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Purpose:
This presentation is for initial phy proposals for 802.16.3 TG3

2^{ND} GENERATION OFDM PROPOSAL

FOR 802.16.3

IEEE 802.16.3c-00/38

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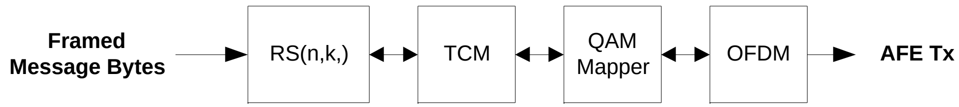
SUMMARIZING KEY BWA REQUIRMENTS

- Physical Channel requirements (Ref 1)
  - 2 to 11 Ghz Frequency Range
  - Bidirectional communications
  - Operate in multipath
  - Support up to 50 km ranges
  - Operate in multicell/sector topology
  - Low BER
- Service requirements (Ref 1)
  - Capacity
    - Up to 10 Mbps per user
    - Aggregate data rate to support multiple users simultaneously
    - Scalable growth
  - Integrated transport
    - Voice, video, data
    - Commensurate levels of QOS
  - Multiple Access capable
    - Point to Multiple Point operation
    - Easy method of service grant

PHY LAYER PROPOSAL SUMMARY

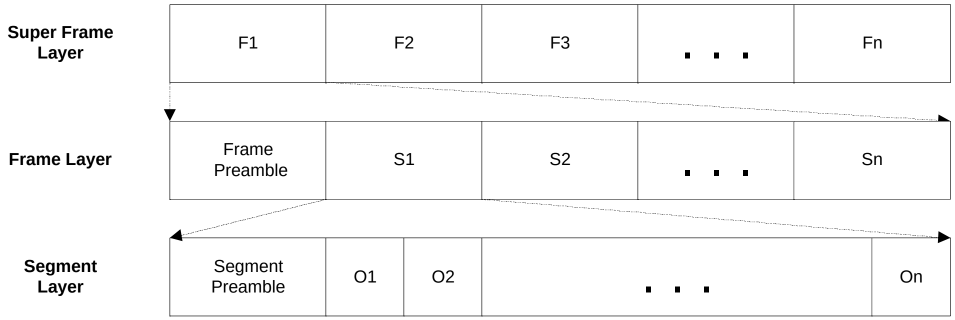
- OFDM modulation basis
  - Waveform inherently designed to mitigate multipath (Ref 2, 3)
  - Integrated processing facilitates low BER
- Concatenated FEC
  - Supports longer ranges
  - Supports low BER operation
- Multilayer Framing link protocol
  - Flexible to efficiently match bursty and non bursty traffic
- Downlink / Uplink
  - OFDM is efficient for both downlink (to users) and uplink (from users)
- Spectrum allocation
  - TDD for uplink / downlink separation
  - Scalable for different channel bandwidth needs

SIGNAL PROCESSING OVERVIEW



- Framing layer
  - Multiplex data via frame structures
  - Framing also supports use of different OFDM modes for range flexibility
- Reed Solomon
  - This outer code is concatenated with inner coding for greater range of operation
  - Selectable length to effectively match frame lengths and OFDM modes
- Use a combined coded modulation method
  - TCM or turbo code
- QAM Modes
  - Increased number of modes for greater flexibility: 2^M, M = 1, 2, 4, 5, 6, 7
- OFDM
  - Longer symbols for more rugged and efficient operation needed by BWA application
  - Key parameters made selectable for greatest flexibility
    - Guard length
    - Pilot operation
    - Active Number of subcarriers
    - Preamble

