Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**BPSK Modulation for IEEE 802.16 WirelessMAN™ OFDM**
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Re:	Supporting document for Sponsor Ballot
Abstract	In P802.16 REVd/D3 [1], both Single-Carrier and OFDMA PHY modes use BPSK as a robust type of modulation recommended for data and/or control channels. Currently OFDM-PHY supports robust modes of operations such as AAS and STC only on data channels and not on the control channels. To achieve true link budget enhancement expected from these optional modes of operation, it is proposed to make BPSK modulation mandatory on the FCH portion of the channel and optional on the data portion. The RNG-REQ message format has been modified accordingly to fit within one OFDM symbol only. This contribution includes simulation results that show over 3 dB gain for BPSK modulation over its equivalent QPSK modulation mode. As best we could, all the requisite changes were made in the standard. This document also provides a number of corrections to Tables 330-336. All sensitivity requirements values of the tables are recalculated and updated for consistency.
Purpose	Adoption
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BPSK Modulation for IEEE 802.16 WirelessMAN OFDM

1 Introduction

The 802.16 combined specification 802.16REVd/D3 [1], defines the coding modes of operation in Table 188 where the most robust coding mode is QPSK rate 1/2. For reasons of robustness and link budget enhancement, including BPSK modulation is desirable. The intent of this contribution is to propose to make BPSK modulation mandatory on the FCH portion and optional on the data portion. Addition of BPSK provides range extension by allowing AAS and STC stations opportunity to see FCH part of transmission.

This document also provides a number of corrections to Tables 330-336. All sensitivity requirements values of the tables are recalculated and updated for consistency.

The rest of the document is organized as follows. In Section 2, the new coding modes are described and performance data is presented. Section 3 describes the requisite changes in the standard required to support BPSK modulation. Finally, Sections 4 and 5 include conclusion and references.

2 Description of Coding Modes

We propose adoption of a new coding mode as follows:

- BPSK, rate 1/2 Unpunctured Convolutional Code (CC), no RS

The following set of simulations show the increase in performance of BPSK modulation over QPSK modulation for several channel scenarios at several SNRs. The following setup is used:

- 3.5 MHz BW
- Oversampling ratio 8/7
- Guard Interval (GI)=1/16

Figure 1 and Figure 2 show the performance of the new BPSK mode versus the QPSK rate 1/2 in AWGN.

