| | |
|---|---|
| Project | **IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>** |
| Title | **[802.16.3 2G OFDM System for Broadband Wireless Access Development]** |
| Date Submitted | **[2000-10-30]** |
| Source(s) | [Dr. Robert M. Ward Jr]<br>[SciCom, Inc.]<br>[13863 Millards Ranch Lane]<br>[Poway, Ca. 92064]<br>Voice: [858.513.4326]<br>Fax: [858.513.4326]<br>mailto:drbmward@ieee.org |
| Re: | IEEE802.16.3-00/14 document.<br>Response to “IEEE 802.16.3 Task Group Call for Contributions: Session #10”<br>“Topic: Initial PHY Proposals” |
| Abstract | [The signal processing functionality for a 2nd Generation OFDM system is described. ] |
| Purpose | [Proposed PHY system technology is described for consideration by 802.16.3 Task group in the development of its standard.] |
| Notice | This document has been prepared to assist IEEE 802.16. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein. |
| Release | The contributor grants a free, irrevocable license to the IEEE to incorporate text contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE’s name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE’s sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.16. |
| Patent Policy and Procedures | The contributor is familiar with the IEEE 802.16 Patent Policy and Procedures (Version 1.0) <http://ieee802.org/16/ipr/patents/policy.html>, including the statement “IEEE standards may include the known use of patent(s), including patent applications, if there is technical justification in the opinion of the standards-developing committee and provided the IEEE receives assurance from the patent holder that it will license applicants under reasonable terms and conditions for the purpose of implementing the standard.”<br>Early disclosure to the Working Group of patent information that might be relevant to the standard is essential to reduce the possibility for delays in the development process and increase the likelihood that the draft publication will be approved for publication. Please notify the Chair <mailto:r.b.marks@ieee.org> as early as possible, in written or electronic form, of any patents (granted or under application) that may cover technology that is under consideration by or has been approved by IEEE 802.16. The Chair will disclose this notification via the IEEE 802.16 web site <http://ieee802.org/16/ipr/patents/notices>. |

# $2^{nd}$ Generation OFDM Architecture for 802.16.3 Broadband Wireless Access

Dr. Robert M. Ward Jr.

SciCom, Inc.

## Introduction

This contribution provides an overview of an advanced OFDM architecture tailored for 802.16.3's wireless application. It combines many of the best attributes of prior systems, taking advantage of proven techniques. Key requirements are summarized first to establish the capabilities that this architecture includes. A system overview precedes the functional descriptions. Potential extensions and example configurations are suggested. Lastly, a review of the evaluation criteria measures the benefits of this approach.

## Requirements summary

Ref 1 documents 802.16.3 systems requirements. A summary of key capabilities necessitated by these system requirements is tabulated here.

| Physical Channel capabilities | Service capabilities |
|---|---|
| • 2 to 11 Ghz Frequency Range<br>• Bidirectional communications<br>• Operate in multipath<br>• Support 50 km ranges<br>• Operate in multicell/sector topology<br>• Low BER | • Capacity<br>  • Up to 10 Mbps per user<br>  • Aggregate data rate to support multiple users simultaneously<br>• Scalable growth<br>• Integrated Transport<br>  • Voice, video, data<br>  • Commensurate levels of QOS<br>• Point to Multipoint Operation<br>• Easy Access<br>• Dedicated Bandwidth |

Table 1: Summary 802.16.3 Network capabilities

## System Overview

Many contributions in IEEE 802.11, 802.16.1 and 802.16.3 illustrate the capability of OFDM to mitigate multipath. Beyond IEEE standardization, deployed systems using OFDM as a basis have demonstrated its robustness and availability of technology. Ref 2 and Ref 3 cite 802.16.3's particular multipath requirements and suggest OFDM as a capable means for combatting it. Successful development of OFDM technology for such diverse applications as 802.11a LANs and DVB-T broadcasts also indicates its versatility in both burst and continuous operation with high data throughput. OFDM is thus chosen as the basis of this proposal.

The OFDM architecture of this proposal has several selectable features to optimize system capacity: FFT length, guard length, subcarrier masking, pilot on/off operation, and preamble format. This proposal also integrates several other functional features with OFDM to enhance overall system performance. A strong layer of concatenated forward error correction (FEC) is included for maximizing range and achieving low bit error rates (BER). The concatenated use of Reed Solomon and Convolutional coding is similar to Ref 4. As an extension to this proposal, using the convolutional inner coding as a Trellis Coded Modulation (TCM) mechanism for additional gain is also offered. New signal constellations for the underlying QAM modulation of the OFDM subcarriers are added for greater system versatility. Lastly, MAC layer framing can be based on 16.1 capabilities to provide access methodology employing both hybrid TDD/FDD methods. Figure 1 illustrates the signal processing order, with the TCM extension highlighted. Minor functionality such as scrambling and interleaving is not detailed here.

