Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**PHY proposal for IEEE 802.16.3**
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Re:	Response to 802.16.3 Invitation to submit contributions representing proposed PHY Solutions.
Abstract	This proposed PHY addresses some criteriae in the Evaluation Table of the Call for proposals document IEEE802.16.3-00/14 with a flexible and scalable modulation/coding scheme that is spectrally highly efficient at low SNR.
Purpose	To be considered by 802.16.3 Task Group as part of the 2-11 GHz Licensed bands' FWA PHY Solution.
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PHY Proposal for IEEE

Introduction

This document gives outline of the proposed PHY layer for 802.16.3 Broadband Fixed Wireless Access sytems. OFDM modulation is prefered to single carrier modulation in order to propose simple, efficient and low cost equalization schemes. Multiple access is TDMA with TDD. A new constellation / coding scheme is proposed to achieve high spectral efficiency at low SNR, and thus increase coverage area and/or reduce transmitted power.

Key features of the PHY Proposal

The main features of this PHY proposal are :

OFDM scheme with PSAM,

TDMA, interleaved TDM multiple access,

Turbo-BICM.

OFDM parameters

Channel assumptions: channel modeling is not the purpose of this proposal, but some elements are needed to show OFDM interest. Non Line-Of-Sight (NLOS) delay spread is estimated at 2 µs, as in HiperLAN2 outdoor channel models. Mobile scatterers generate a Doppler spread that is limited to f_d = 500 Hz, and the channel is considered as slowly varying.

The minimum bandwidth for FWA systems is 3.5 Mhz. Thus delay spread is about 6 samples and direct equalisation is complex. OFDM is therefore a good candidate for FWA, since equalisation is easy through channel estimation. Modulation uses Pilot Symbols (PSAM) and Cyclic Prefix (CP) to achieve channel estimation, equalization and synchronization.

Low Inter Carrier Interference (ICI) requires that sub-carrier spacing (equals size) should be greater or equal to 100 f_d = 50 KHz, where f_d is the maximum doppler frequency of the moving scatterers.

Suited OFDM wave forms:

Bandwith ***MHz***	***Sub-carriers number***	***Cyclic prefix size*** ***in samples***	***PSAM pattern*** ***(freq spacing , time spacing)***	***Spectral Efficiency***
3,5	≤ 64	≈ 10	(4, 16)	0,85 . Rc . log(M)
7	≤ 128	≈ 16	(4, 16)	0,875 . Rc . log(M)

Where Rc is the coding rate and M is the constellation size.

The (4, 16) PSAM pattern means that pilots are spaced by 4 sub-carriers in the current OFDM symbol, and these pilots symbols are not present at each OFDM symbol, but only every 16 OFDM symbols. This low density PSAM matches the slow fading channel and increases spectral efficiency.

Space Time Block Codes

STBC are used to increase diversity with $R_{ST} < 1$, or to increase throughput with $R_{ST}>1$. OFDM and STBC have a mutual gain:

- STBC reduces power on each antenna, thus cheaper and more linear amplifiers can be used.
- OFDM can shift Space-Time codes to Space-Frequency codes (within coherence Bandwidth B_c), a slow frequency varying channel is equivalent to a slow time varying channel. This reduces delay.
- OFDM permits the use of “interspaced PSAM”: channel estimation is simultaneous for all antennas, using sub-carriers orthogonality (figure 1).

