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| Title | **Proposed PHY Layer Parameters for IEEE 802.16s (Revised)** |
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| Re: | Call for Contributions: IEEE 802.16 Working Group on Broadband Wireless Access GRIDMAN Task Group: Project 802.16sIEEE 802.16-16-0035-01-000s |
| Abstract | Describes Full Spectrum’s revised proposal of PHY layer parameters for IEEE802.16s.  |
| Purpose | For consideration during Working Group Session #105 |
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**Proposed PHY Layer Parameters for IEEE802.16s – V2.0**

*August 23, 2016*

1. **General**
	1. This document describes the proposed PHY layer parameters for IEEE802.16s. It is an extension of the or proposal to the ieee802.16s workgroup “Proposed PHY Layer Parameters for IEEE 802.16s” from July 19, 2016. The extension is needed to support operation within a narrower channels down to a channel bandwidth of 100 KHz.

* 1. Paragraph 2 describes some of the consideration which led to the proposed PHY layer paramaters. Paragraph 3 includes the proposed parameters for 1 MHz, 500 KHz, 250 KHz, 125 KHz and 100 KHz wide channels.
	2. Some of the configurations require a modification of the standard 802.16 preamble and CDMA codes to align them with the active subcarriers. These modifications are described in paragraphs 4 and 5.
1. **Considerations**
	1. It is assumed the delay spread of 802.16s deployments does not exceed 10 µs, and therefore the minimum Cyclic Prefix (CP) should be 10 µs. In order to avoid excessive CP overhead, we will maintain CP = 1/8 of useful symbol time, i.e., minimum useful symbol time = 80 µs and minimum total symbol duration = 90 µs. For a 1 MHz wide channel, a 1.12 MHz sampling clock is proposed which leads to a subcarrier spacing of 8.75 KHz. The total symbol duration is 128.57 µs which meets the 90 µs. Moreover, the pilot spacing in the 1 MHz proposal is 78.75 KHz. This is less than the 100 KHz coherent bandwidth for a 10 µs delay spread. This proposal therefore also satisfies the pilot based channel estimation requirement.

* 1. Further reduction of the subcarrier spacing relative to 8.75 KHz does not provide any advantage. On the other hand this degrades performance due to:
	+ Peak to Average Power ratio (PAPR) increases as the number of subcarriers increase
	+ Inter Carrier Interference (ICI) increases as the number of subcarriers increase
	+ For a given oscillator, the frequency error (due to the limited accuracy) as a percentage of the subcarrier spacing, increases as the subcarrier spacing is reduced.[[1]](#endnote-1)

It is therefore preferable to fit the signal into the available channel bandwidth by reducing the number of subcarriers first and reduce the sampling clock only as the last resort.

* 1. Support of channel bandwidth below 1 MHz and down to 100 KHz is done using a combination of the following schemes:
	+ Use the band AMC subcarrier allocations scheme which employs adjacent subcarriers per sub-channel.
	+ Reduce the number of sub-channels down to a minimum of 3 as needed to enable a frequency re-use of (1,3,3) in addition to the more aggressive frequency re-use (1,3,1). As an example, the proposal for 1 MHz wide channel has 6 AMC 2X3 sub-channels. The proposal for 500 KHz maintains only 3 of them so no need to change the sampling clock and the subcarrier spacing.
	+ Reduce the sampling clock. For example, it is proposed to reduce the sampling clock to 560 KHz and the subcarrier spacing to 4.4375 KHz for a channel bandwidth of 125 KHz and to further reduce the sampling clock to 448 KHz and the subcarrier spacing to 3.5 KHz for a channel bandwidth of 100 KHz.

* 1. Support reverse asymmetrical TDD frame configuration ratio of up to DL:UL = 1:10. This will effectively double the throughput for SCADA applications relative to FDD.
	2. Support of 40 miles radius is required. This translates into a round trip delay of 430 µs. In order not to exceed the minimum necessary gaps overhead, the gaps duration in samples, should be configurable according to the longest distance in the system and the sampling clock.
	3. The relatively narrow channel does not offer much benefit in frequency diversity. Continuous subcarriers per sub-channel offers greater flexibility to reduce interference in both transmit and receive directions.
	4. Frame Duration: Some applications require very low latency and therefore a frame duration of 5 ms needs to be supported. On the other hand, delay tolerant applications may require high throughput which increases with the increase in frame duration due to the reduction in the per frame overhead and reduced fragmentation.
	5. The use of multiple zones in downlink and uplink sub-frames offers the opportunity to create groups of Remote Stations in the sector and optimize certain parameters for each of the groups. The downside however is the related inefficiency. It is recommended to maintain a single AMC zone in the downlink and in uplink directions.

