Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [DS-UWB Proposal Update]
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Abstract: [Response to NO voter comments and feedback regarding the DS-UWB (Merger #2) Proposal]

Purpose: [Provide technical information to the TG3a voters regarding DS-UWB (Merger #2) Proposal]

Outline

- DS-UWB
- CSM as base mode
- MB-OFDM
  - Recommended Modifications

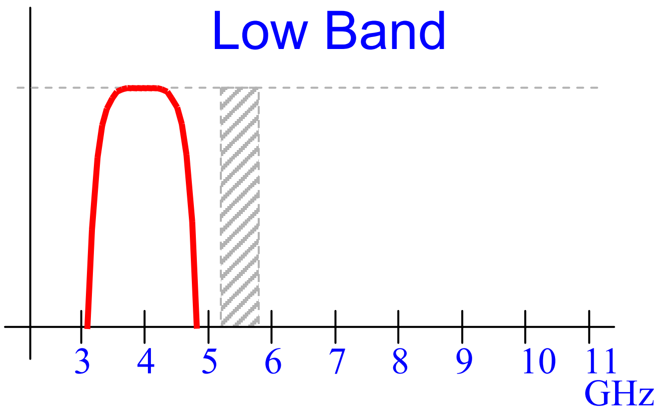
Update of Merger #2 Proposal

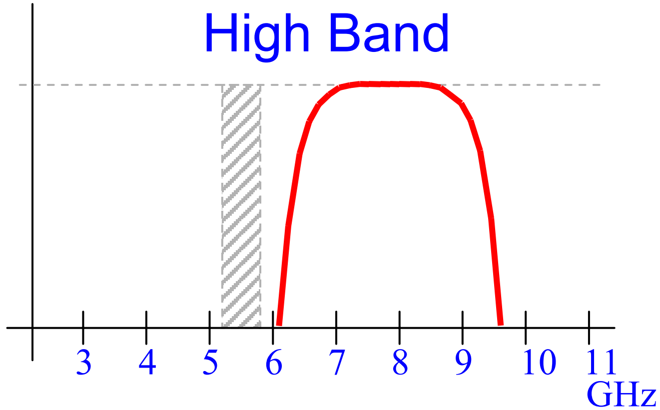
- Our Vision: A single PHY with multiple modes to provides a complete solution for TG3a
- Base mode that is required in all devices, used for control signaling: “CSM”
  - Beacons and control signaling
- Higher rate modes also required to support 110 & 200+ Mbps:
  - Compliant device can implement *either* DS-UWB or MB-OFDM
- Provides wider range of technical options for UWB applications
- Increases options for technology innovations and Regulatory flexibility

Overview of DS-UWB Improvements

- Support for much higher data rates
  - BPSK modulation using variable length spreading codes
- At same time, much lower complexity and power
  - Essential for mobile & handheld applications
  - Digital complexity is 1/3 of previous estimates, yet provides good performance at long range and high rates at short range
- Harmonization & interoperability with MB-OFDM through a Common Signaling Mode (CSM)
  - A single multi-mode PHY with both DS-UWB and MB-OFDM
  - Best characteristics of both approaches with most flexibility

DS-UWB Operating Bands & SOP





- Each piconet operates in one of two bands
  - Low band (below U-NII, 3.1 to 4.9 GHz)
  - High band (optional, above U-NII, 6.2 to 9.7 GHz)
- Support for multiple piconets
  - Classic spread spectrum approach
  - Acquisition uses unique length-24 spreading codes
  - Chipping rate offsets to minimize cross-correlation

Relative Complexity

Architecture	Contains Equalizer ?	Estimate Source	Gate Count Est. (at 85.5 MHz)
(Superceded) MBOK 16-finger rake	No	MBOA	624,000
(Superceded) MBOK CMF, 1-bit ADC	No	Previous DS-UWB	395,000
(Superceded) MBOK CMF, 1-bit ADC	No	MBOA	604,000
MB-OFDM 4-bit ADC with equalizer	Yes	MBOA	455,000
DS-UWB 16-finger rake	**YES**	**New DS-UWB**	**184,000 130,000***
DS-UWB CMF 1-bit ADC	**YES**	**New DS-UWB**	**189,000 135,000***

