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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-01/07

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OUTLINE

- ¥ Review of proposal, IEEE 802.16.3c-00/38
- ¥ More detailed assessments in support of proposal refinements

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 for different channel bandwidths/rates
  - — Integrated transport
    - ¥ Voice, video, data
    - ¥ Commensurate levels of QOS
  - — Multiple Access capable
    - ¥ Point to Multiple Point operation
    - ¥ Easy method of service grant

ADDITIONAL PHY REQUIREMENTS ASSUMED

¥ Signal and Channel Bandwidths

— Signal bandwidths per US and ETSI suggested bandwidths shown in lefthand table

¥ Ref **IEEE 802.16.3c-00/34 as presented at IEEE 802.16.3 Nov 2000**

— 802.11a signal bandwidth assumed also, shaded in grey

Signal Bandwidth (Mhz)
1.5
1.75
3
3.5
6
7
8
12
14
16
28

¥ Required multipath protection: 10 µsec peak

— Multiple sources, one is **IEEE 802.16.3c-00/34**

- **OFDM symbol duration**
  - **32** µsec maximum

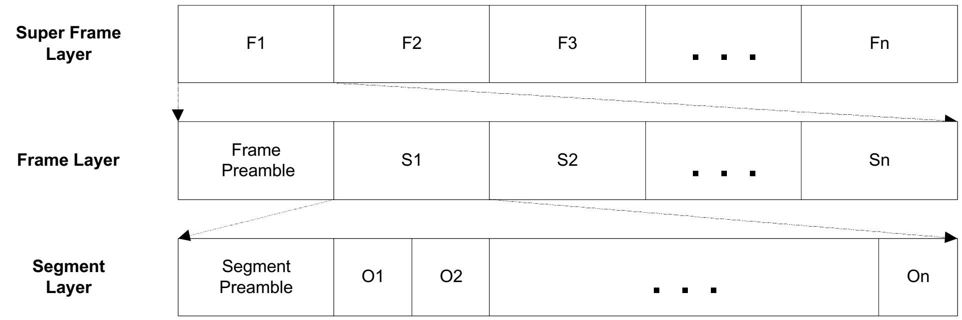
PHY LAYER PROPOSAL SUMMARY

- ¥ OFDM modulation basis
  - — Waveform inherently designed to mitigate multipath (Ref 2, 3)
  - — Flexible FFT scaling for multiple channel bandwidths
- ¥ Downlink / Uplink
  - — OFDM is efficient for both downlink (to users) and uplink (from users)
  - — Allows for multiple access via assignment of users to subcarriers
- ¥ Concatenated FEC
  - — Supports longer ranges
  - — Supports low BER operation
- ¥ Multilayer Framing link protocol
  - — Flexible to efficiently match bursty and non bursty traffic
- ¥ Spectrum allocation
  - — TDD for uplink / downlink separation
  - — Scalable for different channel bandwidth needs

SIGNAL PROCESSING OVERVIEW

- Framing layer
  - Multiplex data via frame structures/subcarriers
  - Framing also supports use of different OFDM modes for range flexibility
- OFDM
  - Longer symbols for more multipath ruggedness and efficient operation needed by BWA application
  - Key parameters made selectable for greatest flexibility
    - Guard length — greater multipath protection
    - Active Number of subcarriers — programable for capacity and access flexibility
    - Preamble — supports distributed nature and uplink/downlink operation
    - FFT size — flexible to support multiple channel bandwidths
    - Pilot operation — selectable for minimized overhead
- QAM Modes
  - Increased number of modes for greater flexibility: 2^M, M = 1, 2, 4, 5, 6, 7
- Coding
  - Baseline: Concatenated convolutional — Reed Solomon; Selectable length to effectively match frame lengths and OFDM modes
  - Optional: Turbo Codes

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
    - Access slots (requests, ranging)

MORE DETAILED ASSESSMENTS

- ¥ Concepts and trades are developed for consideration by 802.16.3 Task Group 3
- ¥ Outline
  - — FFTsize
    - ¥ trade and recommendations are described leading to a 4X and 8X BWA system proposals
  - — The need for enhanced coding is addressed
    - ¥ subcarrier fade/errors per OFDM symbol.