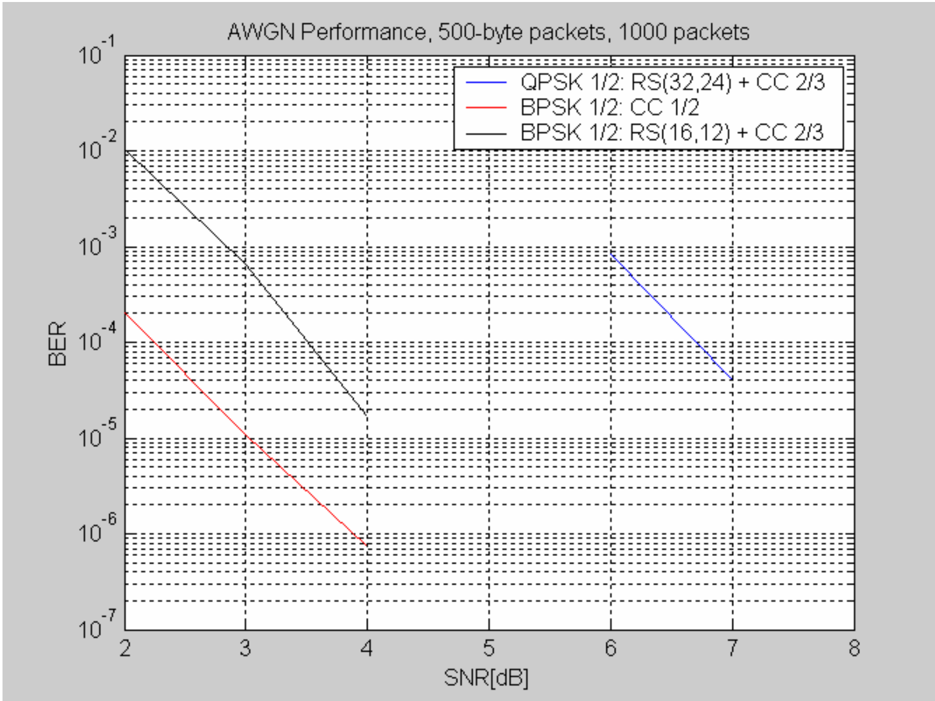


Figure 1. Performance of Suggested 802.16 OFDM BPSK and QPSK in AWGN: Bit Error Rate

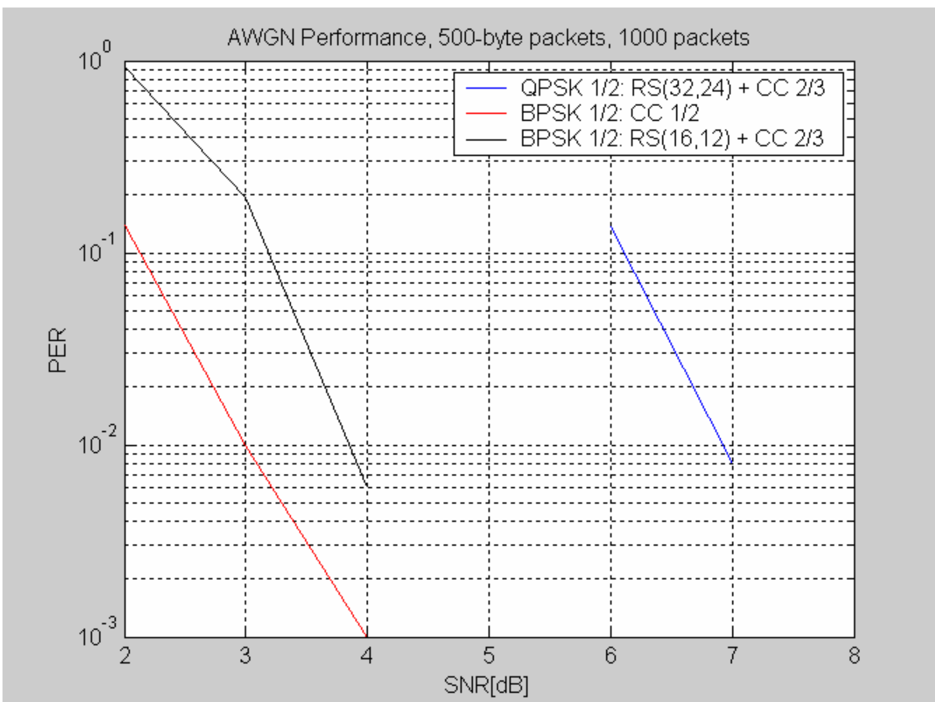


Figure 2. Performance of Suggested 802.16 OFDM BPSK and QPSK in AWGN: Packet Error Rate

Figure 1 and Figure 2 show that BPSK modulation can increase performance by at least 3 dB. Simulation results show an additional enhancement when the RS encoder is turned off. In LOS conditions, this can lead up to two times the coverage. In other realistic channel scenarios, the coverage increase is less.

