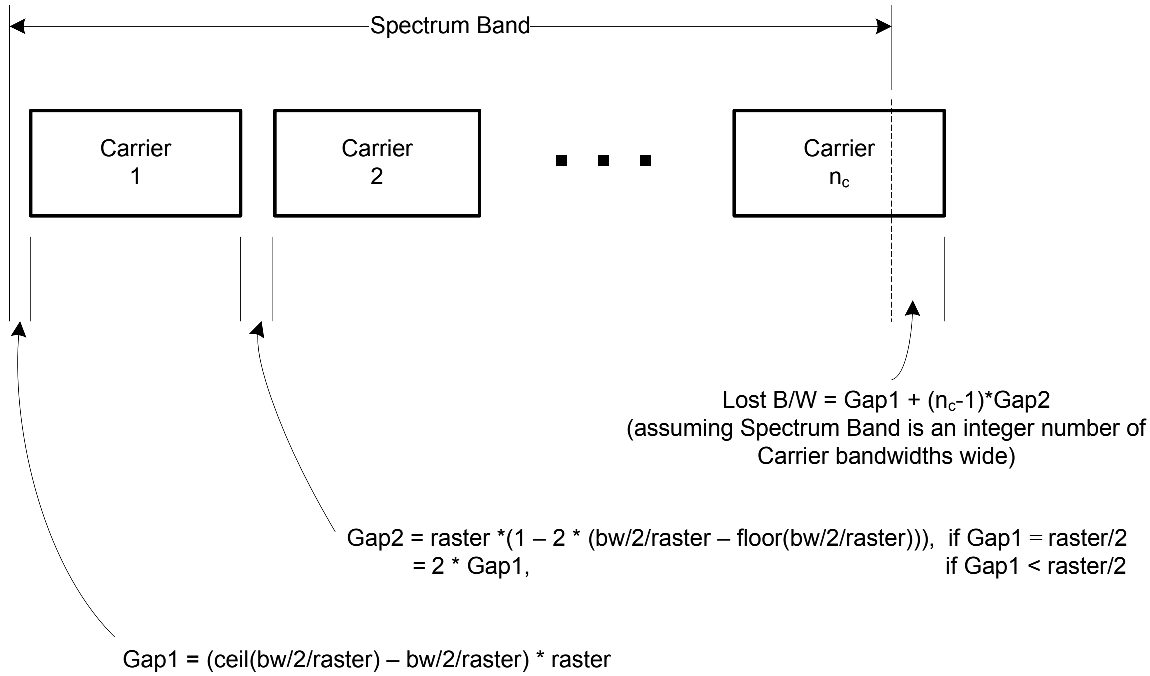
Example of 5-MHz Carriers starting from lower band edge

Figure 5 : Illustration of Carrier Mis-alignment Due to Different Rasters



Legacy operation on carrier aligned to 250-kHz raster.
16m operation on carrier aligned to 175-kHz raster.

Figure 6 : Illustration of Subcarrier Mis-alignment Between Legacy and 16m Operation Due to Different Rasters

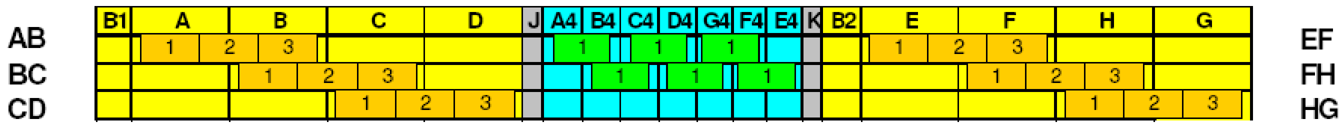


NOTES:

1) *Gap1* is needed so that the center of the 1st carrier from left edge of the spectrum band (Carrier 1) falls at an integer number of rasters from the left edge.

2) *Gap2* is needed so that the centers of all remaining carriers in the spectrum band falls at an integer number of rasters from the left edge without the carriers overlapping.