CHOICE OF FFT SIZE DRIVEN BY TWO CONSIDERATIONS

- Multipath consideration
  - A guard length on order of 2/3 significant multipath peak duration
  - Subcarrier spacing for adequate diversity against frequency selective fading
  - The level of tolerable multipath depends on modulation type
  - Deployment scenario (antenna, sectorization) affects the nature of the multipath
  - The length of the guard selected affects the FFT size. Attempting to minimize overhead suggests the guard length should be no more than _ the FFT size

- Data Transmission consideration
  - Minimizing slot times for efficient system access can be a goal. This can have an impact on OFDM symbol durations.
    - Up/down link transmission speeds
    - Multiple access for many users
  - Allocated channel bandwidths
    - Subcarrier spacing
    - Sampling rate
  - Support synchronization
    - Timing
    - Frequency
      - Smaller FFTs (e.g greater subcarrier spacing) are more tolerant to frequency offsets

USING SOLELY A 64 POINT FFT IS NOT RECOMMENDED

- Design criteria
  - Be similar to 802.11a system (20 Mhz, 64 point FFT, ≈ 16 Mhz signal bandwidth, 25% guard; shaded in grey), yet support the required signal bandwidths
  - Channel bandwidth allocations based on an integer submultiple (2,4,8) of 802.11a system for 16 Mhz and below
- Advantages
  - Fixed FFT, same as 802.11a
- Disadvantages
  - 32 Mhz may not be supported well
  - Varying subcarrier spacing implies different performance
  - Varying sample rates impact analog front end design (AFE)
  - Will not satisfy 10 μsec multipath design goal

Channel BW (Mhz)	Sample BW (Mhz)	Sample Period (nsec)	FFTsize	Subcarrier Spacing (khz)	No. of Active Subcarriers	Symbol Duration with 25% guard (usec)
1.5	2.5	400	64	39.0625	32	32
1.75	2.5	400	64	39.0625	38	32
3	5	200	64	78.125	32	16
3.5	5	200	64	78.125	38	16
6	10	100	64	156.25	32	8
7	10	100	64	156.25	38	8
8	10	100	64	156.25	43	8
12	20	50	64	312.5	32	4
14	20	50	64	312.5	38	4
16	20	50	64	312.5	52	4
28	32	31.25	64	500	47	2.5

802.11a OFDM MULTIPATH OBSERVATIONS

¥ Signaling parameters for 802.11a
  - 20 Mhz Channelization
  - 4 µsec symbol duration
  - 0.8 µsec guard length
  - 64 point FFT

¥ Multipath protection on the order of 1_ guard length
  - For 64 QAM, on the order of 1.2 µsec multipath protection with better than 90% P_{acq} wi/o antenna diversity
  - Better performance results for lower ordered constellations

¥ Satisfying 802.16.3 10 µsec multipath need
  - Use approximately 6 to 7 µsec guard time
  - With a 25% guard overhead, total OFDM symbol duration of 32 to 35 µsec results

MULTIPATH PROTECTION FOR 20 MHZ CHANNELS VS FFTSIZE

¥ What would be a good choice for both FFT size and guard length?