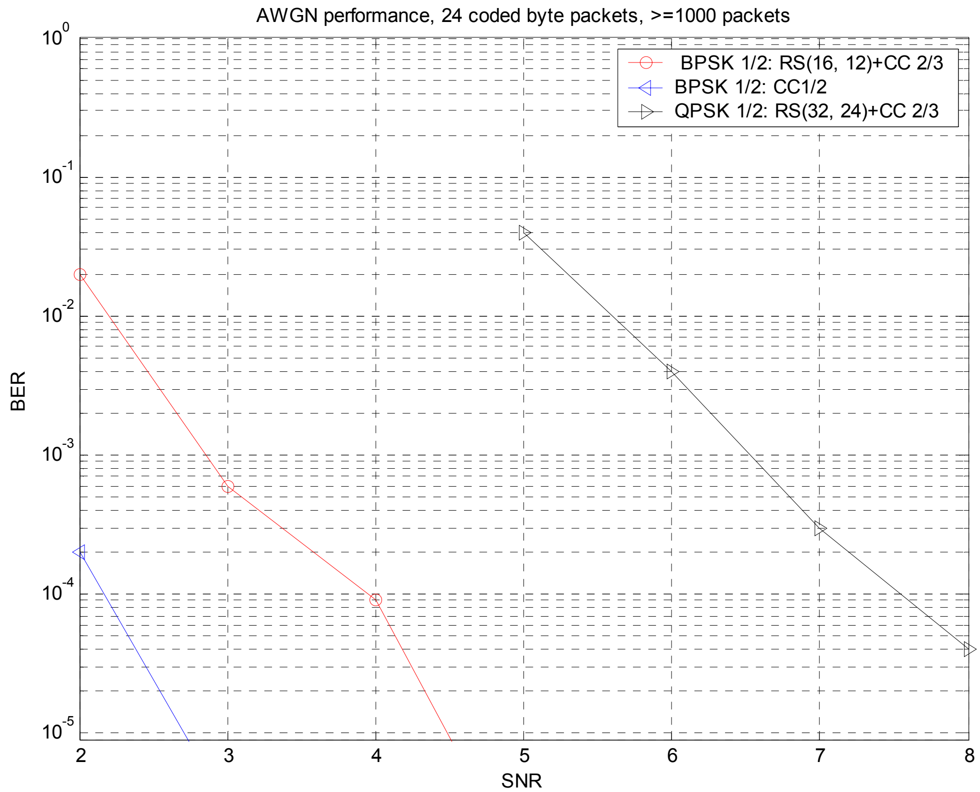


Figure 3. Performance of Suggested 802.16 OFDM BPSK and QPSK in AWGN: Short Control Type Packets

