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Re:	Re: IEEE 802.16.3-00/14 TG3 CFC on PHY proposals
Abstract	OFDM based 802.16.3 PHY Proposal
Purpose	Discussion
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OFDM based 802.16.3 PHY Proposal

OFDM Forum FWA-WG members

1. Introduction

This document contains the outline of an OFDM based PHY proposal to IEEE 802.16 TG3. It discusses the generic layout of the proposed PHY layer and evaluates the criteria set forth in [1] and [2] in as far as the proposal is specific enough at this point to make this evaluation possible.

2. References, Terminology and Abbreviations

2.1. References

[1] IEEE 602.16.3-00/14 Call for Contributions: Session #10
[2] IEEE 802.16.3-00/02r4 Functional Requirements for the 802.16.3 Interoperability Standard
[3] On the computation and reduction of the peak-to-average power ratio in multicarrier comm. Tarokh, V and Jafarkhani, H, IEEE Trans. On Comm. V48.1, pp. 37-44.
[4] OFDM peak power reduction by sub-block-coding and its extended version Zhang et. Al, Proceedings of VTC'99 pp 695-699
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[15] A. Gatherer and M. Polley Controlling Clipping Probability in DMT Transmission," Asilomar Conference on Signals, Systems, and Computers, pp. 578-584, 1997.
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Multicarrier Transmission by Block Coding, IEEE VTC pp. 825-829, 1995.
[17] J. A. Davis and J. Jedwab, "Peak-to-Mean Power Control and Error Correction for OFDM Transmission
using Golay Sequences and Reed-Muller Codes, Elec. Letts. Vol. 33, pp. 267-268, Feb 1997.
[18] J. A. Davis and J. Jebwav, "Peak-to-Mean power Control in OFDM, Golay Complementary Sequences, and Reed-Muller Codes, in IEEE Trans. Infor Theory, vol 45, pp. 2397-2417, Nov. 1999.

2.2. Terminology and Abbreviations

This proposal uses the same terminology and abbreviations as defined in [2]. Deviations and additions are listed below.

PAPR	Peak-to-Average Power Ratio

3. Typical System Framework

In order to be able to compare the different proposals for this document, some common parameters are chosen for evaluation. Inadvertedly, this will more or less lead to an optimization for this typical framework. Naturally, the system shall still be operational over the whole range of parameters set in [2], yet may for example suffer from higher overhead rates.

- Cell-size: 4km
- Delay spread (at 4km): 2us
- Antenna height BS: 30 m
- Antenna height CPE: 3m
- Channelization: 6 MHz
- Frequency band between 2.5 and 3.5 GHz
- Availability of 99.99%

This chapter will be updated as appropriate on decisions of the TG regarding a typical system framework for evaluation.

3. Motivation of OFDM choice

From a frequency band and channel characteristics stand points, FWA below 11 GHz has a much closer relationship to WLANs than to FWA at the LMDS bands. For the intended application, the channel characteristics favor OFDM, as it allows for more flexible deployments because it doesn't suffer from some of the restrictions of systems in the LMDS band, such as short link distances, LOS requirement and antenna limitations.

For the given target markets (single residents through SME's), the cost of engineering LOS links is relatively high and often not possible. To enable this market, especially in competition with DSL and cable-modems, both the hardware and deployment must be cheap. NLOS operation allows for easy installation and improves coverage.

OFDM is robust in adverse channel conditions and allows NLOS operation while maintaining a high level of spectral efficiency. It effectively mitigates performance degradations due to multipath and is capable of combating deep fades in part of the spectrum.

The OFDM waveform can be easily modified to adjust to the delay spread of the channel.
OFDM allows efficient operation in both FDD and TDD mode as very short or no pre-ambles are needed.

Unlike with the use of equalizers, there is no need to load channel coefficients, which requires knowledge of the transmitter and hence mandates polling or scheduling. OFDM therefore allows the ability to use contention time-slots, which increases MAC efficiency.

OFDM can handle large delay spreads easier to due the independence of the carriers and the flexibility of varying the cyclic prefix length.