— Assume a 20 Mhz Channel, which has basic sample period of 50 nsec

— Consider FFT sizes: 64, 128, 256, 512, 1024

— Consider guard lengths of 1/16th, 1/8th, 1/4th

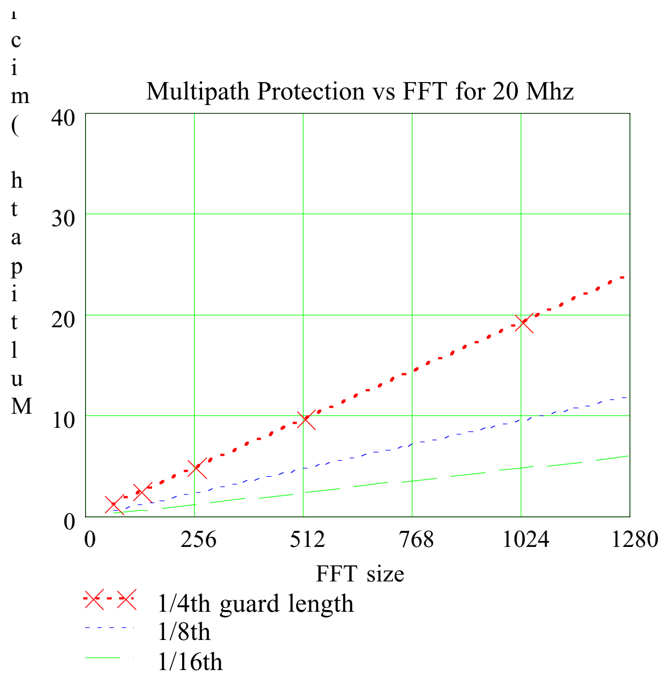
— Consider 10 sec multipath protection as the goal

¥ Good Choice is 512 point FFT with _ guard length

— Approximately 9.6 µsec protection provided (1_ x 128 x 50nsec)

— _ guard overhead may be acceptable

— Total symbol duration of 32 µsec {(512+128)*50 nsec} is assumed reasonable



MULTIPATH PROTECTION WITH FLEXIBLE FFT SIZE

- Flexibility in FFT size supports good scaling across channel bandwidths
  - 10 µsec peak multipath supported
  - Allows common subcarrier spacing
  - Allows for common symbol and guard duration
  - Good use of available subcarriers. Margin remains for pilots and filtering requirements
  - Sample rates are multiple of base rate.
    - Promotes single AFE design
    - Baseband processing with either decimated processing or single long FFT with reduced number of subcarriers possible

Channel BW (Mhz)	Sample BW (Mhz)	Sample Period (nsec)	FFT size	Subcarrier Spacing (khz)	No. of Active Subcarriers	Guard % of active FFT symbol duration	Guard (usec)	Symbol Duration (usec)
1.5	2.5	400	64	39.0625	32	25%	6.4	32
1.75	2.5	400	64	39.0625	37	25%	6.4	32
3	5	200	128	39.0625	63	25%	6.4	32
3.5	5	200	128	39.0625	73	25%	6.4	32
6	10	100	256	39.0625	125	25%	6.4	32
7	10	100	256	39.0625	146	25%	6.4	32
8	10	100	256	39.0625	167	25%	6.4	32
12	20	50	512	39.0625	250	25%	6.4	32
14	20	50	512	39.0625	292	25%	6.4	32
16	20	50	512	39.0625	410	25%	6.4	32
28	40	25	1024	39.0625	583	25%	6.4	32

CAPACITY IS SIMILAR TO 802.11a SYSTEM

- Capacities for 64 QAM are shown
  - BPSK: Divide by 6 for its capacities (approximately)
  - QPSK: Divide by 3
  - 16QAM: Multiply by 2/3
- Occupied bandwidth
  - Number of subcarriers x spacing is less than channel bandwidths shown. For example 1.25 Mhz is occupied in the 1.5 Mhz channel
  - Simply used the 52/64 subcarrier occupancy ratio of 802.11a
- Shaded shows nearly same as 802.11a capacity for same parameters
  - 54 Mbps => 64 QAM, rate _ coded