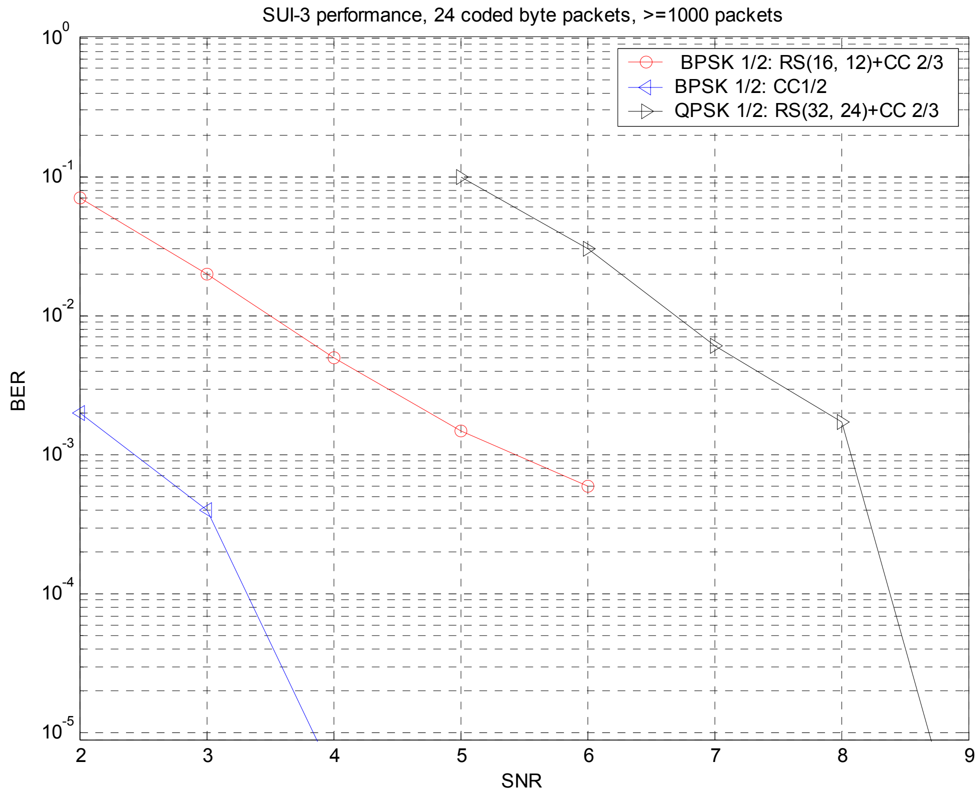


Figure 4. Performance of Suggested 802.16 OFDM BPSK and QPSK in SUI-3: Short Control Type Packets

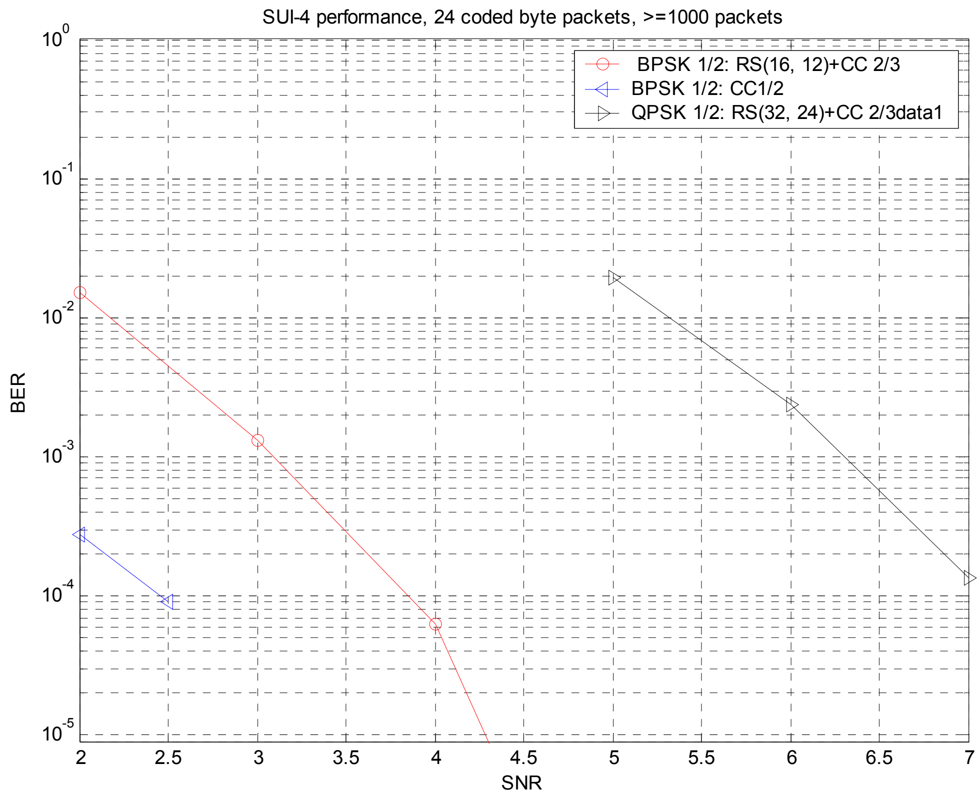


Figure 5. Performance of Suggested 802.16 OFDM BPSK and QPSK in SUI-4: Short Control Type Packets

Figure 3, Figure 4 and Figure 5 show performance of BPSK modulation for FCH type short packets in AWGN, SUI-3 and SUI-4 channel models. An increase of at least 3 dB in performance is observed again. Simulation results show an even larger additional enhancement when the RS encoder is turned off. It is believed that the larger gap is due to ineffectiveness of the interleaver on short packets.

