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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.
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Further Considerations on IEEE 802.16m OFDMA Numerology

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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.

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.

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 1 – basic OFDMA numerology defined by current legacy system

Channel Bandwidth (MHz)	5	10	20	3.5	7	8.75
Sampling Frequency (MHz)	5.6	11.2	22.4	4	8	10
FFT Size	512	1024	2048	512	1024	1024
Subcarrier Spacing (kHz)	10.94	10.94	10.94	7.8	7.8	9.76
Useful Symbol Time (us)	91.4	91.4	91.4	128.2	128.2	102.46
CP (us)	11.42	11.42	11.42	16.025	16.025	12.81

1. Capacity Loss 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.

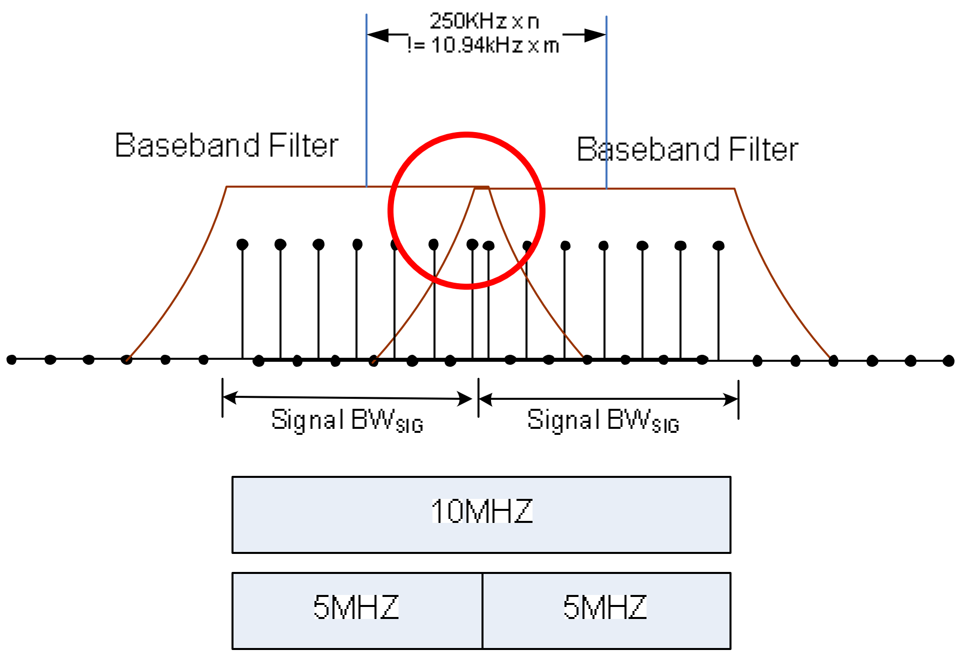


Figure 1: Illustration of Adjacent Carrier and Overlay Carrier Deployments With Legacy Subcarrier Spacing

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 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.

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 2. An important characteristic to note from Figure 2 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 3. 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 4, and 2) eliminate the need for a gap between adjacent carriers by truncating the effective bandwidth of the carrier as shown in Figure 5. 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.