Channel BW (Mhz)	Sample BW (Mhz)	Sample Period (nsec)	FFT size	Subcarrier Spacing (khz)	No. of Active Subcarriers	Guard % of active FFT symbol duration	Guard (usec)	Symbol Duration (usec)	64 QAM (bits per subcarrier)	Rate 3/4 coded capacity (Mbps)
1.5	2.5	400	64	39.0625	32	25%	6.4	32	6	3.94
1.75	2.5	400	64	39.0625	37	25%	6.4	32	6	4.64
3	5	200	128	39.0625	63	25%	6.4	32	6	7.73
3.5	5	200	128	39.0625	73	25%	6.4	32	6	9.14
6	10	100	256	39.0625	125	25%	6.4	32	6	15.33
7	10	100	256	39.0625	146	25%	6.4	32	6	18.28
8	10	100	256	39.0625	167	25%	6.4	32	6	21.23
12	20	50	512	39.0625	250	25%	6.4	32	6	30.66
14	20	50	512	39.0625	292	25%	6.4	32	6	36.56
16	20	50	512	39.0625	410	25%	6.4	32	6	53.16
28	40	25	1024	39.0625	583	25%	6.4	32	6	72.98

TWO 802.16.3 SYSTEMS ARE SUGGESTED BASED ON THESE CONCEPTS

- ¥ 8X system (shown previously and again on next slide)
  - — Offers approximately 10 µsec multipath protection. Name this the 8x Multipath system
  - — Uses 32 µsec Symbols
  - — Provides for various bandwidths
  - — Similar peak user rate relative to 802.11a system
- ¥ 4X system (tabulated on next slide)
  - — Based on 16 µsec Symbols
  - — Offers approximtely 5 µsec multipath protection. Name this 4x Multipath system
  - — Provides for various bandwidths
  - — The same peak rates, but _ symbol times for improved access rates
- ¥ 802.11a system, for comparison
  - — Offers approximately 1.25 µsec multipath protection
  - — Using 4 µsec Symbols
  - — Fixed bandwidth of 20 Mhz
  - — Peak user rate of 54 Mbps

8X & 4X 802.16.3 SYSTEMS

8X

Channel BW (Mhz)	Sample BW (Mhz)	Sample Period (nsec)	FFT size	Subcarrier Spacing (khz)	No. of Active Subcarriers	Guard % of active FFT symbol duration	Guard (usec)	Symbol Duration (usec)	64 QAM (bits per subcarrier)	Rate 3/4 coded capacity (Mbps)
1.5	2.5	400	64	39.0625	32	25%	6.4	32	6	3.94
1.75	2.5	400	64	39.0625	37	25%	6.4	32	6	4.64
3	5	200	128	39.0625	63	25%	6.4	32	6	7.73
3.5	5	200	128	39.0625	73	25%	6.4	32	6	9.14
6	10	100	256	39.0625	125	25%	6.4	32	6	15.33
7	10	100	256	39.0625	146	25%	6.4	32	6	18.28
8	10	100	256	39.0625	167	25%	6.4	32	6	21.23
12	20	50	512	39.0625	250	25%	6.4	32	6	30.66
14	20	50	512	39.0625	292	25%	6.4	32	6	36.56
16	20	50	512	39.0625	410	25%	6.4	32	6	53.16
28	40	25	1024	39.0625	583	25%	6.4	32	6	72.98