* 1. Maximization of throughput within 1 MHz wide channel is accomplished by:
	+ Minimize the PHY layer overhead
	+ Minimize the per-frame overhead
	+ Minimize the MAC PDU overhead
	+ Maximize FEC code in both the downlink and uplink.
	+ Automatic PHS

An analysis of the standard IEEE802.16 overhead when operating in narrower channels and the proposed modifications to the standard to reduce the overhead, are described in the document “FullMAX vs Standard IEEE802.16 Air Interface Protocol Overhead – v1”. These modifications are not described in this document.

1. **Proposed Air Interface Parameters**
	1. Proposed Air Interface Parameters for s 1 MHz wide channel

| **Nominal Channel Bandwidth** | **1 MHz** |
| --- | --- |
| Sampling frequency (MHz) | 1.12 MHz |
| FFT size | 128 |
| Subcarrier spacing (kHz) | 8.75 KHz |
| Subcarrier Allocation Scheme in downlink and in uplink | AMC 2 x 3 and AMC 1 x 6 |
| Subchannels in downlink and in uplink | 6 and 12 |
| Actual Bandwidth (centered on nominal channel) for full channel | 945 KHz  |
| Actual Bandwidth (centered on nominal channel) for single subchannel with AMC 2 x 3 | 157.5 KHz  |
| Actual Bandwidth (centered on nominal channel) for single subchannel with AMC 1 x 6 | 78.75 KHz  |
| Preamble | Standard ieee802.16 preamble for 128 FFT transmitted over 36 subcarriers (every 3rd sub-carrier with the active subcarriers)  |
| CDMA Codes | Standard ieee802.16, 128 fft CDMA codes (transmitted over 96 subcarriers) |
| Frame Size (ms) | 5, 10, 12.5, 20, 25 |
| Number of samples per frame | 5600 @ 5 ms, 11,200 @ 10 ms, 14,000 @ 12.5 ms, 22,400 @ 20 ms, 28,000 @ 25 ms |
| Number of symbols per frame | Up to 38 for 5 ms frame, Up to 77 for 10 ms frame, Up to 97 for 12.5 ms frame, Up to 155 for 20 ms frame, Up to 194 for 25 ms frame  |
| Number of samples per symbol | 144 |
| Symbol duration (µs) | 128.57  |
| Useful symbol duration (µs) | 114.26  |
| Slot definition in downlink and in uplink | AMC 2 x 3: 1 SC x 3 symbolsAMC 1 x 6: 1 SC x 6 symbols |
| Duplexing Mode | TDD |

Notes:

* The bandwidth for N consecutive subchannel is N \* 157.5 KHz, N = 1…,6 for AMC 2x3 and N \* 78.5 KHz for AMC 1X6.
* (Total # of symbols per frame) X 144 + TTG + RTG = # of samples per frame.
	1. Proposed Air Interface Parameters for 500 KHz wide channel

| **Nominal Channel Bandwidth** | **500 KHz** |
| --- | --- |
| Sampling frequency (MHz) | 1.12 MHz |
| FFT size | 128 |
| Subcarrier spacing (kHz) | 8.75 KHz |
| Subcarrier Allocation Scheme in downlink and in uplink | AMC 2 x 3 and AMC 1 x 6 |
| Sub-channels in downlink and in uplink | 3 for AMC 2 x 3 and 6 for AMC 1 x 6 |
| Actual Bandwidth (centered on nominal channel) for full channel | 472.5 KHz  |
| Actual Bandwidth (centered on nominal channel) for single subchannel with AMC 2 x 3 | 157.5 KHz  |
| Actual Bandwidth (centered on nominal channel) for single subchannel with AMC 1 x 6 | 78.75 KHz  |
| Preamble | Preamble set #1 transmitted within the 54 active subcarriers. See description in paragraph 4 |
| CDMA Codes | CDMA code set #1 transmitted over the 54 active subcarriers. See description in paragraph 5 |
| Frame Size (ms) | 5, 10, 12.5, 20, 25 |
| Number of samples per frame | 5600 @ 5 ms, 11,200 @ 10 ms, 14,000 @ 12.5 ms, 22,400 @ 20 ms, 28,000 @ 25 ms |
| Number of symbols per frame | Up to 38 for 5 ms frameUp to 77 for 10 ms frameUp to 97 for 12.5 ms frameUp to 155 for 20 ms frameUp to 194 for 25 ms frame  |
| Number of samples per symbol | 144 |
| Symbol duration (µs) | 128.57  |
| Useful symbol duration (µs) | 114.26  |
| Slot definition in downlink and in uplink | AMC 2 x 3: 1 SC x 3 symbolsAMC 1 x 6: 1 SC x 6 symbols |
| Duplexing Mode | TDD |