The main drawback of pure OFDM is the high PAPR, which places increased linearity requirements on the amplifier. However, various methods are available to reduce this ratio, for example:

- Phase optimization
  - Using a weighted combination of partial transmit sequences [6,7]
  - Using minimum distance decoding to identify codewords with high PAPR [3]
  - Algebraic techniques to cancel large peaks [8]
  - Differentially encoding data on pairs of subcarriers [9]
- Clustered OFDM using multiple power amplifiers and transmit antennas [10]
- Mapping Techniques such as random interleaving [11], scrambling using m-sequences [12], multiplying by a phase vector [13].
- Virtual sub-carrier techniques, where the virtual carriers do not carry data, but are used to create an additive cancellation signal [14,15]
- Block coding [3,4,5,16,17,18]
- Clipping

Another perceived drawback is the required accurate frequency offset estimation. However, the baud timing accuracy required in single carrier approaches is equally difficult. Just as single carrier systems will be less sensitive to carrier offset errors than OFDM systems, OFDM systems are less sensitive to timing errors than single carrier systems. So the two problems are equivalent.

4. Transmit Chain

The transmit chain model is shown in Figure 1.

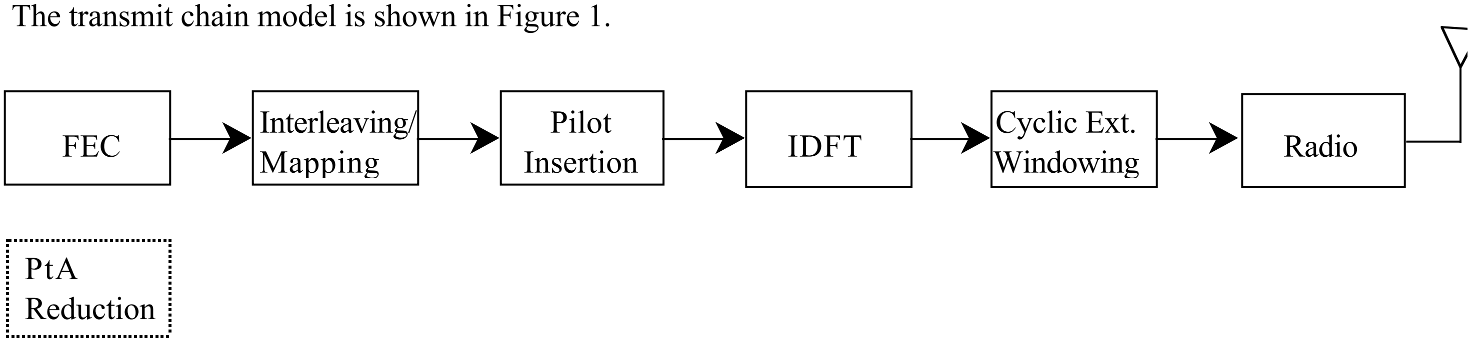

Figure 1 PHY Transmit chain model

4.1. FEC

The encoding could be both of block- and convolutional coding type. The advantage of block-coding over convolutional coding here is that no trailing bits (or reduced performance due to the lack of these) are required. On the other hand, the number of tail bits required for short constraint-length convolutional codes is small. Which specific type of codes should be used is left open until channel models are selected for comparative studies. Various coding rates should be implemented to accommodate a trade-off between throughput and robustness (in addition to modulation-adaptation).

4.2. Interleaving/Mapping

Depending on the FEC chosen, interleaving may be required. If interleaving is required, then unless turbo-codes are selected, one OFDM symbol would be the interleaving size.

The interleaved bits are mapped onto the modulation used. The modulation shall provide for BPSK, QPSK and 16-QAM in the upstream channel and additionally 64-QAM in the downstream channel. 64-QAM in the upstream channel should be optional.

4.3. Pilot Insertion

Pilot signals are inserted on every 32nd carrier in order to recover, by interpolation, the proper constellation magnitudes and the proper constellation phases of the data-carriers.

4.4. Cyclic Prefix / Windowing

Each time-domain OFDM data symbol is extended, by copying a portion from the end of the symbol to the start. This is done to make the OFDM data robust against multipath delays without causing Inter Symbol Interference. The lengths of the extension are TBD pending a decision on the number of carriers, channel measurement data and channel models.

OFDM normally has an out-of-band spectrum that decreases rather slowly. To meet stringent spectral mask and band-edge requirements, either windowing in time-domain or filtering in the frequency domain is required.