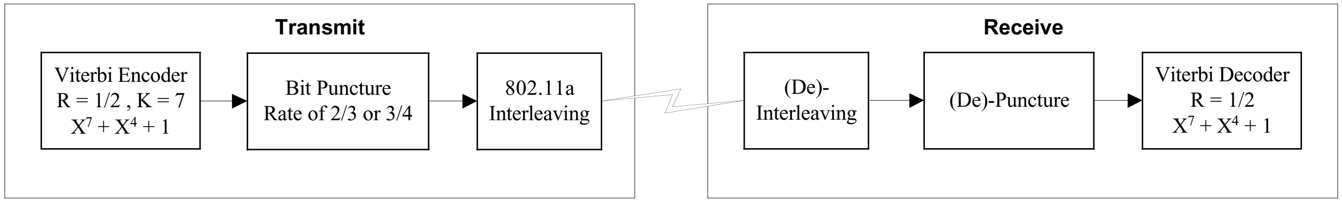
4X

Channel BW (Mhz)	Sample BW (Mhz)	Sample Period (nsec)	FFT size	Subcarrier Spacing (khz)	No. of Active Subcarriers	Guard % of active FFT symbol duration	Guard (usec)	Symbol Duration (usec)	64 QAM (bits per subcarrier)	Rate 3/4 coded capacity (Mbps)
1.5	5	200	64	78.125	16	25%	3.2	16	6	3.38
1.75	5	200	64	78.125	19	25%	3.2	16	6	4.22
3	5	200	64	78.125	32	25%	3.2	16	6	7.88
3.5	5	200	64	78.125	37	25%	3.2	16	6	9.28
6	10	100	128	78.125	63	25%	3.2	16	6	15.47
7	10	100	128	78.125	73	25%	3.2	16	6	18.28
8	10	100	128	78.125	84	25%	3.2	16	6	21.38
12	20	50	256	78.125	125	25%	3.2	16	6	30.66
14	20	50	256	78.125	146	25%	3.2	16	6	36.56
16	20	50	256	78.125	205	25%	3.2	16	6	53.16
28	40	25	512	78.125	292	25%	3.2	16	6	73.13

FURTHER IMPLEMENTATION DETAILS

- ¥ Sample rates are binary multiples of base rates
  - — Allows for single A/D sample rate design and matching AFE
  - — Allows simple decimation post A/D or Operation with single maximum FFT size and subcarrier masking
- ¥ Smaller FFTs can be simply output from maximum size
  - — Use a base radix core and loop control for required number of stages
  - — Reduce number of loops for smaller FFT sizes
- ¥ Use of larger FFT can support out of band suppression requirements
  - — Faster rolloffs
- ¥ Multipath
  - — Two guard lengths provided in the preceding tables. In each case, this was _ of Active OFDM symbol duration (e.g. FFT length)
  - — Make guard length as a ratio selectable: _, 1/8, 1/16. Allows tailoring to various deployment scenarios
- ¥ Pilots
  - — 8X & 4X systems baselined with same overhead of pilots as 802.11a (4/64)
  - — Can be reduced

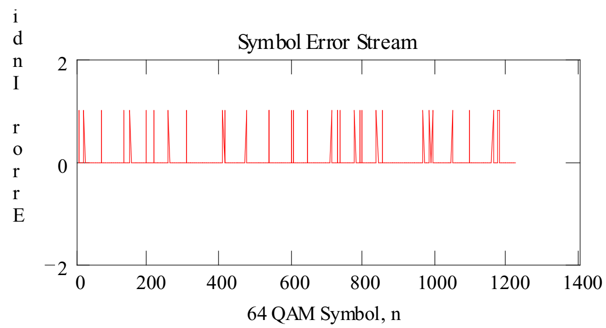
802.11a CODING FUNCTIONAL OVERVIEW



- ¥ Convolutional Coded system
  - — A standard rate = _ , constraint length K = 7 encoding combined with rate 2/3rd and _ puncturing is specified
  - — Bit interleaved per OFDM symbol, mitigating frequency selective error effects
  - — Synchronized and flushed according to PDU structure
  - — Unspecified implementation parameters
    - ¥ Trellis depth
    - ¥ Quantization
- ¥ CRC
  - — Pass/Reject on completed phy packet

802.11a CODING PERFORMANCE OVERVIEW

- AWGN
  - Decoding performance is standard
  - Data rates are easily supported
- Multipath
  - Depending on the nature, error bursts can occur causing multiple subcarrier QAM symbol errors per OFDM symbol.
  - Convolutional decoder can be expected to eliminate errors to a certain degree
    - On the order of less than 2 to 3 x 10^{-3} BER
    - And, error bursts do not exceed constraint length & trellis depth design capabilities of specific designs (two to three QAM symbol errors per OFDM symbol should be typical)