Performance in Multipath

110 Mbps	DS-UWB 90% Outage	**MB-OFDM** 90% Outage	DS-UWB Mean of Top 90%	**MB-OFDM** Mean of Top 90%
CM1	13.5	11.4	16.9	14.0
CM2	11.7	10.7	14.6	13.2
CM3	11.4	11.5	13.4	13.8
CM4	10.8	10.9	13.0	13.8

Simulation Includes:

- **16 finger rake** with coefficients quantized to 3-bits
- 3-bit A/D (I and Q channels)
- RRC pulse shaping
- DFE trained in < 5us in noisy channel (12 Taps)
- Front-end filter for Tx/Rx + 6.6 dB Noise Figure
- Packet loss due to acquisition failure

Common Signaling Mode (CSM) to Support Interoperability of Multiple UWB Physical Layers

Allowing Many Flavors of UWB Signaling to Peacefully and Cooperatively Coexist

What Is The Goal?

- A common signaling mode (CSM) arbitrates between multiple UWB Phy's
  - Multiple UWB Phy's will exist in the world
    - DS-UWB & MB-OFDM are first examples
  - We need an "Etiquette" to manage peaceful coexistence between the different UWB Phy's – a CSM does this
    - Planned cooperation (i.e. CSM) gives far better QoS and throughput than allowing train wreck
  - A CSM improves the case for international regulatory approval
  - A CSM provides flexibility/extensibility within IEEE standard
    - Allows future growth & scalability
    - Provides options to meet diverse application needs
    - Enables interoperability and controls interference

CSM Is Consistent With Common Goals

– e.g. **MBOA Mission**:

"To develop the best overall solution for ultra-wideband based products in compliance with worldwide regulatory requirements, ***to ensure peaceful coexistence with current and future spectrum users,*** and to provide the most benefits to the broadest number of end consumers."

Ref: (online): http://www.multibandofdm.org, 25 Feb 2004.

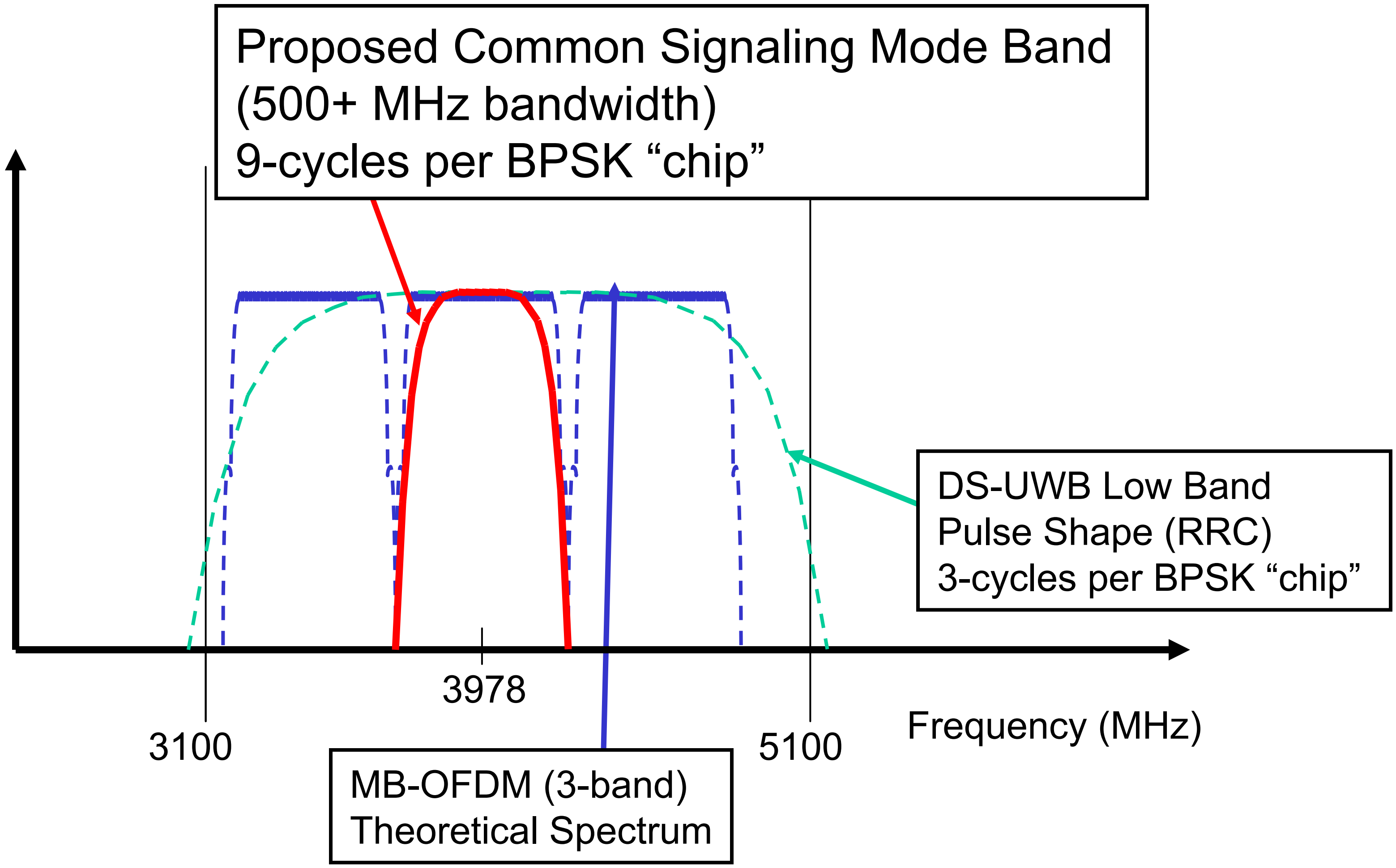
What Is The Problem?