3 Inclusion of BPSK modulation into 802.16REVd

In order to include BPSK modulation in a consistent manner, there are many modifications that are required to be made in IEEE P802.16-REVd/D3-2003 [1]. By reading through the standard, we determined several instances of required changes.

Change 1:

In Section 4, page 13 add "*BPSK* *Binary Phase Shift Keying*" after line 14.

Change 2:

In Table 188 pre-pend the following row:

BPSK	12	24	1/2	(12,12,0)	1/2

And add *"In the case of BPSK modulation, RS encoder should be bypassed*." as a single line paragraph at the end of the Section 8.3.3.2.1.

Change 3:

In Section 8.3.3.3, make the following modification starting at line 49, page 414:

"Let N_{cpc} be the number of coded bits per subcarrier, i.e., 1, 2, 4 or 6 for BPSK, QPSK, 16-QAM or 64-QAM, respectively. Let s = ceil(N_{cpc}/2)."

Change 4:

In Table 196, pre-pend the following row:

BPSK	192	96	48	24	12

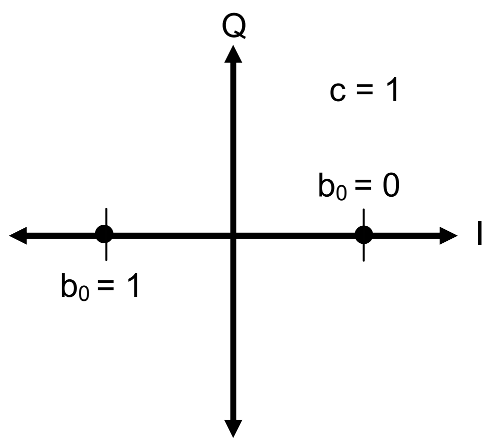
Change 5:

In 8.3.3.4.1 make the following modification starting at line 45, page 415:

"After bit interleaving, the data bits are entered serially to the constellation mapper. BPSK, Gray-mapped QPSK and 16-QAM as shown in Figure 197 shall be supported, whereas the support of 64-QAM is optional. The constellations as shown in Figure 197 shall be normalized by multiplying the constellation point with the indicated factor c to achieve equal average power."

Change 6:

On page 416, Figure 197, add BPSK as follows to the set of constellation options:



Also change the caption on Figure 197 accordingly and as follows:

"BPSK, QPSK, 16-QAM and 64-QAM constellations"

Change 7:

Replace Table 197 with the following table to include BPSK modulation:

Rate ID	Modulation RS-CC Rate
0	BPSK 1/2
1	QPSK 1/2
2	QPSK 3/4
3	16-QAM 1/2
4	16-QAM 3/4
5	64-QAM 2/3
6	64-QAM 3/4
7-15	Reserved

Alternatively, one can add the BPSK 1/2 as Rate ID 6 instead to minimize changes in any existing implementation.

Change 8:

Section 8.3.4.1, page 422, starting line 54, make the following modification:
“A downlink PHY PDU starts with a long preamble, which is used for PHY synchronization. The preamble is followed by a FCH burst. The FCH burst is one OFDM symbol long and is transmitted using BPSK ~~QPSK~~ rate ½ with the mandatory coding scheme. The FCH contains DL_Frame_Prefix to specify burst profile and length of one or several downlink bursts immediately following the FCH. A DL-MAP message, if transmitted in the current frame, shall be the first MAC PDU in the burst following the FCH. An UL-MAP message shall immediately follow the DL-MAP message. If UCD and DCD messages are transmitted in the frame, they shall immediately follow the DL-MAP and UL-MAP messages. Although burst #1 contains broadcast MAC control messages, it is not necessary to use the most robust well-know modulation/coding. A more efficient modulation/coding may be used if it is supported and applicable to all the SSs of a BS.”

