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

Submission Title: [DS-UWB Proposal Update]
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Re: []

Abstract: [Technical update on DS-UWB (Merger #2) Proposal]

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

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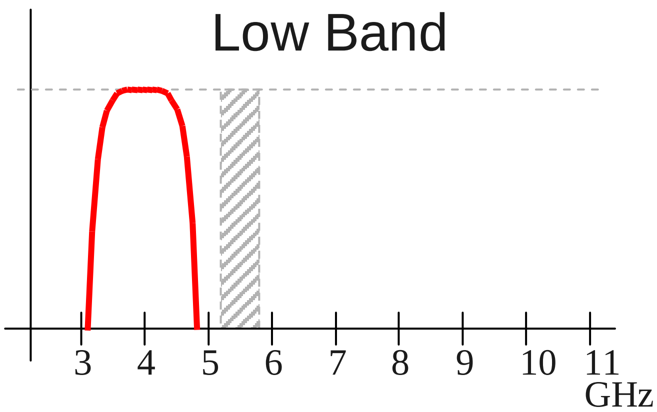
Outline

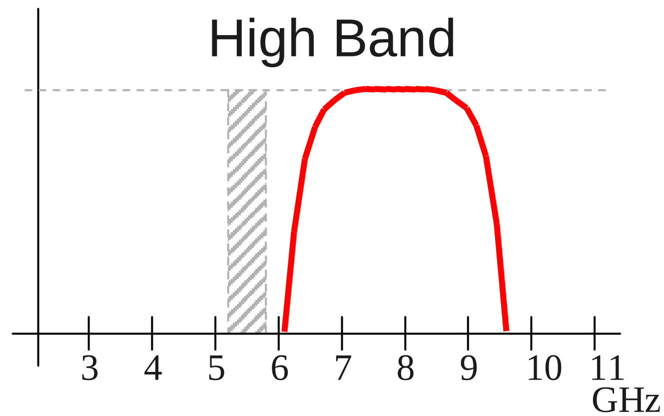
- Merger #2 Proposal & Performance Overview
- Scalability
- A commitment to compromise for TG3a

Key Features of DS-UWB

- Based on true Ultra-wideband principles
  - Large fractional bandwidth signals in two different bands
  - Benefits from low fading due to wide bandwidth (>1.5 GHz)
- An excellent combination of high performance and low complexity for WPAN applications
  - Support scalability to ultra-low power operation for short range (1-2 m) very high rates using low-complexity or no coding
  - Performance exceeds the Selection Criteria in all aspect
  - Better performance and lower power than any other proposal considered by TG3a

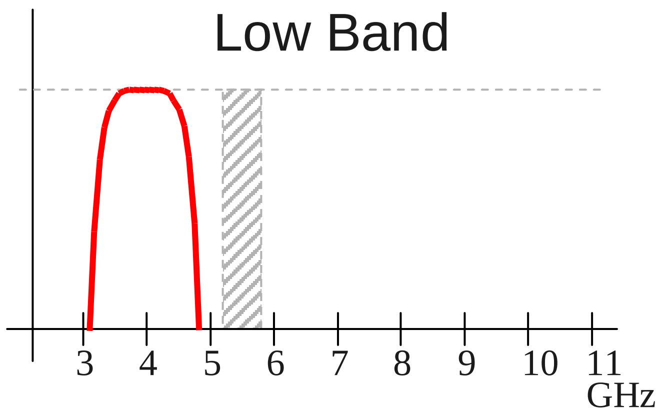
DS-UWB Operating Bands

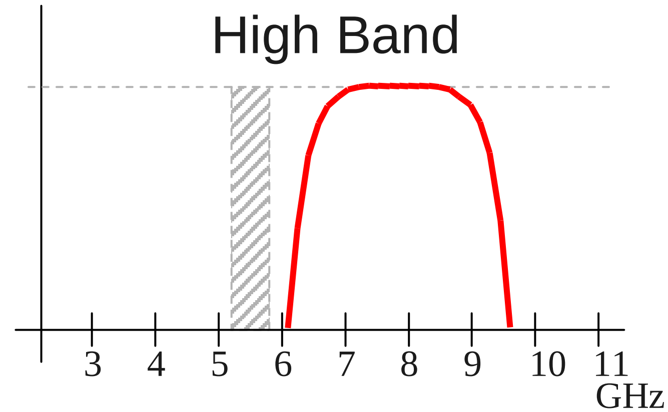




- Each piconet operates in one of two bands
  - Low band (below U-NII, 3.1 to 4.9 GHz) – Required to implement
  - High band (optional, above U-NII, 6.2 to 9.7 GHz) – Optional
- Different “personalities”: propagation & bandwidth
- Both have ~ 50% fractional bandwidth

DS-UWB Support for Multiple Piconets





- Each piconet operates in one of two bands
- Each band supports up to 6 different piconets
- Piconet separation through low cross-correlation signals
  - Piconet chip rates are offset by ~1% (13 MHz) for each piconet
  - Piconets use different code word sets

Data Rates Supported by DS-UWB

Data Rate	FEC Rate	Code Length	Symbol Rate
28 Mbps	½	24	55 MHz
55 Mbps	½	12	110 MHz
110 Mbps	½	6	220 MHz
220 Mbps	½	3	440 MHz
330 Mbps	½	2	660 MHz
500 Mbps	¾	2	660 MHz
660 Mbps	1	2	660 MHz
1000 Mbps	¾	1	1320 MHz