- People's perception
  - Erroneous thought: DS-UWB and MB-OFDM can't interoperate simply or usefully
    - Too much additional complexity
    - Low-complexity CSM is inadequate for MAC control
    - MAC control thru CSM is too hard
  - Erroneous conclusion: It is an insolvable problem
- The problem: That perception is wrong

Is There A Low-Complexity CSM? YES

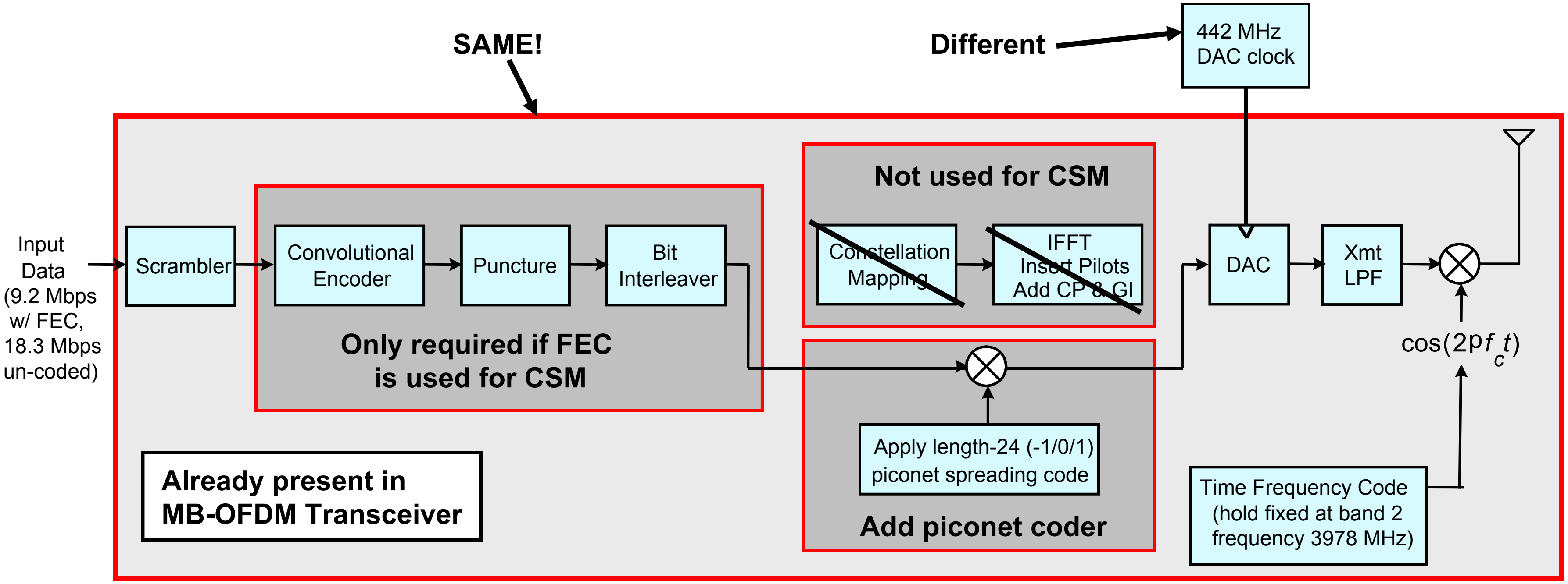
- The keys to CSM interoperability are already built-in
  - Trivial additional hardware is needed
    - 100's of transistors, NOT 10,000's of gates
- MB-OFDM already has a full DS xmit and rec
  - Used for synchronization
    - Xmit IFFT is turned off (DAC is fed with +/- BPSK codes)
    - Rec FFT is turned off (Real-time correlator in receiver decodes DS)
- Hardware modifications for CSM are easy
  - Match center frequency of DS-UWB with an MB-OFDM band
  - Force chip-rates to be compatible
  - Agree on codes, FEC, and preamble