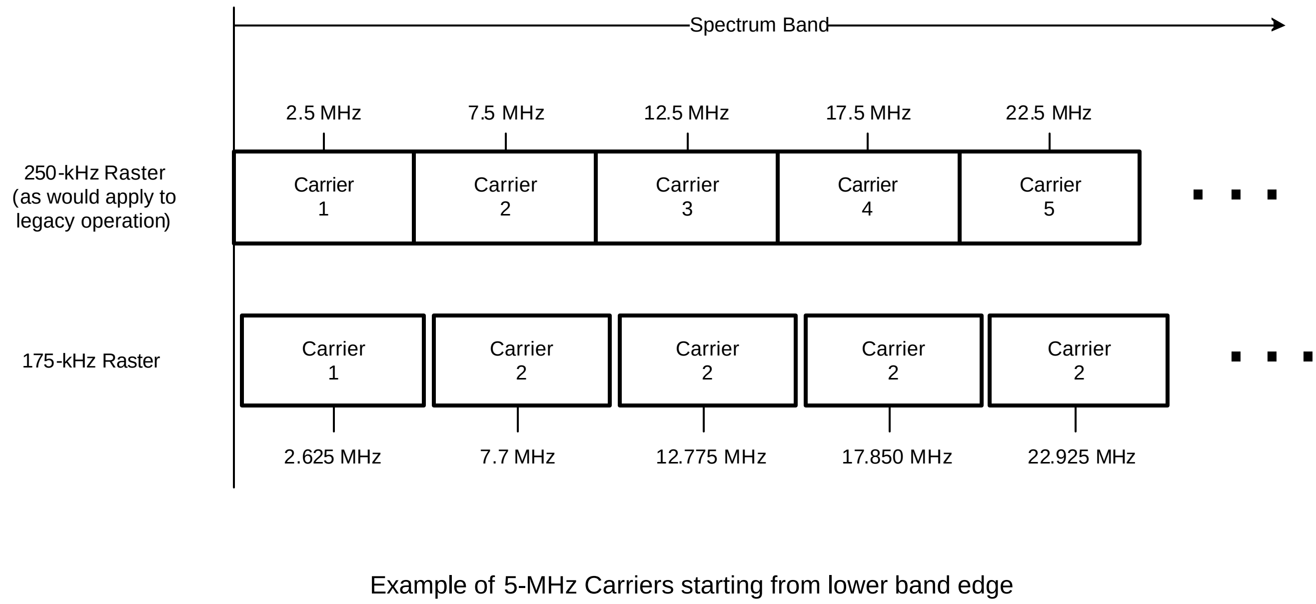


Figure 2 : Illustration of Carrier Mis-alignment Due to Different Rasters

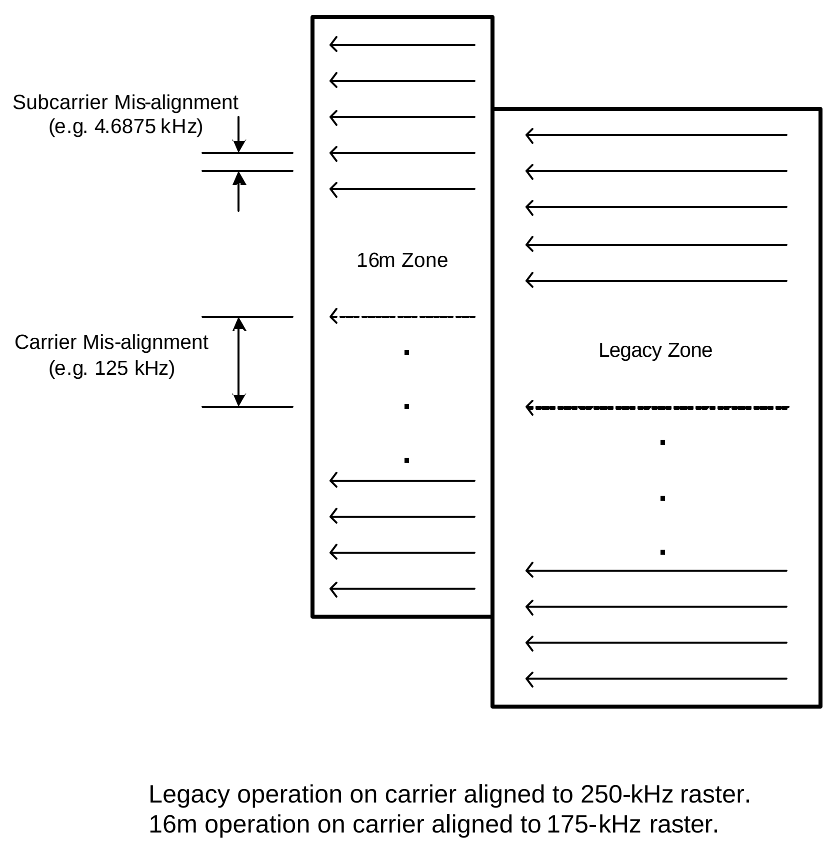


Figure 3 : Illustration of Subcarrier Mis-alignment Between Legacy and 16m Operation Due to Different Rasters