4.5. Peak-to-Average Power Ratio Reduction

As there are various methods of PAPR Reduction, there are various places to introduce this block into the transmit chain. The choice of the best methods needs to be investigated. Example options are various coding algorithms, carrier scaling, clipping, usage of peak reduction carriers, companding techniques etc.

5. Receive Chain

The receive chain is shown in Figure 2.

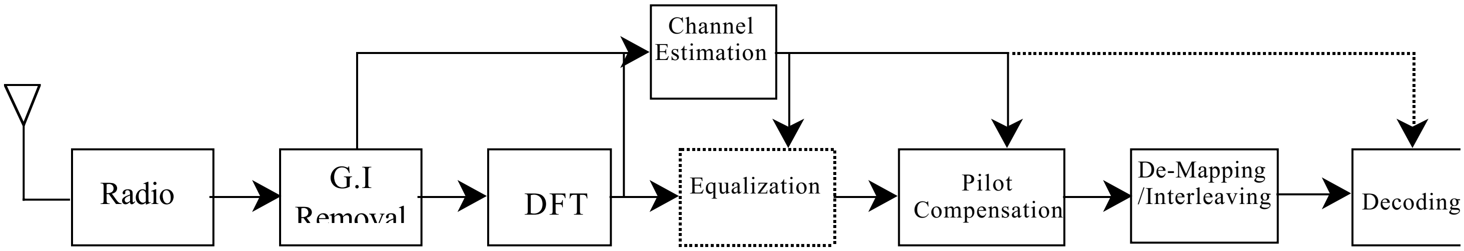

Figure 2 Receive Chain

5.1. Guard-Interval Removal

This block removes the guard-interval and preambles. The preamble is used for packet-synchronization, AGC control (not shown, but embedded in “Radio”), Carrier Frequency Offset Correction and Channel Estimation. The preamble may further carry additional information (TBD).

5.2. Channel Estimation

Channel estimation may be performed on preambles, pilot-carriers, training symbols and even the carried data. Its implementation will however not be specified in the standard as different algorithms do not prohibit devices being interoperable.

5.3. Equalization

The equalizer is used to boost the performance of the delay spread resilience and frequency selective fading. This equalizer should not be confused with equalizers used in single carrier implementations, as it consists only of one independent tap per carrier. Hence, the adaptation of this equalizer, even though the overall number of taps may be larger than in a single-carrier equalizer, is simple and fast. Implementing the Equalizer will be optional.

5.4. Pilot Compensation

The pilots are extracted from the signal to reconstruct the transmitted constellation. The output from the Channel Estimator is used to determine what weight (if any) to attach to each of the pilots. In other words, a pilot in a deep fade will be unreliable and contribute little to the constellation reconstruction.

5.5. De-Mapping/De-Interleaving

This functionality reverses the Interleaving process and maps the received symbols back to bits.

5.6. Decoding

This functionality reverses the block coding operation. Information from the Channel Estimator could be used to improve the decoder’s performance, but is not required.

6. Other functionality

The standard will support adaptive per-CPE modulation and power control. Methods such as adaptive bit-loading will be studied further.

7. Burst Structure

The OFDM burst preamble is depicted in Figure 3. It is followed by a variable amount of data-symbols.

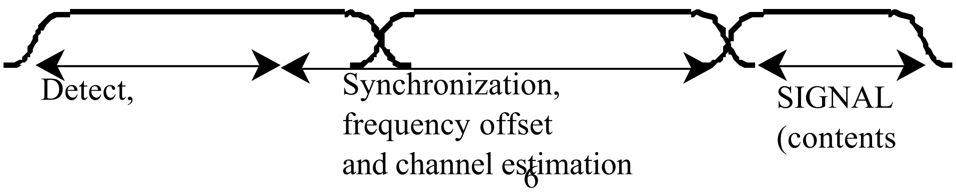

Figure 3 Burst preamble

The burst will be ended by a CRC check, to facilitate ARQ. ARQ is required to achieve reliability.

8. DFT size

Principally, there are two ways to accommodate different channel sizes. One method is to vary the size of the DFT, the other to change the carrier spacing (i.e. adjust the clock rate). Of these two, the latter seems the more practical and flexible, as DFT sizes not powers of 2 are highly impractical.

The remaining question is then what the size of the DFT should be. A higher value of the DFT size allows for higher throughputs and increases the delay spread tolerance. On the other hand, it increases the complexity, it magnifies the Peak-to-Average ratio problem and increases the phase noise sensitivity, hence requiring a more expensive front-end. As both cost and delay spread tolerance (which is larger than in WLAN applications) are an important factors, a DFT size between 64 and 256 probably makes sense.