Figure 7 : Method 1 to Center Carriers on Raster When Non-integer Number of Rasters in Carrier Bandwidth



LBS 10 MHz Center Frequencies

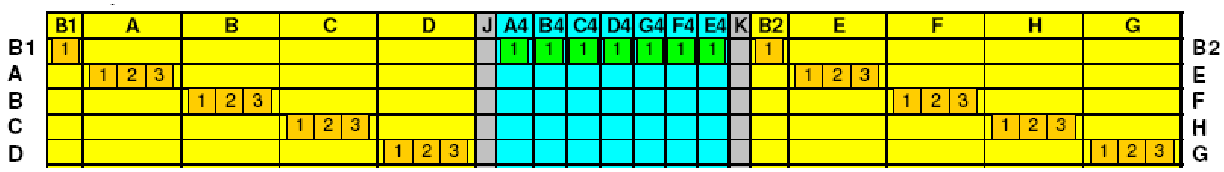
AB	2508.5	2518.5	2528.5
BC	2525	2535	2545
CD	2541.5	2551.5	2561.5

UBS 10 MHz Center Frequencies

EF	2630.5	2640.5	2650.5
FH	2647	2657	2667
HG	2663.5	2673.5	2683.5

MBS 10 MHz Center Frequencies

A4B4	2578	**D4G4**	2596
B4C4	2584	**G4F4**	2602
C4D4	2590	**F4E4**	2608



LBS 5 MHz Center Frequencies

B1	2499		
A	2505.25	2510.25	2515.25
B	2521.75	2526.75	2531.75
C	2538.25	2543.25	2548.25
D	2554.75	2559.75	2564.75

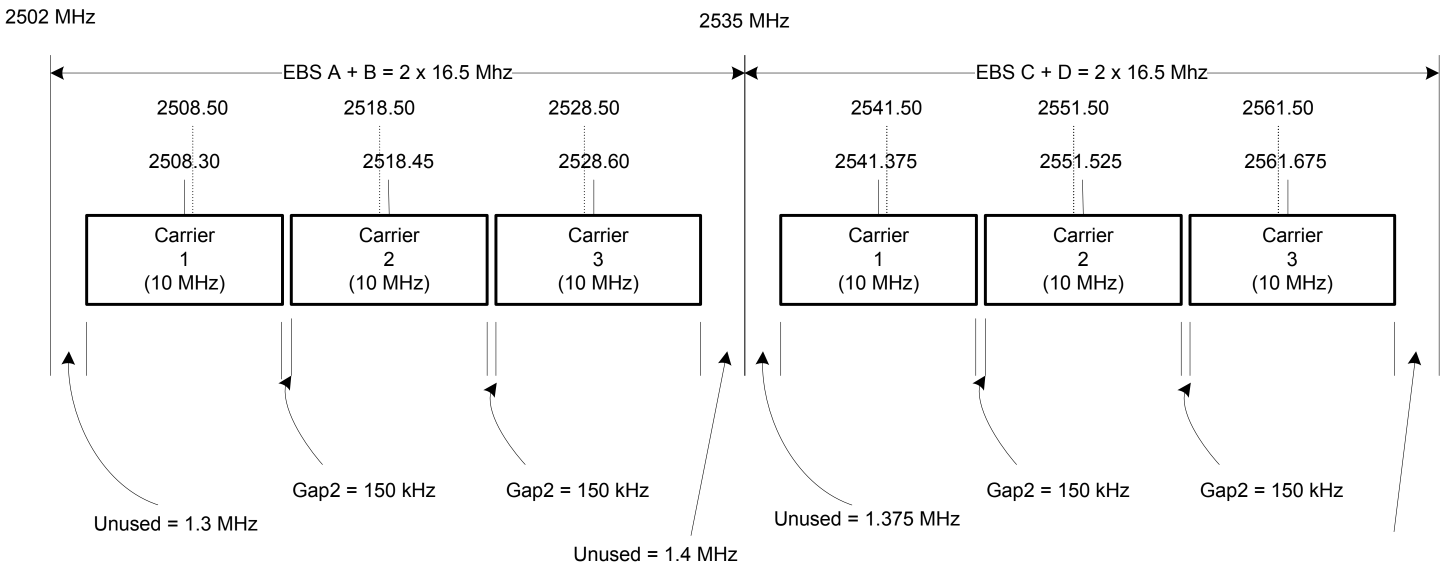
UBS 5 MHz Center Frequencies

B2	2621		
E	2627.25	2632.25	2637.25
F	2643.75	2648.75	2653.75
H	2660.25	2665.25	2670.25
G	2676.75	2681.75	2686.75

MBS 5 MHz Center Frequencies

A4	2575	**G4**	2599
B4	2581	**F4**	2605
C4	2587	**E4**	2611
D4	2593		

Figure 8A: 2.5GHz Band Plan

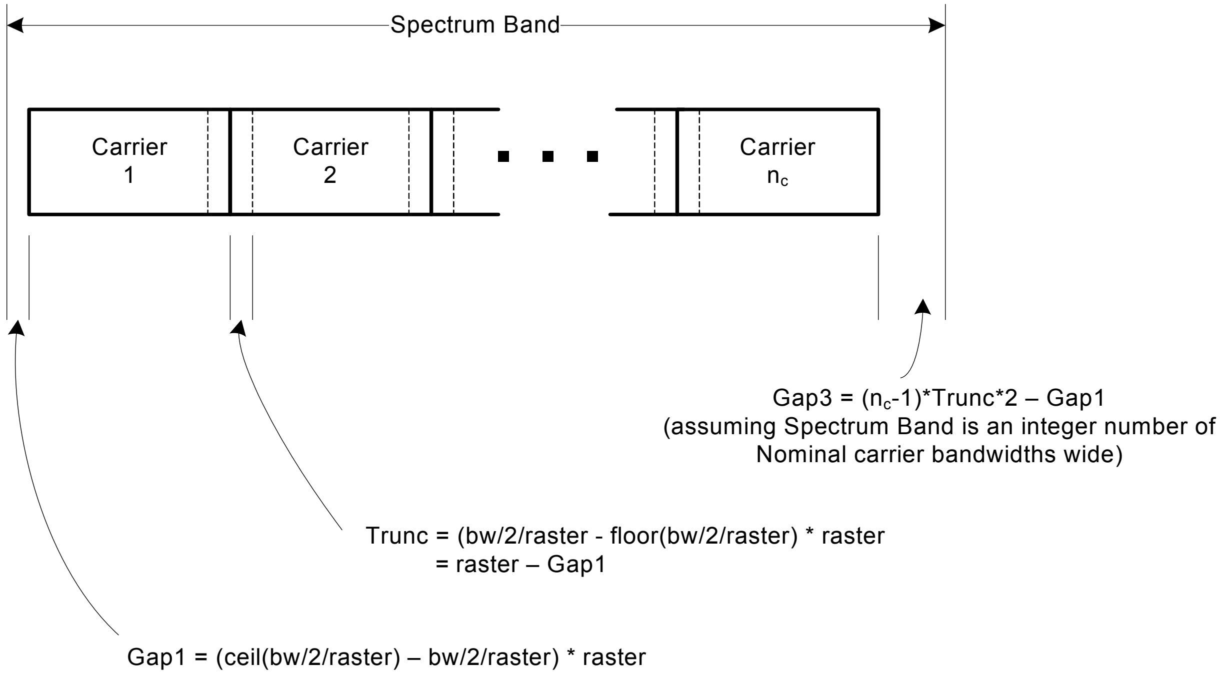


NOTE: 1) The carrier centers with new raster do not line up with existing carrier centers (as marked by the dashed line)
2) There are an additional 1% of unusable bandwidth due to Gap2's to line up center frequencies at a raster location
3) The imperfect and inconsistent centering of a block of carriers within the designated spectrum

Figure 8B: Example of Possible 10-MHz Carrier Assignments in EBS Spectrum Based on 175-kHz Raster

The issues noted above for approach ‘a’ do not apply to approach ‘b’ since for approach ‘b’, by definition there will be an integer number of subcarrier spacings in the 250-kHz raster and as noted earlier, the 250-kHz fits evenly within all carrier bandwidths that currently exist for 802.16. Using a subcarrier spacing that divides evenly into the 250-kHz raster provides the additional benefit of being able to easily accommodate other possible future bandwidths that should be considered in order to maximize the usage of allocated spectrum without incurring any of the issues related to approach ‘a’. An example of the latter would be to support carrier bandwidths based on a 6-MHz increment since quite a few spectrum allocations in the U.S.A. for broadband wireless services are either 6 or 12-Mhz wide.