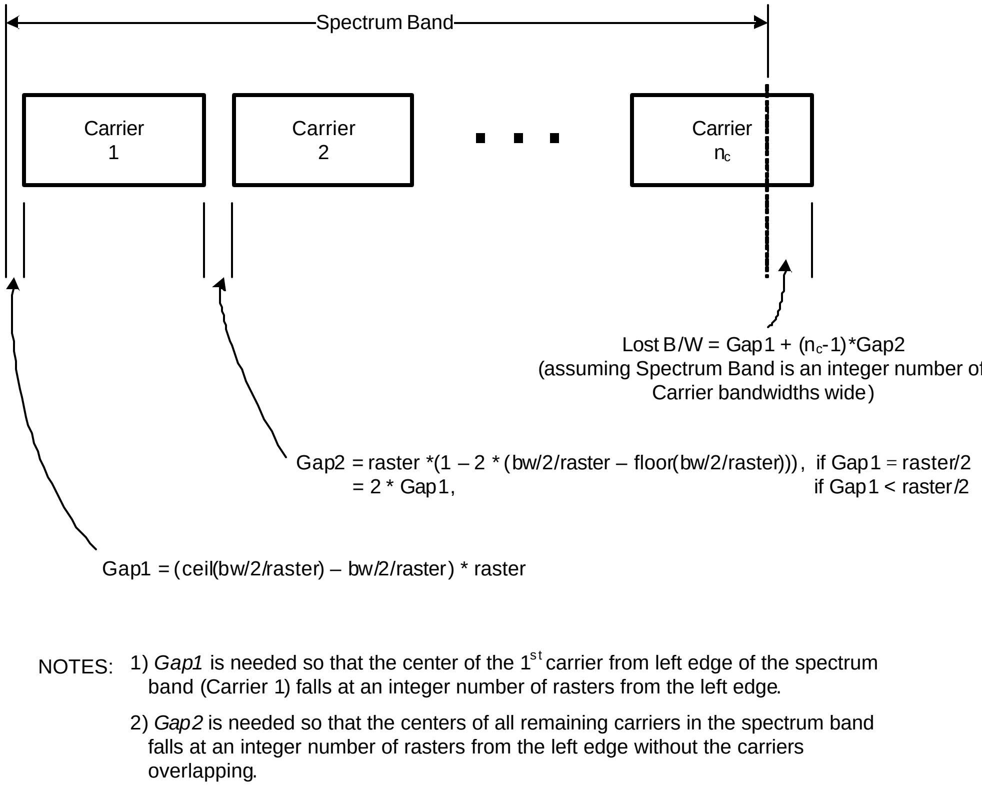
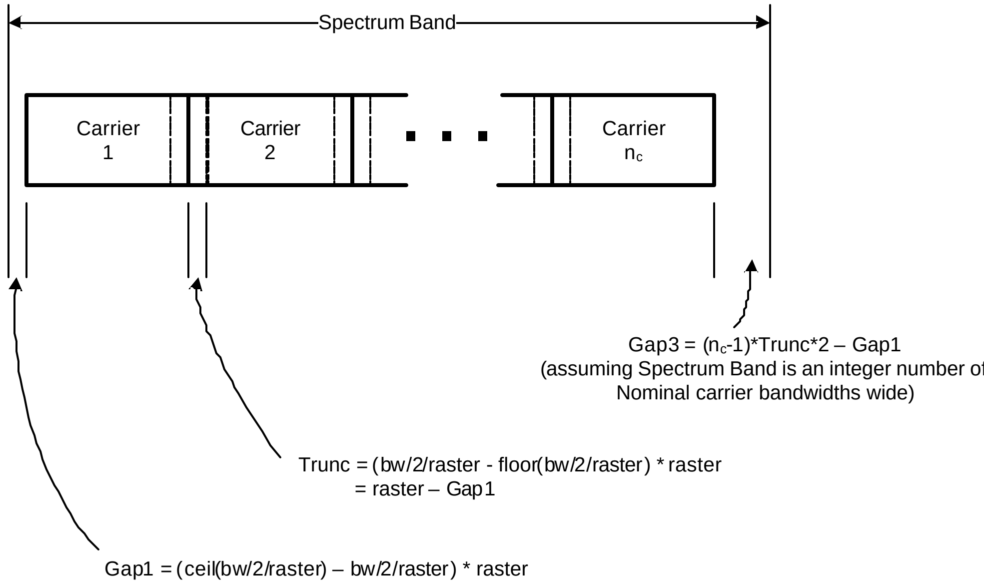