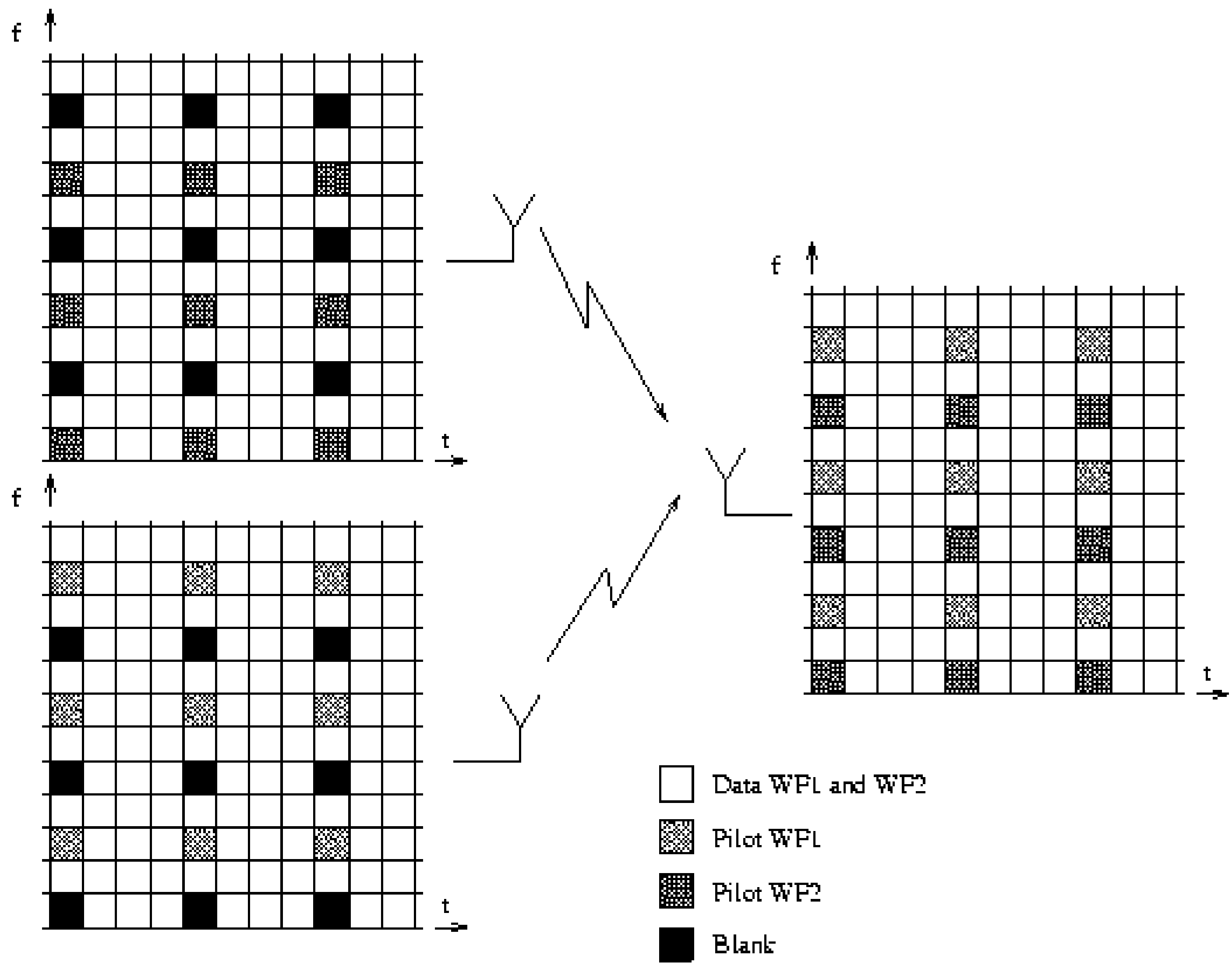

Figure 1: Interspaced PSAM for STBC simultaneous channel estimation. WaveForm1 and WaveForm2 are displayed in the classical [time × freq] representation of OFDM. Blank means that no power is transmitted at a given position.

Turbo BICM

TurboBICM is a new coding scheme which combines Iterative Decoding (Turbo) and Bit Interleaved Coded Modulation (BICM). It is higlhy efficient at low SNR, since it is working at the constellation level, like Treillis Coded Modulations (TCM). Efficient coding rate is in the range from ½ to 2/3.

Complexity is lower than turbo-codes: one turbo iteration in Turbo BICM is only one decoding instead of 2 with usual turbo codes. Component codes are short, thus decoding has reasonable complexity.

Scalability is mostly achieved with constellation choice: 4QAM, 8PSK, 16QAM, 32QAM and 64QAM. Thus channel coding can then be the same for all constellations.

Figures 2 and 3 show Turbo BICM simulated performances on Gaussian and Rayleigh channels, with a RS(15,8) code over GF(2^4). 5 iterations are performed. This is a maximum number: in most cases fewer iterations are performed.