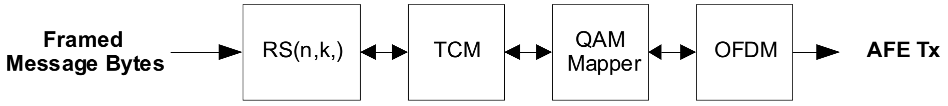

Figure 1: Functional Signal Processing

## Interfacing into the MAC Layer

The principal focus of this proposal is on the PHY layer signal processing. However as a frame of reference for the following discussion, framing concepts with modulation and coding sets adaptable per subscriber station such as described in Ref 4 will be assumed.

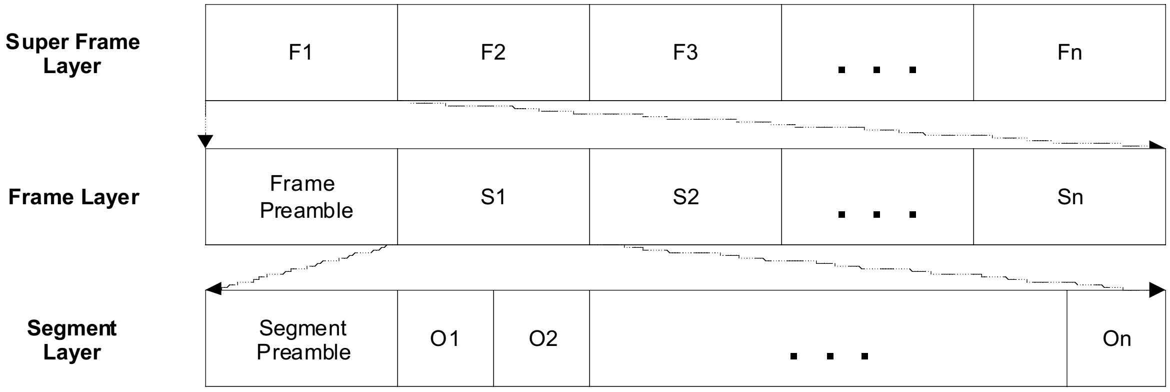

Figure 2: Adaptable Framing

Figure 2 is a simple illustration of the concept of adaptable framing. At the highest layer is a super frame composed of a number of frames. Each frame is subsequently broken down into segments at the segment layer. Within the segment layer, OFDM symbols, serve the dual purpose of basic time slots for access as well as the basic modulation symbol. With this top down methodology, many variants can be considered. For example, at the frame layer, each segment may be allocated a different OFDM modulation format. Higher capacity formats, which require greater power, may be used for short range. The longest ranges can be served by the lower capacity formats.

This multilayer framing methodology can also be used to support downlink/uplink operation and multipliexing modes (TDD, FDD or hybrids). One scenario is to use the allocate uplink and downlink transmissions at the frame layer. Preamble format may also differ between the Frame and Segment layers to optimize efficiency. Frame preambles could be designed to support coarse acquisition and segment preambles would then provide fine acquisition per OFDM mode.

## PHY Layer Signal Processing Description

### FEC

As mentioned, Ref 4 describes a concatenated coding approach. A similar approach could be used in this proposal, combining Reed Solomon coding as the outer code and convolutional as the inner code in the same manner. Standard convolutional coding (rate _, constraint length $k = 7$) with puncturing ( _ , 2/3 , _ , 5/6 , 7/8) is suggested. Interleaving to the same $I = 12$ depth, to spread burst error effects prior to Reed Solomon decoding separates the two coding blocks.

The above capability can be extended in two ways. First, the Reed Solomon block coding is made programmable. To flexibly match the PHY Layer framing and the coding strength required, both the length of the Reed Solomon codeword (n) and the length of the parity symbols ($2t = n-k$) is made selectable:
RS(n,k,t): $0 < n \le 255$; $0< 2t \le 38$.

The second technique is to combine the power of the convolutional encoding as part of a TCM concept. First the QAM constellations are broken into subsets. Next the selection of the subsets are protected by convolutional encoding. Within each subset, the symbol decision distances are doubled, affording significant processing gain. As an example, 64 QAM has four 16 point subsets. Because the convolutional encoding is used on the two bits which select the subset, the bandwidth would not increase as significantly as if all of the bits are encoded with the same code.

### QAM

A fixed QAM constellation is recommended for the signal mapping onto each active subcarrier within the same OFDM symbol. 801.11a utilizes BPSK, QPSK, 16 and 64 QAM as the underlying mappings. This proposal includes 32 and 128 QAM constellations as additional modes for greater flexibility and performance.