Figure 4 : Method 1 to Center Carriers on Raster When Non-integer Number of Rasters in Carrier Bandwidth

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's bandwidth that must be lost (truncated) from the edge of the carrier's 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's 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.

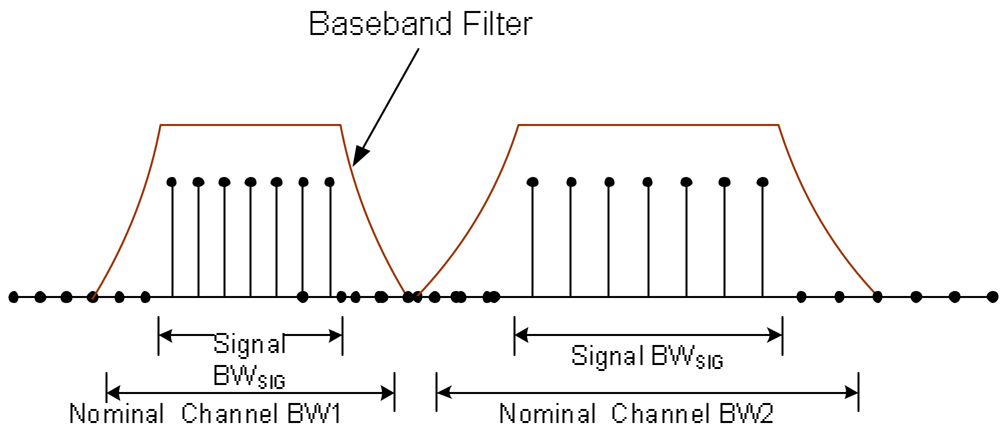
Figure 5 : Method 2 to Center Carriers on Raster When Non-integer Number of Rasters in Carrier Bandwidth

2. Subcarrier Spacing & Sampling Frequencies

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. Therefore, the definition of 802.16m operation should converge on a single subcarrier spacing that can be applied to all carrier bandwidths.

3. Multi-carrier Scalability

The incompatible subcarrier spacing makes it impossible for 1.25MHz series (5, 8.75, 10, 20MHz) and 3.5Mhz series (3.5, 7, 14MHz) to work in multicarrier mode simultaneously.



4. 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. 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 is not dependent on the useful symbol time, especially in current legacy system where the useful symbol time changes between different sampling frequency sets.

5. Number of used subcarriers

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 2 – 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%