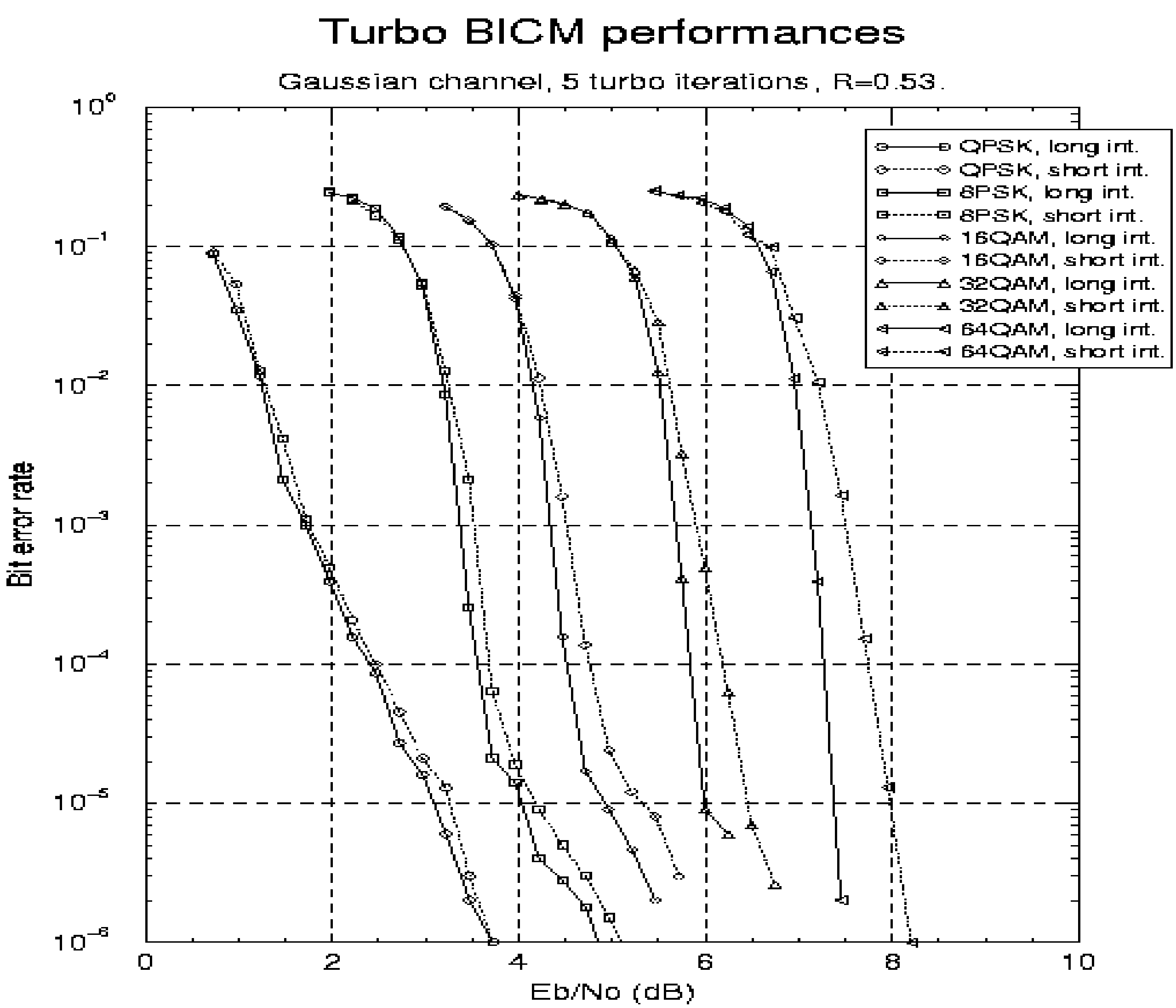

Figure 2: Turbo BICM performances on Gaussian channel

Constellation	Spectral Efficiency Bits / s / Hz	Req C/N for BER = 10^{-4}	Req C/N for BER = 10^{-6}	Interleaver size		Complexity
				Minimum	Nominal	
QPSK	1,1	2,8 dB	4,0 dB	4000 bits	5300 bits	5 T_d (1+ε)
8PSK	1,6	5,8 dB	7,0 dB	4000 bits	8000 bits	5 T_d (1+ε)
16QAM	2,1	8,0 dB	9,2 dB	4000 bits	10700 bits	5 T_d (1+1/8)
32QAM	2,7	10,1 dB	11,0 dB	4000 bits	13300 bits	5 T_d (1+1/4)
64QAM	3,2	12,4 dB	12,6 dB	4000 bits	16000 bits	5 T_d (1+1/2)

Where T_d is the time to compute a single SISO decoding of RS(15,8) over GF(16). Deinterleaving complexity is negligible, but it needs memory.