A potential drawback of approach ‘b’ may be the need for an 802.16m BS to be able to switch between two subcarrier spacings dynamically when operating with legacy support enabled. The additional implementation complexity this incurs should be manageable since this type of dynamic switching can be handled by straightforward designs, and the need to support multiple subcarrier spacings with the same hardware exist with the WirelessMAN-OFDMA Reference System today if a BS is designed to support two or more of 5/10-MHz, 3.5/7-MHz, and 8.75-MHz operation. In addition, approach ‘a’ also introduces disparate operation between legacy zones and 802.16m zones due to a misalignment of carrier bandwidth and subcarrier spacings between the zones. The complexity of addressing this issue with approach ‘a’ may be greater than simply addressing two subcarrier spacings between these zones as in approach ‘b’.



NOTES: 1) *Gap1* is needed so that the center of the 1st carrier from left edge of the spectrum block (Carrier 1) falls at an integer number of rasters from the left edge – assuming truncation is not desirable at band edge since some gap is required anyway for filter rolloff to control out-of-band emissions.

2) *Trunc* is the minimum amount of the carrier担bandwidth that must be lost (truncated) from the edge of the carrier担nominal bandwidth so that the effective bandwidth of the carrier (i.e. for used subcarriers) is an integer number of rasters. For the carriers not at the edge of the band, the amount of truncation is 2 x *Trunc* since an amount equal to *Trunc* is lost at each end of the carrier担bandwidth.

3) *Gap3* is the unused spectrum at the other edge of the band due to the truncations occurring between the carriers within the band.

Figure 9 : Method 2 to Center Carriers on Raster When Non-integer Number of Rasters in Carrier Bandwidth

Legacy Numerology Problem # 6: Single Subcarrier Spacing of 10.9375kHz Required To Define All the Used Subcarriers for Each System Bandwidth

The used subcarrier number of each bandwidth needs new definition with modification needed in Problems 3 and 4. The new system profile needed for each new system bandwidth. Using the 12.5kHz subcarrier spacing, it can be divided evenly in ALL existing bandwidth 5/6/7/8.75/10/12/14/20/28 allocation in ALL frequency band classes. NO NEED TO DEFINE USED SUBCARRIERS FOR EACH NEW SYSTEM BANDWIDTH. Today, we know that 6MHz and 12MHz allocated in 700MHz Band and other Frequency Bands. It is also very hard for us to predict what other bandwidths will be allocated for the IMT-Advanced Bands. With 12.5kHz subcarrier spacing, we know exactly what are the used subcarriers for these bandwidths, the 16m design will be forward compatible. When additional guard subcarriers are needed, the resource blocks on the edge can be dropped to meet out of band emission requirements.

Legacy Numerology Problem # 7: Different Number of Used Subcarriers in Legacy Numerology

For one given FFT size of legacy system, the values of the number of used subcarriers are different due to different permutation mode, even for same channel bandwidth. The following table lists the number of used subcarriers and bandwidth efficiency for different permutation modes. Here 10MHz channel bandwidth is used as an example while counting the corresponding bandwidth efficiency.

Table 4: Number of used subcarriers defined by current legacy system

		Permutation mode	Number of used subcarrier	Bandwidth efficiency (Channel bandwidth: 10MHz)
FFT size -1024	DL	PUSC	841	92%
		FUSC	851	93.1%
		Optional PUSC	865	94.63%
		AMC	865	94.63%
	UL	PUSC	841	92%
		Optional PUSC	865	94.63%
		AMC	865	94.63%

All the above problems caused by legacy OFDMA numerology shall be prevented in 802.16m frame structure design. With common 12.5kHz subcarrier spacing, the used subcarrier number is well determined without confusion.

3.2 CP

On the one hand, as specified by Mobile WiMAX System Profile, only one type of CP exists in current legacy system, which is 1/8 of useful symbol time.