What Does CSM Look Like?
One of the MB-OFDM bands!



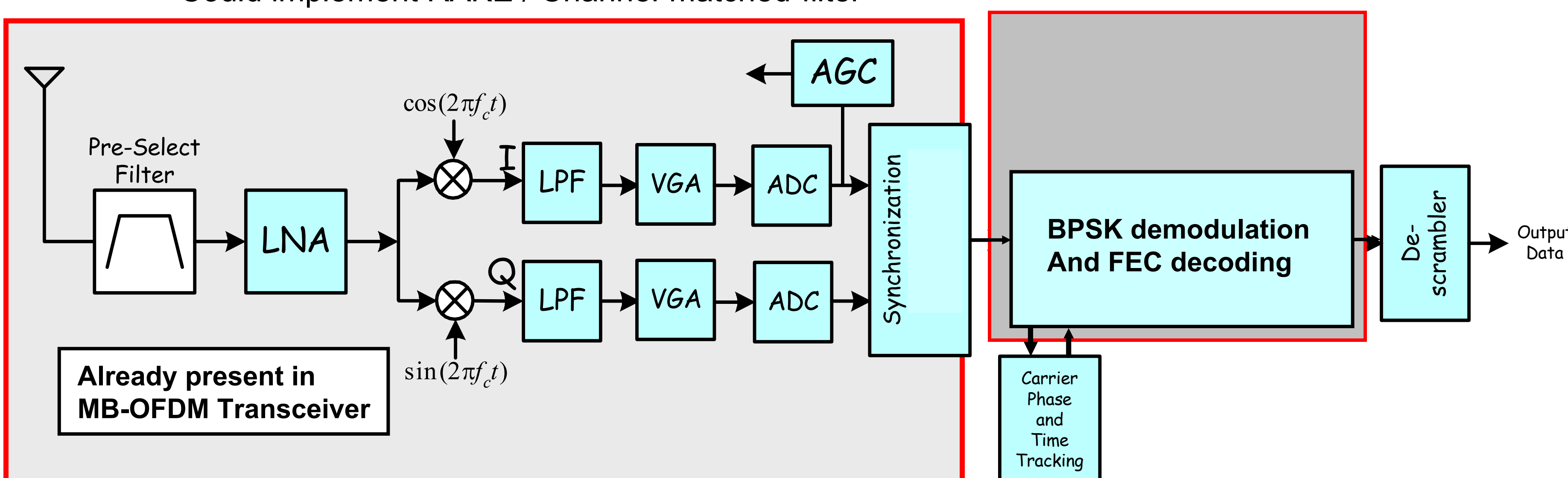
MB-OFDM Xmit Already Transmits DS

- ***NO/FEW additional Gates Needed***
  - Use real-valued (single) DAC clocked at 442 MHz (less than design speed)
  - Use length-24 ternary (-1/0/1) per-piconet spreading code
    - This would be matched in DS-transmitter with a 3*24 = 72 length code
  - Result is BPSK signal with 520+ MHz bandwidth (at -10 dB points)
  - BPSK "chip" is a "pulse" of nine cycles of a sinusoid at 3978 MHz