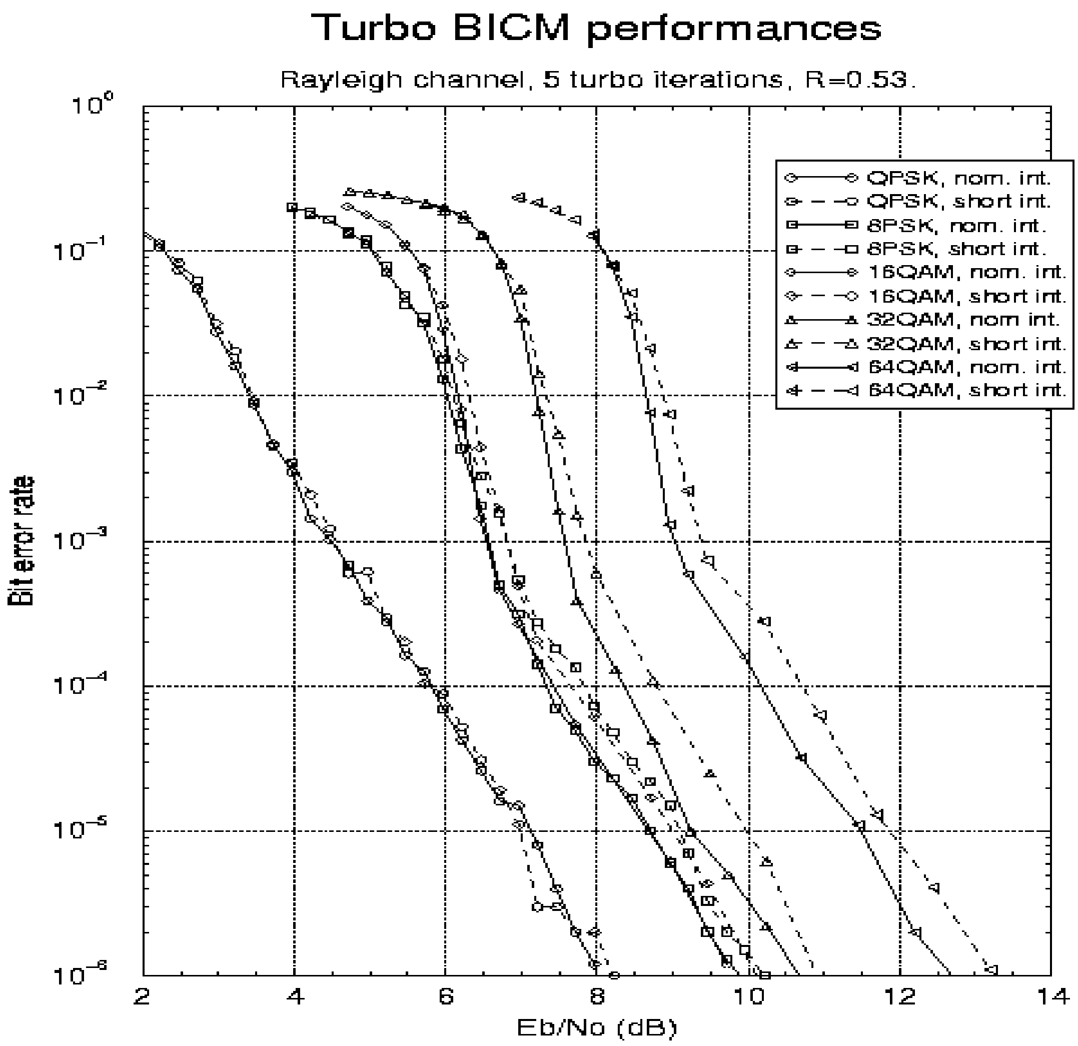

Figure 3: Turbo BICM performances on Rayleigh channel with perfect channel state information

Simulations show that Turbo BICM residual errors have a bursty nature, thus frame error rate is low (for a given BER). As a consequence, ARQ is very well suited to this scheme, this task is left to the MAC layer.

Interleaver size is quite critical for Turbo BICM performances, this might be a problem for low data rates connexions and small packets (fortunately most IP datagrams are big enough to fit one full interleaver). For low data rate connexions, long interleaving results in long delay. For small packets, interleaving is not possible and BER raises.

The same problem is encountered for all efficient coding schemes: spectral efficiency at low SNR requires long codes or long interleavers. For example the NASA turbo code uses a 65536 bits interleaver. Shannon’s capacity proof shows that the BER can reach zero when code size increases to infinity. “Interleaved TDM” is the proposed solution to this problem.

Interleaved TDM

Small packets are interleaved together, inside one PHY frame. This is only possible on the Downlink. Packets interleaved together must share the same constellation. This schemes keeps high spectral efficiency and good QoS even with small packets.

The decoding algorithm remains the same.

The modification of the TDM access is small and quasi straightforward for MAC layer. The slot number fields is interpreted in a slightly different manner: time slot $i \rightarrow$ bit slot i or interleaved slot i. This modification can also be part of the PHY layer only.