Change 9:

[Change in 6.4.2.3.5]

6.4.2.3.5 Ranging Request (RNG-REQ) message

An RNG-REQ shall be transmitted by the SS at initialization and periodically to determine network delay and to request power and/or downlink burst profile change. The format of the RNG-REQ message is shown in Table 19. Compressed RNG-REQ message shall be used in OFDM PHY in Initial Ranging Interval as specified in (Table NNN). In other PHY modes the RNG-REQ message may be sent in Initial Ranging and data grant intervals

[Add at the end of 6.4.2.3.5]

Table NNN. Compressed RNG-REQ message format

Syntax	Size	Notes
Compressed_RNG-REQ_Message_Format() {		

Downlink_Channel_ID	8 bits	The identifier of the downlink channel on which the SS received the UCD describing the uplink on which this ranging request message is to be transmitted. This is an 8 bit field.
SS_MAC_Address	48 bits	48-bits SS MAC Address
MAC_Version	8 bits	Encoded same way as TLV value at 11.1.3
Requested_Downlink_Burst_Profile	8 bits	4 MSBs: DIUC of the downlink burst profile requested by the SS for downlink traffic. 4 LSBs: copy of 4 LSBs of Configuration Change Count value of DCD defining the burst profile associated with DIUC.
Reserved	8 bits	
HCS	8 bits	
}		

Change 10:

Section 8.3.6.4, page 442, line 39, make the following modifications:
"The current transmitted power is the power of the burst which carries the message. The maximum available power is reported for <u>*BPSK,*</u> *QPSK QAM16 and QAM64 constellations. The current transmitted power and the maximum power parameters are reported in dBm. The parameters are quantized in 0.5dBm steps ranging from -64dBm (encoded 0x00) to 63.5dBm (encoded 0xFF). Values outside this range shall be assigned the closest extreme. SSs that do not support QAM64 shall report the value of 0x00 in the maximum QAM64 power field."*

Change 11:

Section 8.3.9.1.2, page 447, pre-pend the following row to Table 222:

BPSK- 1/2	-13

Change 12:

Section 8.3.10.1, page 449, pre-pend the following row to Table 224:

BPSK	1/2	6.4

On page 450, insert *"SBPSK=[0xE4,0xB1]"* in line 16 and replace lines 31-34 with:

"Short length test message payload (288 data bytes): <u>*(144, SBPSK)*</u>*, (72,SQPSK), (36,S16QAM), (6,S64QAM)*

Mid length test message payload (864 data bytes): <u>*(432, SBPSK)*</u>*, (216,SQPSK), (108,S16QAM), (18,S64QAM)*

Long length test message payload (1536 data bytes): <u>*(768, SBPSK)*</u>*, (384,SQPSK), (192,S16QAM), (32,S64QAM)"*

Change 13:

Section 11.3.1.1, page 611, Table 284, replace *"value (variable length)"* entry of the table corresponding to the row *"FEC code type"* with the following:

0= BPSK (RS) 1/2
1 = QPSK (RS+CC) 1/2
2= QPSK (RS+CC) 3/4
3= 16-QAM (RS+CC) 1/2
4= 16-QAM (RS+CC) 3/4
5= 64-QAM (RS+CC) 2/3
6= 64-QAM (RS+CC) 3/4
7= QPSK (BTC) 1/2
8= QPSK (BTC) 3/4 or 2/3
9= 16-QAM (BTC) 3/5
10= 16-QAM (BTC) 4/5
11 = 64-QAM (BTC) 2/3 or 5/8
12 = 64-QAM (BTC) 5/6 or 4/5
13 = QPSK (CTC) 1/2
14 = QPSK (CTC) 2/3
15 = QPSK (CTC) 3/4
16 = 16-QAM (CTC) 1/2
17 = 16-QAM (CTC) 3/4
18 = 64-QAM (CTC) 2/3
19 = 64-QAM (CTC) 3/4
20–255 Reserved

Note: Alternatively, one can add the BPSK 1/2 as FEC code types 19 instead to minimize changes in any existing implementation.