Based on the typical system framework parameters, the overhead associated with a guard interval of 2us is in the order of 20% for a DFT size of 64 and 5% for a DFT size of 256. The downsides of 256 DFT are the phase noise and the granularity of the packet sizes. Additionally, the overhead of the training sequences increases.

9. Antenna Diversity support

It is well known that antenna-diversity provides a significant improvement in throughput and link-budget, and that transmit antenna diversity can reduce overall interference. The cost of this is however fairly significant. It is therefore the aim of this proposal to make this feature supported but optional.

10. Convergence Layer Interface

The Convergence Layer should pass the following data to the PHY.

- Data Length
- Pointer to Data or data itself
- TX start time
- FEC Rate
- Modulation Type
- TX Power
- TX Channel
- RX Channel

The PHY Layer should pass the following data to the Convergence Layer

- Data Length
- Pointer to Data or data itself
- Modulation Type
- TX Power
- FEC Rate

- RX Time
- RSSI value
- BER value
- PHY busy signal

11. Evaluation Criteria

Meets system requirements?	Yes (so far)
Channel spectrum efficiency -defined in terms of single channel capacity (TDD or FDD) assuming all available spectrum is being utilized (in terms of bits/sec/Hz).Supply details of PHY overhead. -Modulation Scheme -Gross Transmission Bit Rate -User information bit rate at PHY-to-MAC Interface -Occupied Bandwidth	Capable of over 2 bits/sec/Hz. 64 QAM downstream only and BPSK, QPSK, 16- QAM up- and downstream. 64 QAM upstream is optional. Estimated to be in the order of 1.5 Mbps for a 3 MHz channel, up to 40 Mbps for a 20 MHz channel using 16 QAM TBD TBD
Simplicity of implementation -How well does the proposed PHY allow for simple implementation or how does it leverage on existing technologies?	OFDM is well understood from WLAN and DVB implementations. No blind copying of these standards is proposed, however, as channel and application conditions are different.
SS cost optimization	Allows for an SS with reduced component cost as compared to the BS. Turn up cost is reduced due to the high delay spread tolerance allowing NLOS installation (i.e. no pointing and placing of highly directional antennas in LOS position is required).
BS cost optimization -How does the proposed PHY affect Base Station cost?	Digital and analog baseband can be performed in one chip each. OFDM does not preclude direct conversion. PAPR reduction reduces the PA cost. Hence no big cost issues are noted between OFDM and single carrier methods.

Spectrum resource flexibility -Flexibility in the use of the frequency band (i.e.channelization,modularity,band pairing,and Upstream/Downstream data asymmetry)	All channelization and duplexing modes mentioned in the Functional Requirements document are supported. Channelization and band-pairing are extremely flexible. Full data-asymmetry is supported.
System service flexibility -How flexible is the proposed PHY to support FRD optional services and potential future services?	No restrictions are evident. Especially allowing for antenna diversity support allows potentially for very high throughput, creating ample bandwidth for future and optional services.
Protocol interfacing complexity -Interaction with other layers of the protocol,specifically MAC and Network Management.Provide the PHY delay.	TBD
Reference system gain -Sector coverage performance for a typical BWA deployment scenario (supply reference system gain). Provide practical link budget analysis.	TBD
Robustness to interference -Resistance to intra-system interference (i.e.,frequency re-use)and external interference caused by other systems. -Provide co-channel,adjacent channel interference levels and spectral spillage resulting from modulation.	Very robust to narrowband interference. Rest TBD
.Robustness to channel impairments -Small and large scale fading (Rain fading,multipath,N (non or near)LOS,LOS, Foliage effects,frequency-selective fading,atmospheric effects,etc.)	Very robust to frequency selective fading and delay spread.
Robustness to radio impairments -Specify the degradation due to radio impairments such as phase noise,group delay of filters,amplifier non-linearities,etc.	The DFT size will be chosen such that the phase noise is low enough to allow for oscillators of reasonable cost. Group delay is neglegible. OFDM is the best transmission scheme for avoiding group delay problems. For the amplifier, a number of dB's of backoff will be required. PAPR reducing algorithms will be investigated to reduce the backoff requirements.