MB-OFDM Receiver Already Recovers DS

- ***NO/FEW additional Gates Needed***
  - Data processing speed is much lower due to reduced data rates (10x slower)
  - No Equalization needed (symbol interval is 55ns, almost no ISI, hence 60ns CP)
  - Proposed MB-OFDM receiver already contains the needed blocks
    - MB-OFDM receiver contains both time-domain and frequency-domain processing
    - Time domain processing of BPSK signal is straight-forward
      - MB-OFDM already contains correlator blocks used for synchronization functions
    - Frequency domain processing possible using FFT engine for fast correlation
      - MB-OFDM receiver uses I&Q sampling with 4-5 bits resolution, could be under-clocked at 442 MHz
      - Could implement RAKE / Channel-matched-filter

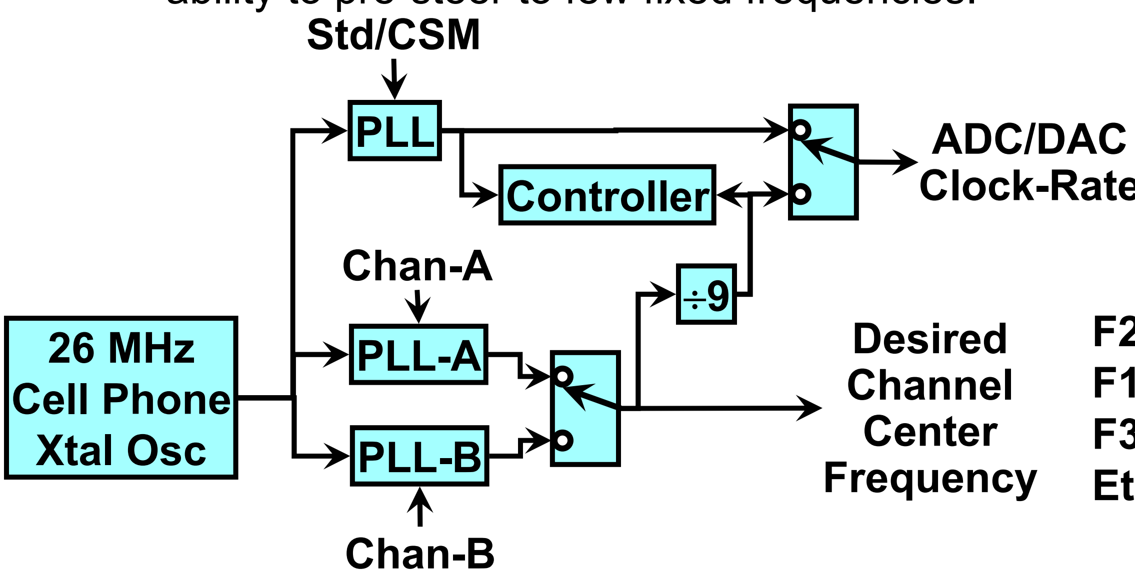


Can It Be Even Less Complex? YES

- The clock-generation diagram proposed for MB-OFDM is unlikely to work at low-cost
  - Too many SSB stages
    - Low % frequency offsets means filtering is difficult
      - Thus the SSB (image reject mixer) requirement
    - Too many I/Q signals with high precision requirements
      - 1 degree phase match & .5 dB amplitude match
    - Results in deleterious leakage terms
      - Leakage is susceptible to drift out of compliance over time
- We designed CSM to allow ***lower complexity*** common clocking structure
  - Runs both DS & MB-OFDM
  - Does not require multiple difficult SSB stages
  - Use ultra-low-cost 26 MHz cell-phone crystal
  - Simple PLL's, All frequencies are an integer multiple of 26 MHz
    - 572 MHz DAC, by 128 tones ► 4.46875 MHz per tone ►223.8 ns burst
    - 572/34 = 59.44 ns blank-CP & gap for switching
    - 572/(128+34) = 283.2168 ns cycle time
    - CSM mode runs DAC at 442 MHz to give 9 RF-cycles (at 3978 MHz) per BPSK pulse