Change 14:

Section 11.4.2, page 615, Table 290, replace *"value(variable length)"* entry of the table corresponding to the row *"FEC code type"* with the following:

0= BPSK (RS) 1/2
1= QPSK (RS+CC) 1/2
2= QPSK (RS+CC) 3/4
3= 16-QAM (RS+CC) 1/2
4= 16-QAM (RS+CC) 3/4
5= 64-QAM (RS+CC) 2/3
6= 64-QAM (RS+CC) 3/4
7= QPSK (BTC) 1/2
8= QPSK (BTC) 3/4 or 2/3
9= 16-QAM (BTC) 3/5
10= 16-QAM (BTC) 4/5
11 = 64-QAM (BTC) 2/3 or 5/8
12 = 64-QAM (BTC) 5/6 or 4/5
13 = QPSK (CTC) 1/2
14 = QPSK (CTC) 2/3
15 = QPSK (CTC) 3/4
16 = 16-QAM (CTC) 1/2
17 = 16-QAM (CTC) 3/4
18 = 64-QAM (CTC) 2/3

19 = 64-QAM (CTC) 3/4
20–255 Reserved

Note: Alternatively, can add the BPSK 1/2 as FEC code types 19 instead to minimize changes in any existing implementation.

Change 15:

Section 11.8.2.2, page 623, line 50, replace the first sentence with
"The maximum available power for BPSK, QPSK, QAM16 and QAM64 constellations."

Also, replace the table in the section with the following:

Type	Length	Value	Scope
3	**4**	**Byte 0: Transmit power backoff for BPSK** **Byte 1: Transmit power backoff for QPSK** **Byte 2: Transmit power backoff for QAM16** **Byte 3: Transmit power backoff for QAM64. SSs that do not support QAM64 shall report the value 0x00.**	**SBC-REQ**

Note: Alternatively, can specify the BPSK transmit power backoff for BPSK in Byte 3 instead to minimize changes in any existing implementation.

Change 16:

Section 12.3.2, page 710, Table 330, replace the row corresponding to *"Tx relative constellation error"* with the following:

Tx relative constellation error: BPSK-1/2 QPSK-1/2 QPSK-3/4 16QAM-1/2 16QAM-3/4 64QAM-2/3 (if 64-QAM supported) 64QAM-3/4 (if 64-QAM supported)	 ≤ -13.0 dB ≤ -16.0 dB ≤ -18.5 dB ≤ -21.5 dB ≤ -25.0 dB ≤ -28.5 dB ≤ -31.0 dB

Change 17:

Section 12.3.2.1, page 711, Table 331, replace the row corresponding to *"BER performance threshold, BER=10^{-6}"* with the following:

BER performance threshold, BER=10^{-6}: BPSK-1/2 QPSK-1/2 QPSK-3/4 16QAM-1/2 16QAM-3/4 64QAM-2/3 (if 64-QAM supported) 64QAM-3/4 (if 64-QAM supported)	 ≤ -94 dBm ≤ -91 dBm ≤ -89 dBm ≤ -84 dBm ≤ -82 dBm ≤ -77 dBm ≤ -76 dBm

Threshold change if subchannelization used	$10 \cdot \log(N_{subchannels}/16)$

All sensitivity requirements values are recalculated and updated for consistency.