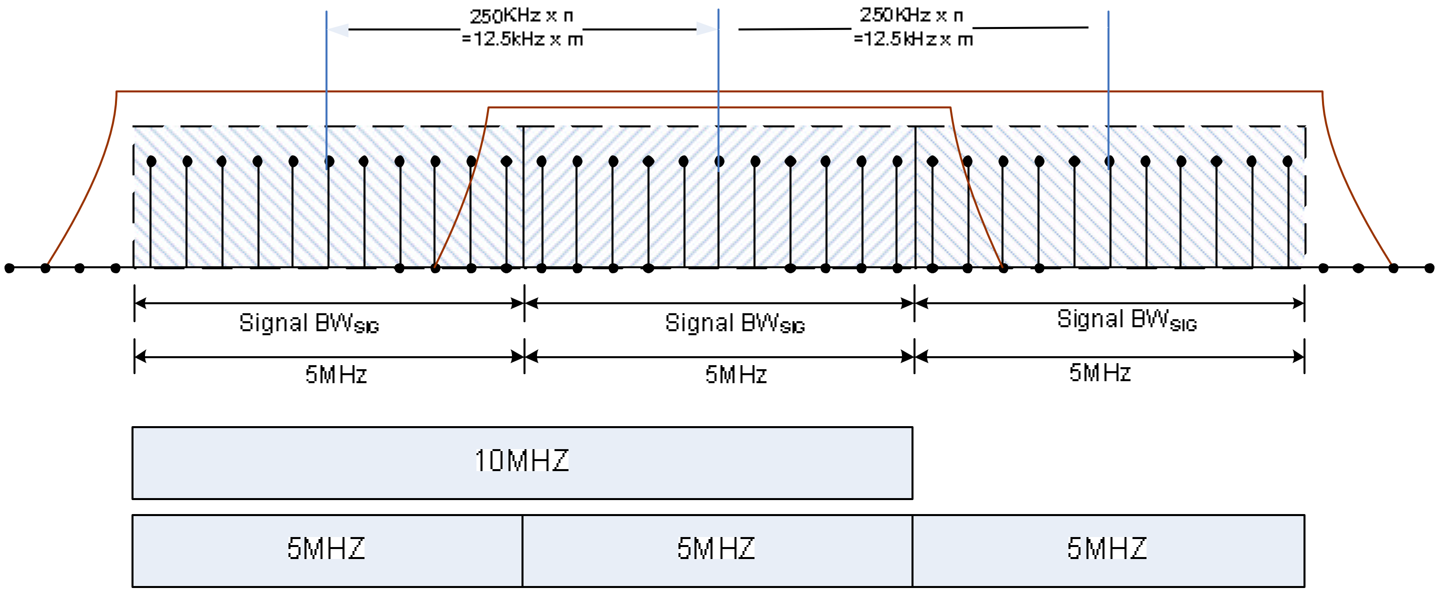
All the above problems caused by legacy OFDMA numerology shall be prevented in 802.16m frame structure design.

Proposed Solution

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

Subcarrier spacing

We propose 12.5KHz subcarrier spacing which is applied for all the channel bandwidth, e.g. 5/10/20MHz, 3.5/7/14MHz and also 8.75MHz. A 12.5KHz 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 bandwidth will be based on this subcarrier spacing and appropriate FFT size. It means that all the channel bandwidth will have the same base sampling frequency. The mobile can roam to different base bandwidth in different frequency bands, while is very crucial for a unify 4G standard and developing a healthy ecosystem.



CP

We propose three CP lengths based on 12.5KHz 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 with 9.375us duration which is typically used for outdoor urban and suburban environments, and long CP with 16.875us duration which is needed for the large delay spreads that may be encountered with large rural cells.

Number of used subcarriers

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.

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	9.375	9.375	9.375	9.375	9.375	9.375
	Long CP	µs	16.875	16.875	16.875	16.875	16.875	16.875

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

Proposed Text Change

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

Delete lines 17 through 19 on page 4 – [Table 11.3.1: OFDMA parameters for IEEE 802.16m] -> proposal-1

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	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
Useful Symbol Time (T_u)		µs	80					
CP Length (T_{CP})	**Short CP**	µs	$T_u/32 = 2.5$					
	Normal CP	µs	[9.375], [$T_u/8 = 10$]					
	Long CP	µs	[16.875], [$T_u/4 = 20$]					
Symbol Time	**Short CP**	µs	82;.5					
	Normal CP	µs	[89.375], [90]					
	Long CP	µs	[96.875], [100]					

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

-- End ---

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'