UTILIZE A FRAMING STRUCTURE TO ENHANCE MULTIPLE ACCESS AND CAPACITY



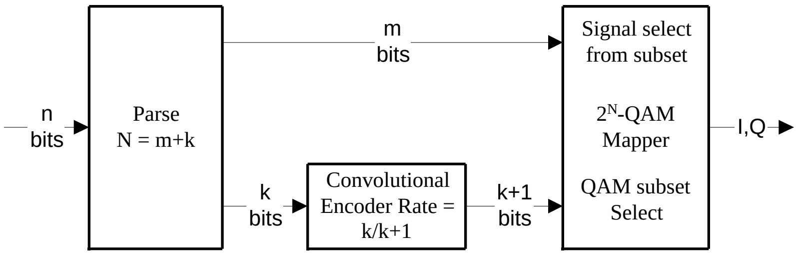
- Super Frame Layer
  - Composed of N_{frames} to match requirements at Mac/Phy layer
- Frame Layer
  - Composed of $N_{segments}$ to:
    - Frame preamble for coarse synchronization
    - QAM mode can be selected for each segment
    - Assign uplink/downlink segments to match traffic load (TDD operation)
- Segment Layer
  - Composed of $N_{OFDM\_symbols}$
    - Preamble for improved synchronization of segment
    - OFDM symbols as minimum time resolution of user assignment

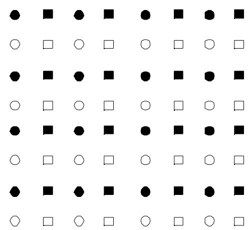
REED SOLOMON OUTER CODING

- Standard Reed Solomon code parameters
  - Galois Field: 2^8
  - Selectable Lengths to effectively match OFDM frames/symbols:
    - RS(n,k), $n \leq 256$, $k \leq 16$
  - Generator Polynomial $g(x) = \prod_{i=m}^{m+2t} \left(x + \alpha^{i}\right)$
  - Field Primitive: $x^8 + x^4 + x^3 + x^2 + 1$
- Performance
  - Capable of satisfying decoding rates needed to meet system data rates with reasonable complexity
  - Decoding latency low

BASE THE INNER CODING STRUCTURE ON A COMBINED CODED MODULATION METHOD

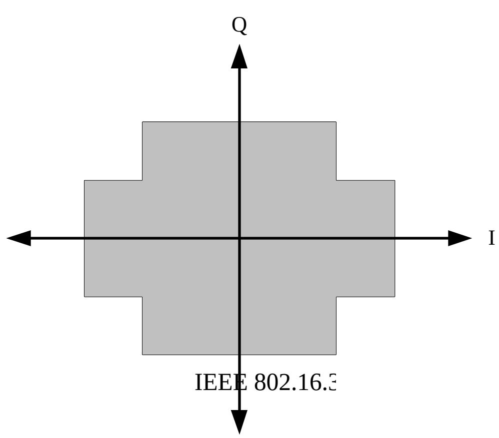
- Basic trellis coding modulation demonstrates the potential
  - Code constellations to use subsets
  - Decision regions within subsets are enlarged, thereby improving decision performance
- Simple Example for 64 QAM/OFDM
  - A parser divides n bits into m + k bits
  - k bits are encoded into k+1 bits, the coded k +1 bits select a QAM subset
  - The uncoded m bits select the constellation point within the selected QAM subset
  - Coding gain achieved since
    - Decision on subset protected by convolutional decoding
    - QAM decoding error rate within each subset is reduced since minimum distance between points is doubled
  - Specifics for 64 QAM, 4 bytes mapped to 36 bits
    - 24 bits not encoded: protected by outer coding and OFDM structure
    - 8 bits encoded to 12 bits with 2R(1/2,2/3P) (note 2/3 puncturing => 3 bits out for every two in)