Both 32 and 128 QAM are utilized successfully in European cable systems to effectively raise capacity. Theory indicates that an additional 6db is required to operate at the same point as the mode is changed from 16 to 64 QAM. 32 QAM splits that difference, while 128 QAM requires 3 db more than 64 QAM. Thus in applications where 64 QAM is not achieveable, 32 QAM offers a compromise, gaining 25% more basic capacity over 16 QAM. Mean while, 128 QAM offers 17% capacity increase over 64 QAM. A perceived penalty regarding non square constellations should be mentioned though. Cable systems experience slightly longer acquisition times with these non square constellations, such as the one depicted in Figure 3. However, an OFDM system does not experience the longer acquisition penalty, as initial synchronization is not dependent on the constellation within the data part of the PHY layer frame.

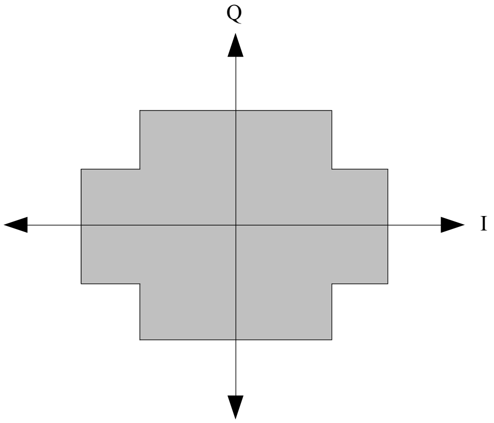

Figure 3: Non square constellation

## OFDM

The OFDM architecture of this proposal has several selectable features to optimize system capacity: active symbol length (e.g. FFT length), guard length, subcarrier masking, pilot on/off operation, and preamble format.

Multipath is expected to be significant and vary differently in different deployment scenarios for 802.16.3 systems. The OFDM waveform is inherently designed to combat this effect by introduction of a preceding guard. While multipath is not completely eliminated by this technique, it greatly weakens its effect and thereby reduces the design requirements on the equalizer. The one obvious penalty with the use of the guard is the overhead incurred by repeating part of the data transmission. Key parameters of the OFDM structure are made selectable in this proposal to meet the wide variety of multipath channels and at the same time keep system capacity high. These are summarized in Table 2.

| Parameter | Values |
|---|---|
| FFT length | 64, 256, 512 |
| Guard Length | 1/32*, 1/16*, 1/8, 1/4 (* n/a for 64 point FFT) |
| Active Subcarriers | binary on/off subcarrier mask |
| Pilot Operation<br>number of pilots | on/off<br>4/8/16/32 |
| Preamble | selected from predefined set of masks |

Table 2: Selectable OFDM Structure parameters

Having selectable parameters raises the overall strength of the OFDM system as highlighted here. More rugged multipath protection can be gained by the use of longer FFT sizes at the same guard/FFT length ratios. As an additional degree of freedom, a selectable guard length can be used to reduce the overhead incurred by the guard. Pilot operation can be turned off to raise efficiency. Typically pilots are available as a synchronization aid, but with decision directed techniques, they are not necessarily required. Finally, making use of different synchronization preambles can be used to support framing methodology. For example, different preamble lengths can be used for frame layer, (initial or coarse synchronization) or segment layer, (repeated preambles for fine synchronization).

## Example of Partial Downlink configuration

To illustrate the above proposal, segments of the frame layer may be designed to provide high capacity to users close in range. For comparative purposes with 802.11a, a 20 Mhz OFDM operational sample rate is presumed.

- OFDM: Shorter range segments: 64 QAM operation, 256 point FFT, guard length 32
  - => Approximately twice the multipath robustness due to prior symbols relative to 802.11a, but with half of the guard overhead
- FEC: TCM mode concatenated with RS(204,188)
  - => greater coding strength than RS alone; TCM has less bandwidth expansion than concatenation with typical convolutional coding

## Evaluation

The criteria of the evaluation table in the call for contribution have been satisfied. Flexibility of key parameters as outlined in this contribution permit the system to optimize performance, both in terms of system capacity and robustness. Complexity is on the same order as 802.11a systems and 802.16.1. The PHY layer contained herein is also considered 802.16.1 MAC functionality as a point of reference for interface into complete 802.16 system.

## References

Ref 1: 802.16.3-00/02r4, Functional Requirements for the 802.16.3 Interoperability Standard

Ref 2: 802.16.3c-00/16, Selection Criteria pertinent to Modulation, Equalization, Coding for the for 2-11 GHz Fixed Broadband Wireless Systems, Robert M. Ward, Jr

Ref 3: 802.16.3c-00/13, Modulation and Equalization Criteria for 2-11 GHz Fixed Broadband Wireless Systems, David Falconer and Sirikiat Lek Ariyavisitakul

Ref 4: 802.16.1-00/01 Air Interface for Fixed Broadband Wireless Access Systems