Notes:

* The bandwidth for N consecutive subchannel is N \* 157.5 KHz, N = 1…,6 for AMC 2x3 and N \* 78.5 KHz for AMC 1X6.
* (Total # of symbols per frame) X 144 + TTG + RTG = # of samples per frame
	1. Proposed Air Interface Parameters for 250 KHz wide channel

| **Nominal Channel Bandwidth** | **250 KHz** |
| --- | --- |
| Sampling frequency (MHz) | 1.12 MHz |
| FFT size | 128 |
| Subcarrier spacing (kHz) | 8.75 KHz |
| Subcarrier Allocation Scheme in downlink and in uplink | AMC 1 x 6 |
| Sub-channels in downlink and in uplink | 3  |
| Actual Bandwidth (centered on nominal channel) for full channel | 236.25 KHz  |
| Actual Bandwidth (centered on nominal channel) for single subchannel with AMC 1 x 6 | 78.75 KHz  |
| Preamble | Preamble set #2 transmitted within the 27 active subcarriers. See description in paragraph 4 |
| CDMA Codes | CDMA code set #3 transmitted over the 27 active subcarriers. See description in paragraph 5 |
| Frame Size (ms) | 5, 10, 12.5, 20, 25 (\*) |
| Number of samples per frame | 5600 @ 5 ms, 11,200 @ 10 ms, 14,000 @ 12.5 ms, 22,400 @ 20 ms, 28,000 @ 25 ms |
| Number of symbols per frame | Up to 38 for 5 ms frameUp to 77 for 10 ms frameUp to 97 for 12.5 ms frameUp to 155 for 20 ms frameUp to 194 for 25 ms frame |
| Number of samples per symbol | 144 |
| Symbol duration (µs) | 128.57  |
| Useful symbol duration (µs) | 114.26  |
| Slot definition in downlink and in uplink | AMC 1 x 6: 1 SC x 6 symbols |
| Duplexing Mode | TDD |

Notes:

* The capacity of 5 and 10 ms frames may be too small and the per frame overehad too high if ferquency re-use (1,3,3) scehme is used.
* (Total # of symbols per frame) X 144 + TTG + RTG = # of samples per frame
	1. Proposed Air Interface Parameters for 125 KHz wide channel

| **Nominal Channel Bandwidth** | **125 KHz** |
| --- | --- |
| Sampling frequency (MHz) | 560 KHz |
| FFT size | 128 |
| Subcarrier spacing (kHz) | 4.375 KHz |
| Subcarrier Allocation Scheme in downlink and in uplink | AMC 1 x 6 |
| Sub-channels in downlink and in uplink | 3  |
| Actual Bandwidth (centered on nominal channel) for full channel | 118.125 KHz  |
| Actual Bandwidth (centered on nominal channel) for single subchannel with AMC 1 x 6 | 39.375 KHz  |
| Preamble | Preamble set #2 transmitted within the 27 active subcarriers. See description in paragraph 4 |
| CDMA Codes | CDMA code set #3 transmitted over the 27 active subcarriers. See description in paragraph 5 |
| Frame Size (ms) | 10, 12.5, 20, 25, 50 (\*) |
| Number of samples per frame | 5,600 @ 10 ms, 7,000 @ 12.5 ms, 11,200 @ 20 ms, 14,000 @ 25 ms, 28,000 @ 50 ms  |
| Number of symbols per frame | Up to 38 for 10 ms frameUp to 77 for 20 ms frameUp to 97 for 25 ms frameUp to 194 for 50 ms frame |
| Number of samples per symbol | 144 |
| Symbol duration (µs) | 257.14 µs |
| Useful symbol duration (µs) | 228.57 µs |
| Slot definition in downlink and in uplink | AMC 1 x 6: 1 SC x 6 symbols |
| Duplexing Mode | TDD |

Notes:

* The capacity of 5 and 10 ms frames may be too small and the per frame overehad too high if ferquency re-use (1,3,3) scehme is used.
* (Total # of symbols per frame) X 144 + TTG + RTG = # of samples per frame
	1. Proposed Air Interface Parameters for 100 KHz wide channel

| **Nominal Channel Bandwidth** | **100 KHz** |
| --- | --- |
| Sampling frequency (MHz) | 448 KHz |
| FFT size | 128 |
| Subcarrier spacing (kHz) | 3.5 KHz |
| Subcarrier Allocation Scheme in downlink and in uplink | AMC 1 x 6 |
| Sub-channels in downlink and in uplink | 3  |
| Actual Bandwidth (centered on nominal channel) for full channel | 94.5 KHz  |
| Actual Bandwidth (centered on nominal channel) for single subchannel with AMC 1 x 6 | 31.5 KHz  |
| Preamble | Preamble set #2 transmitted within the 27 active subcarriers. See description in paragraph 4 |
| CDMA Codes | CDMA code set #3 transmitted over the 27 active subcarriers. See description in paragraph 5 |
| Frame Size (ms) | 12.5, 20, 25, 50 (\*) |
| Number of samples per frame | 5,600 @ 12.5 ms, 8,960 @ 20 ms , 11,200 @ 25 ms, 24,400 @ 50 ms  |
| Number of symbols per frame | Up to 38 for 12.5 ms frameUp to 62 for 20 ms frameUp to 77 for 25 ms frameUp to 169 for 50 ms frame |
| Number of samples per symbol | 144 |
| Symbol duration (µs) | 321.43 µs |
| Useful symbol duration (µs) | 285.71 µs |
| Slot definition in downlink and in uplink | AMC 1 x 6: 1 SC x 6 symbols |
| Duplexing Mode | TDD |

Notes:

* The capacity of 5 and 10 ms frames may be too small and the per frame overehad too high if ferquency re-use (1,3,3) scehme is used.
* (Total # of symbols per frame) X 144 + TTG + RTG = # of samples per frame
1. **Preamble modifications**
	1. **Description of the standard ieee802.16 preamble for 128 FFT**

The first symbol of the DL transmission is the preamble. For each FFT size, three different preamble carrier-sets are defined, differing in the allocation of subcarriers. Those subcarriers are modulated using a boosted BPSK modulation with a specific pseudo-noise (PN) code.

The preamble carrier-sets are defined using PreambleCarrierSetn = n+3k. Where PreambleCarrierSetn specifies all subcarriers allocated to the specific preamble. n is the designating number of the preamble carrier-set indexed 0, 1, and 2. k is a running index, 0-567 for 2K-FFT, 0-283 for 1024-FFT, 0-142 for 512-FFT, and 0-35 for 128- FFT.

Each segment uses a preamble composed of a single carrier-set in the following manner:

* Segment 0 uses preamble carrier-set 0.
* Segment 1 uses preamble carrier-set 1.
* Segment 2 uses preamble carrier-set 2.

In the case of segment 0, the DC carrier will not be modulated at all, and the appropriate PN will be discarded. Therefore, the DC carrier shall always be zeroed. For 128-FFT size, the PN series modulating the preamble carrier-set has predefined look up table of length 36. For the preamble symbol, there are 10 guard band subcarriers on each side of the spectrum.

* 1. **The need and considerations in modifying the standard preamble**

The standard ieee802.16s 128 FFT preamble employs 36 subcarriers interleaved over 108 subcarriers (i.e., over all 6 sub-channels in the case of band AMC 3X2 permutations and over all 12 sub-channels in the case of band AMC 6X1 permutation. This will not fit into the 54 subcarriers proposed for use at 500 KHz wide channel (see paragraph 3.2 above) and 27 subcarriers proposed for use at 250 KHz, 125 KHz and 100 KHz wide channels (see paragraphs 3.3, 3.4 & 3.5). Two new preamble sets are proposed, one for 54 subcarriers is referred to as Preamble set #1 and the second for 27 subcarriers is referred to as Preamble set #2. The two preamble sets are described in paragraphs 4.3 and 4.4 respectively.

The performance of the proposed new preamble sequences was evaluated and compared with the standard 128 FFT preamble sequences. The performance parameters evaluated include:

* Preamble set gain: the auto-correlation and cross correlation of all preamble sequences in the respective preamble set were computed. The gain is the lowest ratio between autocorerlation and cross correlation over all sequences in the set. The higher the gain, the more robust is the preamble detection algorithm. The minimal auto correlation to cross correlation ratio (auto corerlation gain) of the standard ieee802.16 128 FFT preamble sequences is 1.7 dB. This can be improved by maintaining just a subset of the preamble sequences. Note that the gain is independent of whether the subcarriers are interleaved or not.
* Peak to Average Power Ratio (PAPR): the standard ieee802.16 preamble has a very low PAPR compared to the data. The standard requires the preamble to be boosted in power 9 dB relative to the data signal which has a PAPR of 10.25 dB @ CCDF = 1% . This property allows to avoid PA power backoff during the tarsmission of the preamble. The PAPR of the standard ieee802.16 128 FFT preamble is 4 dB @ CCDF = 1%.
	1. **Preamble set #1**

Preamble set #1 employs 54 bit preamble sequences which can be mapped into any of the sectors, i.e.:

* Each preamble index can be used in each sector independent of IDcell and Segment ID
* The 54 bit sequence is mapped into 54 consecutive subcarriers employed in the resepctive sector.