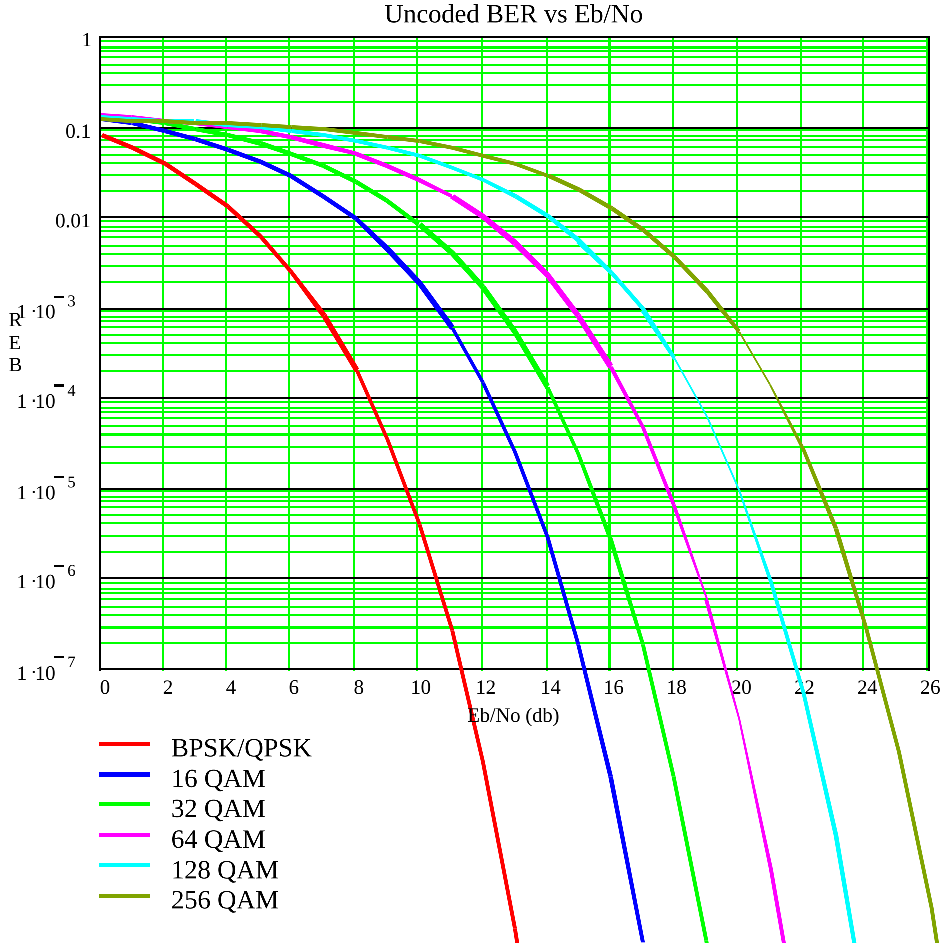
MULTIPLE QAM MODES ADD FLEXIBILITY

- Added Modes of 32 and 128 QAM
  - Feasibility of up to 64 QAM demonstrated in 802.11a, DVB-T implementations
  - Also recommended is 802.11a's BPSK, QPSK, 16 and 64 QAM modes
- Advantages of multiple modes
  - Larger constellations for increased spectral efficiency
  - Smaller constellations for greater range, more robustness
  - Increased flexibility to traffic allocation
- 32/128 constellations are standard configurations in DVB systems
  - Eliminates corner points of square constellations
  - Provides 5 and 7 bits per subcarrier respectively (4 and 6 bits for 16 and 64 QAM respectively)
  - Do not suffer same acquisition penalties in OFDM as incurred with single carrier QAM systems due to less corner energy



UNCODED BER PERFORMANCE

- More regular increase in power per QAM mode
  - 32 QAM mode splits the 6db additional power requirement to use 64 over 16 QAM
  - For approximately 3 db more power, 128 QAM relative to 64 QAM increases capacity by 17% (7/6)



COMPARING CONSTELLATION PEAK TO AVERAGE POWERS

- 32 and 128 QAM constellations also stand out as having smaller PARs relative to the next smaller constellation

M	Peak Power	P_{avg}	PAR
16	18	10	2.553
32	34	20	2.304
64	98	42	3.680
128	170	82	3.166