Change 18:

Section 12.3.2.2, page 712, Table 332, replace the row corresponding to *"BER performance threshold, BER=10^{-6}"* with the following:

BER performance threshold, BER=10^{-6}:	
BPSK-1/2	≤ -91 dBm
QPSK-1/2	≤ -88 dBm
QPSK-3/4	≤ -86 dBm
16QAM-1/2	≤ -81 dBm
16QAM-3/4	≤ -79 dBm
64QAM-2/3 (if 64-QAM supported)	≤ -74 dBm
64QAM-3/4 (if 64-QAM supported)	≤ -73 dBm
Threshold change if subchannelization used	$10 \cdot \log(N_{subchannels}/16)$

All sensitivity requirements values are recalculated and updated for consistency.

Change 19:

Section 12.3.2.3, page 713, Table 333, replace the row corresponding to *"BER performance threshold, BER=10^{-6}"* with the following:

BER performance threshold, BER=10^{-6}:	
BPSK-1/2	≤ -88 dBm
QPSK-1/2	≤ -85 dBm
QPSK-3/4	≤ -83 dBm
16QAM-1/2	≤ -78 dBm
16QAM-3/4	≤ -76 dBm
64QAM-2/3 (if 64-QAM supported)	≤ -71 dBm
64QAM-3/4 (if 64-QAM supported)	≤ -70 dBm
Threshold change if subchannelization used	$10 \cdot \log(N_{subchannels}/16)$

All sensitivity requirements values are recalculated and updated for consistency.

Change 20:

Section 12.3.2.4, page 714, Table 334, replace the row corresponding to *"BER performance threshold, BER=10^{-6}"* with the following:

BER performance threshold, BER=10^{-6}:	
BPSK-1/2	≤ -91 dBm
QPSK-1/2	≤ -88 dBm
QPSK-3/4	≤ -87 dBm
16QAM-1/2	≤ -81 dBm
16QAM-3/4	≤ -80 dBm
64QAM-2/3 (if 64-QAM supported)	≤ -75 dBm

64QAM-3/4 (if 64-QAM supported) Threshold change if subchannelization used	≤ -73 dBm $10 \cdot \log(N_{subchannels}/16)$

All sensitivity requirements values are recalculated and updated for consistency.

Change 21:

Section 12.3.2.5, page 714, update Table 335 as following:

T_b	$40\frac{120}{157}\mu s$
BER performance threshold, BER=10^{-6}: BPSK-1/2 QPSK-1/2 QPSK-3/4 16QAM-1/2 16QAM-3/4 64QAM-2/3 (if 64-QAM supported) 64QAM-3/4 (if 64-QAM supported) Threshold change if subchannelization used	 ≤ -89 dBm ≤ -86 dBm ≤ -84 dBm ≤ -79 dBm ≤ -77 dBm ≤ -72 dBm ≤ -71 dBm $10 \cdot \log(N_{subchannels}/16)$

All sensitivity requirements values are recalculated and updated for consistency.

Change 22:

Section 12.3.2.6, page 715, Table 336, replace the row corresponding to *"BER performance threshold, BER=10^{-6}"* with the following:

BER performance threshold, BER=10^{-6}: BPSK-1/2 QPSK-1/2 QPSK-3/4 16QAM-1/2 16QAM-3/4 64QAM-2/3 (if 64-QAM supported) 64QAM-3/4 (if 64-QAM supported) Threshold change if subchannelization used	 ≤ -86 dBm ≤ -83 dBm ≤ -81 dBm ≤ -76 dBm ≤ -74 dBm ≤ -79 dBm ≤ -68 dBm $10 \cdot \log(N_{subchannels}/16)$

All sensitivity requirements values are recalculated and updated for consistency.

4 Conclusion

Addition of BPSK provides range extension of at least 3 dB allowing AAS and STC stations the opportunity to see FCH part of transmission. The targeted enhancement is shown to be achievable in AWGN and SUI model for both short and long packets. Because of ineffectiveness of the interleaver on short packets, it is recommended to disable RS encoder for BPSK modulation. Simulation results confirm the claim.

5 References

[1] IEEE P802.16-REVd/D3-2004 Standard for Local and metropolitan area networks Part 16: Air Interface for Fixed Broadband Wireless Access Systems