Low Cost & Power Frequency Generator

- Ping-Pong PLL's running from 26 MHz cell-phone crystal
  - Simple PLL – Not fractional-N – All freq's are a multiple of 26 MHz
  - Relaxed VCO phase-noise requirement – very wide loop bandwidth
  - Eliminates spurious responses and feed-through in SSB mixers
    - Eliminates complexity of generating I and Q of all signals
    - Eliminates hard-to-maintain tolerances (phase and mag) of I & Q signals
- Supports any number of bands (1 to 14 hops)
  - Ping-Pong of 2 PLL's can cover all bands
  - 283ns Settling-time is achievable due fast 38ns/cycle (26 MHz) core reference and ability to pre-steer to few fixed frequencies.



Fstd = 22*26 = 572 MHz
Fcsm = 17*26 = 442 MHz

F2 = 153*26 = 3*3*17*26 = 3978 MHz
F1 = F2-Fdac = 131*26 = 3406 MHz
F3 = F2+Fdac = 175*26 = 4550 MHz
Etc.

Protocol Requirements Are Easy

- Low-power mechanism
  - high percent of time sleeping
- Provide provisions for
  - Discovery beacon
  - Capability-passing
  - Scheduling of different PHY’s
    - QoS
    - Time-slot allocation
- All are minimal changes to MAC

Is CSM PHY Adequate To Support MAC? YES

- CSM is less than 1% of time budget
- ~ 5 dB of extra link margin
  - Assumes 10 Mbps after FEC
  - Bandwidth is dropped by 1/3 and data-rate is dropped by 1/10 to end up with about 5 dB extra margin
    - Relative to 110 Mbps baseline MB-OFDM proposal mode
- 18 Mbps raw

Would the CSM mode need to use Forward Error Correction? YES

- Based on link budget analysis, an un-coded CSP mode (18 Mbps) would have less margin at 10 m than the 110 Mbps MB-OFDM
- But we want the CSM to be *more* robust, not less…
- Adding FEC to the CSM can result in as much as 5 dB coding gain
  - Would require a common FEC code
    - Pick one of the codes from the two proposals, or
    - Choose a different code with relatively low complexity

- At this time there is not a code that is common to both MB-OFDM & DS-UWB proposals
  - MB-OFDM uses punctured codes based on a rate 1/3 k=7 code
  - DS-UWB uses punctured codes based on a rate 1/2 k=7 code

- Following slides show link budgets for a few sample FEC choices
  - Ideally, CSM will have more link margin (e.g. be more robust) than mandatory data rate modes (110 Mbps)

Link Budget Spreadsheet for CSP with Several Possible FEC modes

	CSP Uncoded	CSP 5/8 k=7	CSP 1/2 k=7	CSP 1/2 k=6	CSP 1/2 RM	MB-OFDM 110 Mbps
FEC Rate	1.0	0.6	0.5	0.5	0.5	0.3
Data Rate	18.3	11.5	9.2	9.2	9.2	110.0
Theoretical Tx Power	-14.8	-14.8	-14.8	-14.8	-14.8	-10.3
Transmit Power (dBm)	-16.7	-16.7	-16.7	-16.7	-16.7	-10.8
Total Path Loss (dB)	64.2	64.2	64.2	64.2	64.2	64.2
Received Power	-80.9	-80.9	-80.9	-80.9	-80.9	-75.0
Noise Power per Bit	-101.4	-103.4	-104.4	-104.4	-104.4	-93.6
Noise Figure	6.6	6.6	6.6	6.6	6.6	6.6
Total Noise Power	-94.8	-96.8	-97.8	-97.8	-97.8	-87.0
Code Gain	0.0	4.9	5.2	4.8	2.5	5.6
Required Eb/No	9.6	4.7	4.4	4.8	7.1	4.0
Implementation Loss	2.5	2.5	2.5	2.5	2.5	2.5
Link Margin at 10 m	1.7	8.7	9.9	9.5	7.2	5.5
Sensitivity	-82.7	-89.6	-90.9	-90.5	-88.2	-80.5