Legacy Numerology Problem # 8: Single CP Ratio for System Deployment

Current legacy system does not support different CP length for different BS in the network, but only one effective CP value is used for all the BSs. Actually there are no mechanisms to allow BS to change or configure the CP duration in current legacy system. It is not suitable to use only one type of CP length for different deployment environments. For example, in the scenario with severe multipath (i.e. larger delay spread), longer CP should be used to eliminate the ISI and ICI. But simple scenario with fewer multipath only requires short CP in order to reduce overhead and transmission power.

On the other hand, the CP length defined by current legacy system is a fraction of useful symbol time. But actually the CP duration SHOULD NOT BE DEPENDENT ON THE USEFUL SYMBOL TIME, especially in current legacy system where the useful symbol time changes between different sampling frequency sets, so are the CP lengths. IT CAUSES UNNECESSARY OVERHEADS IN MOST OF THE DEPLOYMENT SENARIOS BY DESIGN, AND RESULTS UNECCESSARY REDUCTION IN FREQUENCY EFFICIENCY.

3.3 Frame Structure

The 16m frame structure design evolved from the existing legacy numerology make it favorable to symbol partition as subframes due to un-deterministic nature of symbol duration. Therefore the 16m subframe design (or equivalent term of "slot") will not and can not be aligned with the current LTE design, please refer the details of the proposal in the Frame Structure Option 1 of the **C80216m-08_118r1.pdf**. It can not be backward compatible with LTE Super-frame in time.

Legacy Numerology Problem # 9: New 16m Frame Design Based on Legacy Numerology Is Not Backward Compatible with LTE Frame Structure in Time

Now that 16m has been targeted to be adopted as IMT-Advanced technology, then inevitably it will co-exist with LTE side-by-side in the same IMT-Advanced and IMT-2000 Bands. IT WILL BE A GREAT DISADVANTAGE NOT BEING ABLE TO BE DEPLOYED AFTER LTE SYSTEM HAS BEEN DEPLOYED IN THE SAME FREQUENCY BAND. As we all know that most likely LTE equipment will be deployed ahead of 16m in the next few years. The potential of 16m has been unnecessarily limited by design.

By changing 16m to adopt 12.5kHz subcarrier spacing, 16m design will be more favorable to time aligned subframe design. The subframe is designed to time aligned with current LTE multiple 0.5ms slots superframe structure, please refer the details of the proposal in the Frame Structure Option 2 of the **C80216m-08_118r1.pdf**. We believe that it is important to co-exist with LTE and TD-SCDMA frame structure. It will be designed with PHY optimization for across RAT hand-off design. The 16m should be designed technically superior to existing LTE and is cable of being the technology candidate of LTE future evolution. The 16m can the base line technology for IMT-Advanced harmonization.

4. Proposed Solution

Based on the above description and suggested criteria, we propose the following OFDMA numerology for IEEE 802.16m.

4.1 12.5kHz As 16m Subcarrier Spacing

We propose 12.5-kHz subcarrier spacing which is applied for all the channel bandwidth, e.g. 5/10/20MHz, 3.5/7/14MHz and also 8.75MHz. A 12.5-kHz subcarrer spacing has a property of good trade-off of mobility and frequency efficiency with CP overhead, and divides evenly into the 250-kHz channel raster. The sampling frequency of different channel bandwidths will be based on this subcarrier spacing and appropriate FFT size. It means that all the channel bandwidths will have the same base sampling frequency. The mobile can roam to different carrier bandwidths in different frequency bands while utilizing the same OFDMA parameter set - this feature is very crucial for a simplified coherent 4G standard and developing a healthy ecosystem.