Preamble sequences suggested in Table 8-252 of the IEEE 802.16-2012 standard, are considered.

There are 114 possible sequence, we choose those candidates which satisfy a PAPR constraint of less than 4 dB, while ensuring the auto and cross correlation gains of these sequences are better than 3 dB.

The following 34 sequences meet both the constraints.

5, 8, 11, 12, 16, 20, 22, 28, 31, 32, 33, 41, 43, 47, 50, 52, 57, 58, 59, 63, 72, 76, 77, 78, 85, 88, 90, 91, 94, 96, 100, 101, 102, 103.

A length 54 sequence is created by appending 9 zeros each on either side of the length-36 sequence.

* 1. **Preamble set #2**

Preamble set #2 employs length-27 preamble sequences that can be mapped onto any of the sectors, i.e.:

* Each preamble index can be used in each sector independent of IDcell and Segment ID
* The 27 bit sequence is mapped into 27 consecutive subcarriers employed in the resepctive sector.

Preamble sequences suggested in Table 8-252 of the IEEE 802.16-2012 are considered. There are 114 possible candidates, each of length-36. The first 27-bits from each of these sequences are considered to form length-27 preamble sequences. We shall refer to this as truncated sequences.

Among the possible 114 truncated sequence, we choose those candidates which satisfy a PAPR constraint of less than 4 dB, while ensuring the auto and cross correlation gains of these sequences are better than 3 dB.

The following 12 sequences meet both the constraints: 17, 21, 25, 35, 38, 39, 45, 73, 87, 88, 89, 97.

1. **CDMA Codes modifications**
	1. **Description of the standard ieee802.16 CDMA codes for 128 FFT**

IEEE802.16 employs CDMA codes in the uplink direction for ranging and bandwidth request procedures. Multiple CDMA codes can be transmitted by remote stations and decoded by the base station at the same time.

The CDMA codes for 128 FFT are defined in a paragraph 8.4.7.3 of IEEE802.16-2012. There are 256 possible CDMA codes, each of length 144 bits. The codes are truncated into 96 bits.

The CDMA codes are transmitted over 2 consecutive OFDMA symbols for initial ranging and 2 OFDMA symbols for periodic ranging.

The worst cross correlation gain performance for 96 bit CDMA code is 4.2 dB.

Unlike the preamble sequences, CDMA code sequences do not have low PAPR properties. The worst case PAPR of the 96 bit CDMA code is 9.2 dB @ CCDF = 1%.

CDMA codes for 54 and for 27 subcarriers are generated by truncating the 144 bit sequences to 108 bits. The following 200 out of the 256 code sequences satisfy the requirement of auto/cross correlation gain > 4.2 dB:

29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 117, 118, 119, 120, 121, 122, 123, 124, 125, 126, 127, 128, 129, 130, 131, 132, 133, 134, 135, 136, 137, 138, 139, 140, 141, 142, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 153, 154, 155, 156, 157, 158, 159, 160, 161, 162, 163, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 174, 175, 176, 177, 178, 179, 180, 181, 182, 183, 184, 185, 186, 187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 199, 200, 201, 202, 203, 204, 205, 206, 207, 208, 209, 210, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 223, 224, 225, 226, 227, 228

The 108 bit truncated code sequences are folded over multiple OFDMA symbols as described below. Note that unlike the preamble, initial and periodic ranging codes are not transmitted every frame so the ranging overhead depends on the initial and periodic ranging periods.

* 1. CDMA Code set #1

CDMA Code set #1 consists of 108 bit sequences generated by truncating the original 144 bit code sequences The 108 bit code sequences are spread across 2 symbols (54x2) for periodic ranging and repeated over 4 symbols (54x2, 54x2) for initial ranging. This is described in figure 1.



Fig 1: Band AMC 54 Sub-carrier Map for Initial and Periodic Ranging

* 1. CDMA Code set #2

CDMA Code set #2 consists of 108 bit sequences generated by truncating the original 144 bit code sequences bits. The 108 bit code sequences are spread across 4 symbols (27x4) for periodic ranging and repeated over 8 symbols (27x4, 27x4) for initial ranging. This is described in figure 2.



Fig2: Band AMC 27 Sub-carrier Map for Initial and Periodic Ranging

1. The degradation due to higher number of subcarriers and reduced subcarrier spacing within a given channel bandwidth is quantified in a separate document. [↑](#endnote-ref-1)