FEC Conclusions

- Conclusion is that rate ½ convolutional code with k=6 provides best complexity versus performance
  - ¼ the complexity
  - Much better match to handheld devices & high speed

Conclusions

- We have incorporated a common signaling mode (CSM)
- It allows co-existence and interoperability between DS-UWB and MB-OFDM devices
  - Prevents coexistence problems for two different UWB PHYs
  - Provides interoperability in a shared piconet environment
- CSM supports 802.15.3 MAC
  - Achieves desired 10 Mbps data rates and robust performance
- Requires very low additional cost/complexity
  - Almost no additional complexity for either MB-OFDM or DS-UWB

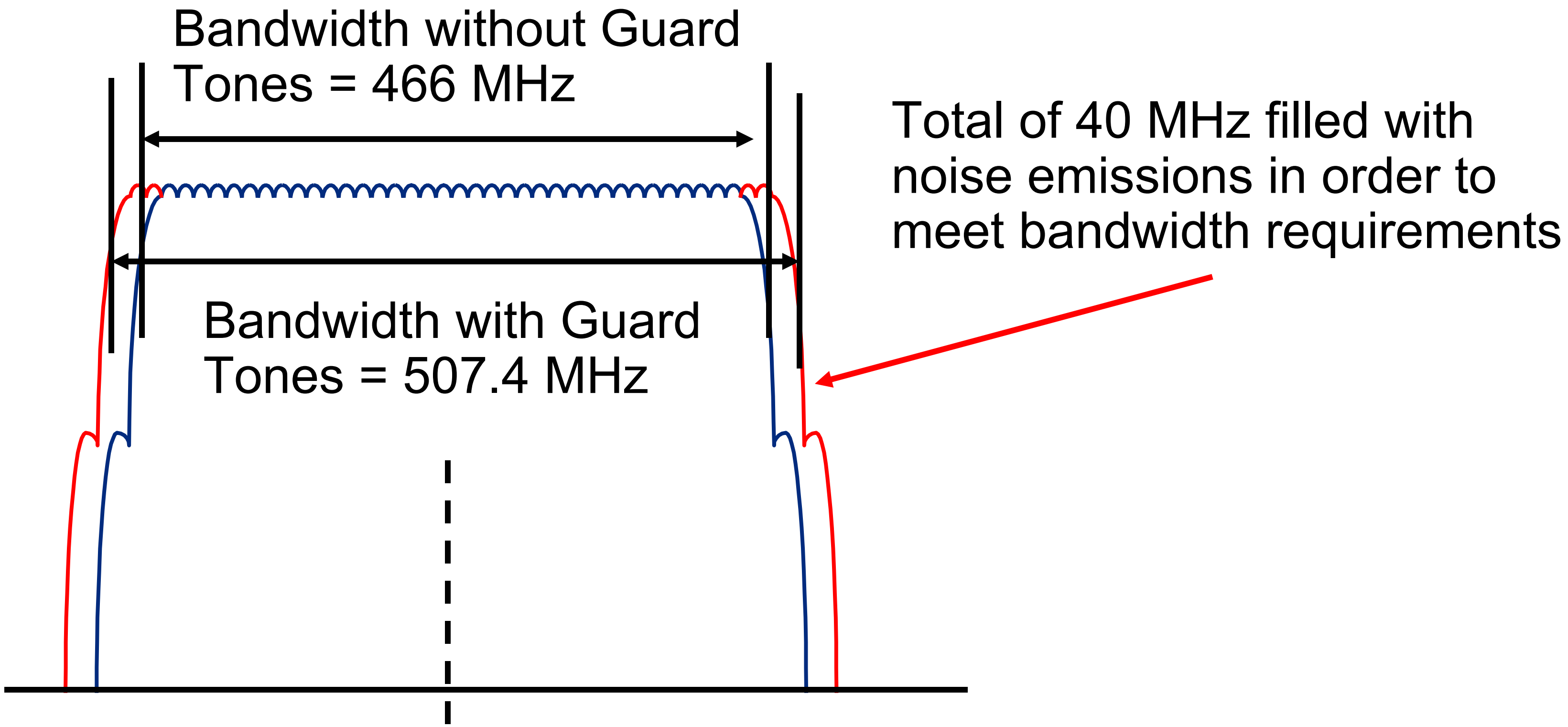
MB-OFDM Modifications Motivation

- Modifications recommended for two reasons:
  - Bandwidth considerations
    - MB-OFDM use of guard tone to meet FCC 500 MHz minimum instantaneous BW
    - Recent statements by NTIA have raised concerns about techniques used to meet minimum BW requirements
  - Harmonization with DS-UWB for use in a single multi-mode PHY based on a CSM
    - Changes in frequency plan to move Band #2 to center frequency of 3978 MHz