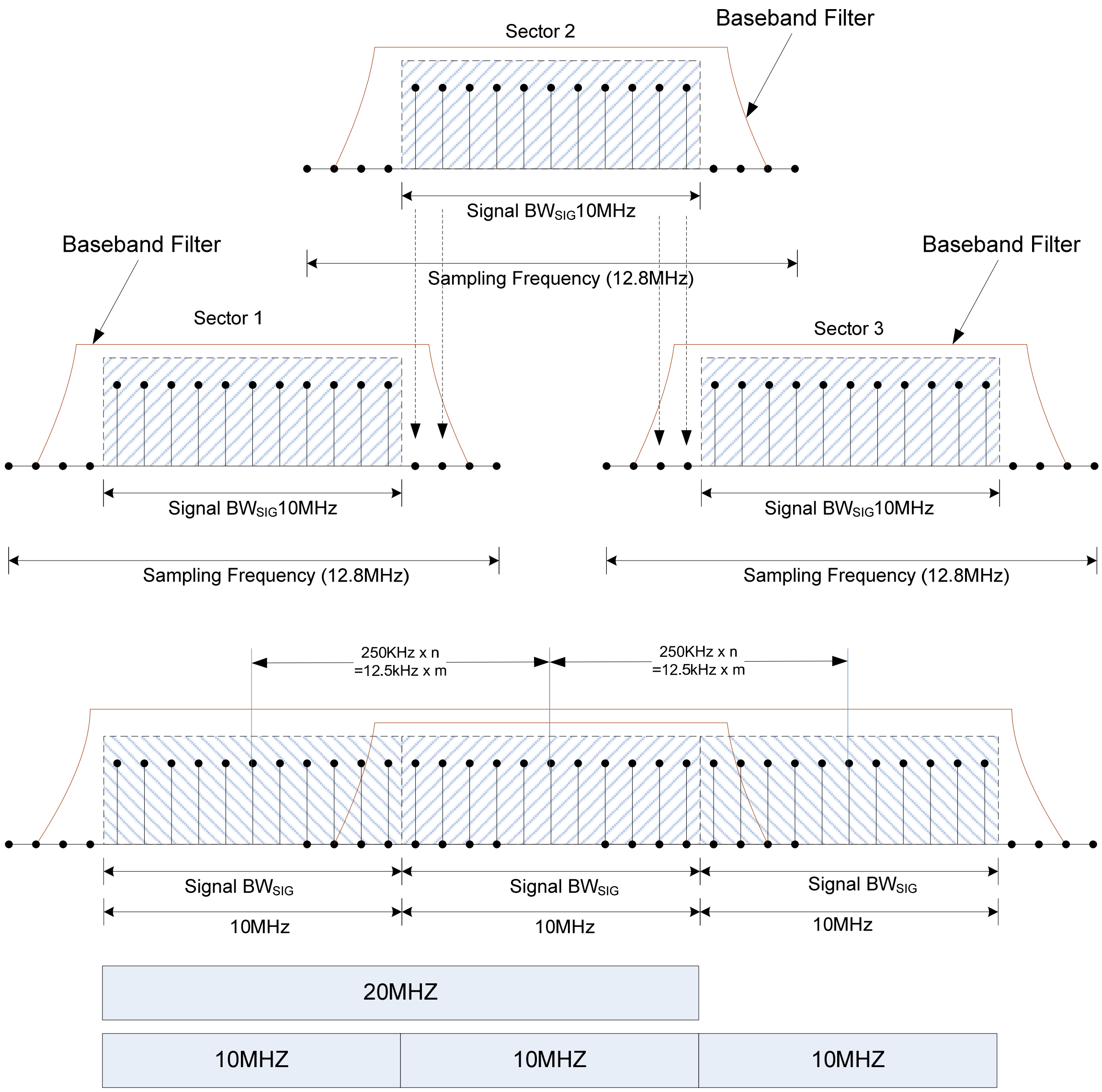


Figure 10 : Mult-Carrier Deployment without Guard Bands

4.2 Support New Frame Structure Backward Compatible to LTE

The existing 16e numerology will make it impossible to design a frame structure that will be backward compatible to LTE. The 16m with 16e numerology will not be able to design sub-frame or slots that will time aligned with LTE slots. We know that 16m will be in IMT-Advanced, it will make sense to be able to deployed side-by-side with LTE in the same frequency band.

4.3 Multiple CP Selections

We propose three CP lengths based on 12.5-kHz subcarrier spacing, which are used for different radio scenarios. These three CP lengths are needed to adequately balance the required length of CP with the loss of capacity due to the CP in order to serve the breadth of radio environments envisaged for 802.16m. These three types of CP are short CP with 2.5us duration, which is typically used for very small cell deployments such as indoor, normal CP with10us duration which is typically used for outdoor urban and suburban environments, and long CP with 15us duration which is needed for the large delay spreads that may be encountered with large rural cells.

We propose the number of used subcarriers independent of permutation mode. For all the types of permutation modes, with the same bandwidth, the number of used subcarriers is same.