OFDM STRUCTURE

- Selectable parameters
  - Selectable FFT length 64, 256, 512, (1024)
    - Greater lengths offer more ruggedness, spectral rolloff efficiency
  - Selectable Guard length up to 25% of FFT length
    - Match multipath requirements
    - Guard Intervals relative to active part of symbol: 1/32, 1/16, 1/8, 1/4
  - Select OFDM parameters relative to needs within framing layer
    - For example match QAM mode
  - Selectable pilot on/off operation. If off, use alternatively
    - Distributed preambles
    - Decision feedback methodolgy to lessen need for pilots
  - Selectable active number of subcarriers
    - Avoid frequency selective interference/multipath
    - Can be used to support channelization design

FLEXIBLE DATA CAPACITY

- OFDM system
  - Larger constellations offer greater spectral efficiency to boost rates
  - Larger 512 FFT size can be used to support higher rates
  - Capacity is easily calculated (as exemplified for 802.11a's 64 QAM mode with _ coding with 54 Mbps capability)

$$bps := \frac{M \cdot N_{ASC} \cdot R_{code}}{T_{Symb}} \qquad bps = 5.4 \times 10^{7}$$

for 64 QAM, 6 bits per subcarrier	$M = 6$
Number of active subcarriers	$N_{ASC} = 48$
Coding rate	R_{code}
OFDM symbol duration	T_{Symb}

- Concatenated Coding with selectable rates
  - Punctured convolutional coding to optimize rate
  - Selectable Reed Solomon parameters to optimize rate

- System Structure
  - Multilayer structure can also be used to tailor user/system rates
  - FDMA & FDD/TDD methods

SUMMARY OF ADVANTAGES

- Improved system capacity
  - Mode flexibility allows tuning to deployment needs
  - Increased number of QAM modes provides greater spectral efficiencies
  - Framing uses modal operation efficiently
  - Longer packet capabilities
- Performance
  - Increased range
    - Concatenated TCM scheme improves link margins
  - Good synchronization
    - Distributed preambles
  - Reduced Overhead
    - Selectable guard times, pilot on/off, selectable active subcarriers
    - Framing used to minimize preamble overhead
  - Greater OFDM ruggedness
    - More subcarriers (frequrency selective impairments more easily combatted)
    - Selectable subcarriers (avoidance, aids analog filtering)
    - Guard times tunable to multipath environment
  - Longer Packets supported
    - Overall architecture more resilient to channel imperfections

EVALUATION

Item	Comments
1. Meets Systems Requirements	Yes. OFDM based proposal for bi-directional communications in 2 – 11 Ghz with capabilities to support system capacity and reliability needs.
2. Channel Spectrum efficiency	Very Efficient. OFDM technology with underlying multimode QAM supports higher spectrum efficiency. Concatenated RS-convolutional coding with selectable coding rates to afford best match to channel needs.
3. Simplicity of implementation	Moderately simple. Utilizes proven technologies in current implementations. Also, inherent mode flexibility allows tailoring implementation to meet specific cost/performance criteria.
4. Spectrum Resource Flexibility	Uses spectrum flexibly. Supports TDD/FDD, Hybrid channel access methodologies.
5. System Service flexibility	Flexibility is good. OFDM subcarriers can support logical assignment of services.
6. Protocol Interface Complexity	Supports simple interfaces.
7. Reference System Gain	Allows optimization of System Gain as OFDM technology supports frequency selective gain and via coding technique.
8. Robustness to Interference	Moderate. Reducing QAM mode for longer range diminishes interference outside immediate cell.
9. Robustness to Channel Impairments	OFDM is inherently designed to mitigate multipath. Preamble can be designed to support antenna diversity.
10. Robustness to radio impairments	Linearity is required due to use of higher order constellations. OFDM provides an integrating gain for synchronization.
11. Support of advanced antenna techniques	Not specifically addressed by this proposal. However, does not prohibit.
12. Prior Standards	Supports standards based operation.

REFERENCES

- 802.16.3-00/02r3, Functional Requirements for the 802.16.3 Interoperability Standard
- 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
- 802.16.3c-00/13, Modulation and Equalization Criteria for 2-11 GHz Fixed Broadband Wireless Systems, David Falconer and Sirikiat Lek Ariyavisitakul