MB-OFDM use of Guard Tones

- MB-OFDM relies on Guard Tones to meet 500 MHz
  - Each MB-OFDM "hop" consists of a single OFDM symbol
  - 122 modulated carriers, each with 4.125 MHz BW
  - Total BW = 123* 4.125 MHz = 507.4 MHz
  - 5 tones on either edge of symbol are "guard tones" which carry no data
  - Total BW without guard tones is 113 * 4.125 MHz = 466 MHz
  - If guard tones are not transmitted → MB-OFDM fails to meet the 500 MHz requirement
  - Authors state "Used to meet 500 MHz BW requirement"
    - Document 802.15-03/267r6, dated September 2003, page 13
  - Per MB-OFDM proposal, guard tones are simply carriers modulated with PN sequence to make them look noise-like

Use of Noise to Meet BW Requirements



Guard Tones Relax Filter Constraints

- MB-OFDM proposers state that the use of guard tones is justified by the desire to ease filter implementation constraints
  - Result is a less complex implementation
- But, easing of filter requirements does not require *transmission of noise* on the guard tones
- It only requires that *data is not transmitted* on guard tones
- The simple solution to not transmit tones at all

Use of Noise to Meet BW Requirements

- Cited by TG3a “NO” voters in earlier confirmation vote as problematic
  - No technical changes made to rectify concerns
- Recent comments by NTIA in FCC Rulemaking (FNPRM)
  - Manufacturers are required to minimize emissions as much as practicable
  - Specific addition of noise to increase bandwidth in order to meet UWB minimum 500 MHz requirement is unacceptable
  - Should be grounds for FCC rejection of certification
- Compounded by the fact most MB-OFDM guard bands fall in restricted bands → intentional emissions are specifically prohibited to protect sensitive systems

NTIA Comments on Using Noise to meet FCC 500 MHz BW Requirement

- NTIA comments specifically on the possibility that manufacturer would intentionally add noise to a signal in order to meet the minimum FCC UBW 500 MHz bandwidth requirements:

  "Furthermore, the intentional addition of unnecessary noise to a signal would violate the Commission's long-standing rules that devices be constructed in accordance with good engineering design and manufacturing practice."

- And:
  - "It is NTIA's opinion that a device where noise is intentionally injected into the signal should never be certified by the Commission."

- Source: NTIA Comments (UWB FNPRM) filed January 16, 2004

available at http://www.ntia.doc.gov/reports.html

FCC Rules Regarding Unnecessary Emissions

- FCC Rules in 47 CFR Part 15 to which NTIA refers:

"§ **15.15 General technical requirements.**

(a) An intentional or unintentional radiator shall be constructed in accordance with good engineering design and manufacturing practice. Emanations from the device shall be suppressed as much as practicable, but in no case shall the emanations exceed the levels specified in these rules."

Recommended MB-OFDM Modifications

- Specific recommendations to rectify bandwidth issues:
  - Frequency Plan
    - Change spacing from 528 MHz to 572 MHz
    - Center frequencies: 3406 + 572(n+1) MHz
    - 12 total frequencies defined
  - No transmissions on guard tones (resulting bandwidth is now bandwidth is 505 MHz)
- Support for required data rates:
  - Increase symbol rate to 3.3 MHz
  - FEC code: k=6 code with puncturing: ½, 5/8, ¾
  - “Spreading rates”
    - 3x (110 Mbps), 2x (205 Mbps), 1x (495 Mbps)

Conclusions

- Our Vision: A single PHY with multiple modes to provides a complete solution for TG3a
- Base mode that is required in all devices, used for control signaling: “CSM”
  - Beacons and control signaling
- Higher rate modes also required to support 110 & 200+ Mbps:
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