Table 5: Numerology with 12.5kHz Subcarrier Spacing

Parameter		Unit	Parameter Values							
Channel Bandwidth (BW)		MHz	5	6	7	8.75	10	12	14	20
Sub-carrier Spacing ($\triangle f$)		KHz	12.5							
Sampling Frequency (Fs)		Mhz	6.4	12.8	12.8	12.8	12.8	25.6	25.6	25.6
FFT size			512	1024	1024	1024	1024	2048	2048	2048
Number of Used sub-carriers (Nused)			400	480	560	700	800	960	1120	1600
CP Length (T_{CP})	Short CP	μs	2.5							
	Normal CP	μs	10							
	Long CP	μs	15							

With consideration of legacy system support, we propose TDM mode to be used for DL and UL.

4.4 Frame Structure Design Time-Aligned with LTE

By changing 16m to adopt 12.5kHz subcarrier spacing, 16m design will be more favorable to time aligned subframe design. The subframe is designed to time aligned with current LTE multiple 0.5ms slots superframe structure, please refer the details of the proposal in the Frame Structure Option 2 of the **C80216m-08_118r1.pdf**. We believe that it is important to co-exist with LTE and TD-SCDMA frame structure. It will be designed with PHY optimization for across RAT hand-off design. The 16m should be designed technically superior to existing LTE and is cable of being the technology candidate of LTE future evolution. The 16m can the base line technology for IMT-Advanced harmonization.

Table 6: Subframe Partition to Be Backward Compatible with LTE Slots

Parameter		Unit	Parameter Values					
Channel Bandwidth (BW)		MHz	5	7	8.75	10	14	20
Sub-carrier Spacing (△f)		KHz	12.5					
Sampling Frequency (Fs)		Mhz	6.4	12.8	12.8	12.8	25.6	25.6
FFT size			512	1024	1024	1024	2048	2048
Number of Used sub-carriers (Nused)			401	561	701	801	1121	1601
CP Length (T_{CP})	Short CP	μs	2.5	2.5	2.5	2.5	2.5	2.5
	Normal CP	μs	10	10	10	10	10	10
	Long CP	μs	15	15	15	15	15	15
	Long CP 2	μs	20	20	20	20	20	20

Sub-frame duration		ms	**0.5**	**0.675**	**1**	**1.5**	**2**	**2.5**
Number of OFDM Symbols Per Sub-frame	Short CP (N_S)		6	8	12	18	24	30
	Normal CP (N_R)		5	7	10	16	22	27
	Long CP (N_L)		4	6	10	15	20	26
	Long CP 2 (N_L)		4	6	9	14	19	24

5. Proposed Text Change

To modify the proposed SDD text in C802.16m-08/118r1 as follows:

Modify '[Table 11.3-1: OFDMA parameters for IEEE 802.16m] -> proposal-2' on page 5 as follows:

Parameter		Unit	Parameter Values							
Channel Bandwidth (BW)		MHz	5	6	7	8.75	10	12	14	20
Sub-carrier Spacing (△f)		KHz	12.5							
Sampling Frequency (Fs)		Mhz	6.4	12.8	12.8	12.8	12.8	25.6	25.6	25.6
FFT size			512	1024	1024	1024	1024	2048	2048	2048
Number of Used sub-carriers (Nused)			400	480	560	700	800	960	1120	1600
CP Length (T_{CP})	Short CP	μs	2.5							
	Normal CP	μs	10							
	Long CP	μs	15							

[Table 11.3-1: OFDMA parameters for IEEE 802.16m] → proposal-2

-- End --

6. Reference

[1] IEEE802.16m-07/002r4, IEEE802.16m system requirements
[2] IEEE Std 802.16e-2005 and IEEE Std 802.16-2004/Cor1-2005 (Amendment and Corrigendum to IEEE Std 802.16-2004)
[3] WiMAX Forum Mobile System Profile Release 1.0 Approved Specification
[4] IEEE 802.16m-08/080r1, 'Proposal for IEEE 802.16m OFDMA numerology'
[5] IEEE 802.16m-08/118r1, 'Proposed 802.16m Frame Structure Baseline Content Suitable for Use in the 802.16m SDD'