  - Example performance
    - 802.11a — Can cause severe NLOS channel, exceeding convolutional decoder capability
    - SUI - #2 and #3 — 23 dB EsNo; set taps at 5 @ _, -10 @ 1 µsec in both cases
      - Exceeds 0.8 µsec guard capability of 802.11, but suitable case
      - Flat fades of #3 not handled by decoder, must be handled by other means (e.g. antenna diversity)
      - #2 has K factor = 5, multipath easily mitigated (< 10^{-3} BER)

CODING RECOMENDATIONS

- ¥ Baseline
  - — Same standard rate _ convolutional coding
    - ¥ Puncturing rates expanded to include 5/6, 7/8
  - — Reed Solomon
    - ¥ During heavy multipath, packet is reliably demodulated, but a few QAM symbol errors can occur for 64 QAM which may exceed the decoder s capability. For smaller constellations, less errors result.
    - ¥ Make selectable the Reed Solomon protection to support the different FFT sizes and different number of errors depending on constellation size
      - — RS(n,k), $n \leq 256$, $k \leq 16$
  - — Interleaving
    - ¥ Make use of 802.11a interleaving concept. That is, maximizing diversity across subcarriers. Modify to support different FFT sizes.
    - ¥ Trade use of additional interleaving between viterbi decoder and Reed Solomon decoder
- ¥ Optional
  - — Turbo Coding is offered by other contributions

SUMMARY OF KEY FEATURES

- Level of multipath is selectable
  - Scalable FFT size, guard length permits tailoring to scenario
- Scalable capacities
  - Multiple channel bandwidths
  - Multiple rates per channel
- Various mechanisms for multiple access
  - Multilayer link framing for TDD or FDD or Hybrid operation
  - Demand assignment of subcarriers
- Consistent interface for MAC
  - Regular symbol duration for all channel bandwidths allows for easy time slot management
  - Modes organized as in 802.11a for simple control interface
- Performance is consistent across channel bandwidths
  - Regular subcarrier spacing for similar BER/PER performance
  - Concatenated coding for enhanced packet error rate performance

EVALUATION

¥ Systematic design considerations were made in the preceding to support the criteria of interest to 802.16.3

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. 8x and 4x scalable design were describe, which provide similar data capacities to 802.11a, support varying channel bandwidths, and afford greater multipath protection.
2. Channel Spectrum efficiency	Very Efficient. Gross bit rates in excess of 802.11a were presented. 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. Signal design supports consistent radio front end designs, expected to be the cost driver for both basestations and subscriber stations, for different deployment scenarios. 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. A wide variety of system configurations was presented, supporting different data rates and offering similar performance.
5. Spectrum Resource Flexibility	Flexibility is good. Standard interfaces of the network topology and protocol access points are planned.
6. System Spectrum Efficiency	Up to 128 QAM is recommended, providing 7 bits/subcarrier. The use of consistent subcarrier spacing across channels and data framing techniques lends itself to efficient utilization of the system capacity. Channelized operation is provided for, supporting frequency reuse. TDD operation was described for uplink/downlink operation in single frequency channels.
7. Protocol Interface Complexity	Supports the standard 802.16.3 interfaces required.
8. Reference System Gain	Allows optimization of System Gain as OFDM technology supports frequency selective gain and via coding technique.
9. Robustness to Interference	Moderate. Reducing QAM mode for longer range diminishes interference outside immediate cell.
10. Robustness to Channel Impairments	OFDM is inherently designed to mitigate multipath. Preamble can be designed to support antenna diversity.
11. Robustness to radio impairments	Linearity is required due to use of higher order constellations. OFDM provides an integrating gain for synchronization.
12. Support of advanced antenna techniques	Not specifically addressed by this proposal. However, does not prohibit.
13. Prior Standards	Supports standards based operation.