Similar Modes defined for high band

Range for 110 and 220 Mbps

Channel Model	90% outage range 110Mbps	90% outage range 220Mbps
AWGN	23.4m	16.5m
CM1	14.0m	9.7m
CM2	11.9m	8.1m
CM3	12.4m	7.9m
CM4	11.8m	7.4m

Range for 500 and 660 Mbps

Channel Model	500Mbps 90% outage range	660Mbps 90% outage range*
AWGN	8.5m	9.1m
CM1	4.3m	4.2m
CM2	3.7m	3.2m

•This result if for code length = 1, rate ½ k=6 FEC
•Additional simulation details and results in 15-04-483-r5

Ultra High Rates

Channel Model	Range 1Gbps	Range 1.33Gbps
AWGN	5.2m	2.5m
CM1 mean	2.7m	-
CM1-90%	0.0m	-
CM1-85%	1.7m	-
CM1-80%	2.3m	-
CM1-70%	3.1m	-

Scalability

- Baseline devices support 110-200+ Mbps operation
  - MB-OFDM device
    - Reasonable performance in CM1-CM4 channels
    - Complexity/power consumption as reported by MB-OFDM team
  - DS-UWB device
    - Equal or better performance than MB-OFDM in essentially every case
    - Lower complexity than MB-OFDM receiver
- What about:
  - Scalability to higher data rate applications
  - Scalability to low power applications
  - Scalability to different multipath conditions
  - Scalability to higher frequency bands

High Data Rate Applications

- Critical for cable replacement applications such as wireless USB (480 Mbps) and IEEE 1394 (400 Mbps)
- High rate device supporting 480+ Mbps
  - DS-UWB device uses shorter codes (L=2, symbol rate 660 MHz)
    - Uses same ADC rate & bit width (3 bits) and rake tap bit widths
    - Rake: use fewer taps at a higher rate or same taps with extra gates
    - Viterbi decoder complexity is ~2x the baseline k=6 decoder
    - Can operate at 660 Mbps without Viterbi decoder for super low power
    - Current proposal scales to 1 Gbps in low band, 2 Gbps in high band
  - MB-OFDM device
    - 5-bit ADCs required for operation at 480 Mbps
    - Increased internal (e.g. FFT, MRC, etc) processing bit widths
    - Viterbi decoder complexity is ~2x the baseline k=7 decoder (twice the complexity of k=6 decoder, ***8 times*** the complexity of k=4 decoder)
    - Increased power consumption for ALL modes (55, 110, 200, etc.) results when ADC/FFT bit width is increased

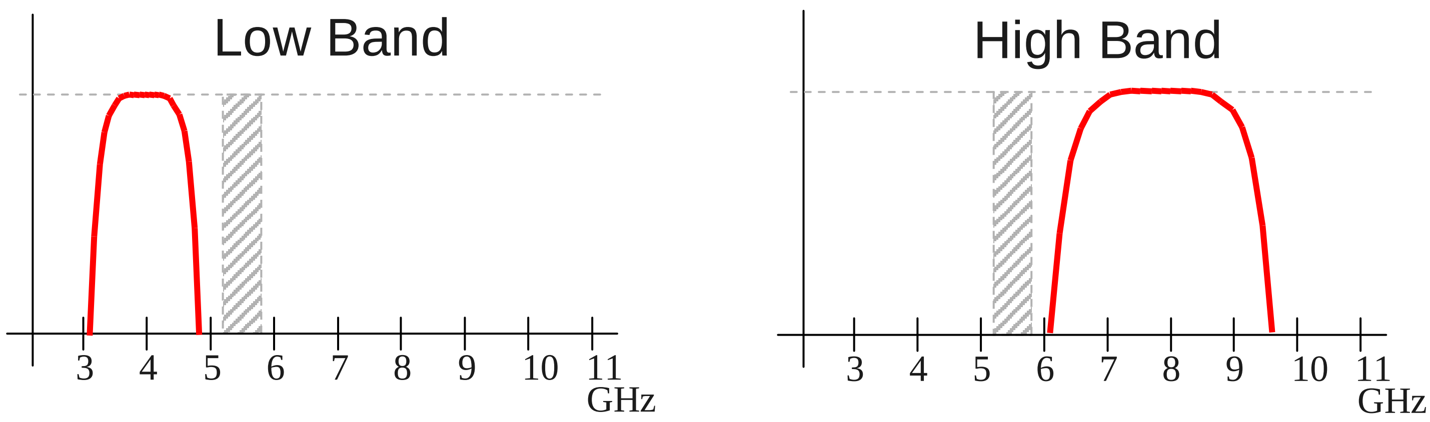
Low Power Applications

- Critical for handheld (battery operated) devices that need high rates
  - Streaming or file transfer applications: memory, media players, etc.
  - Goal is lowest power consumption and highest possible data rates in order to minimize session times for file transfers
- Proposal support for scaling to lower power applications
  - DS-UWB device
    - Has very simple transmitter implementation, no DAC or IFFT required
    - Receiver can gracefully trade-off performance for lower complexity
    - Can operate at 660 Mbps without Viterbi decoder for super low power
    - Also can scale to data rates of 1000+ Mbps using L=1 (pure BPSK) or 4-BOK with L=2 at correspondingly shorter ranges (~2 meters)
  - MB-OFDM device
    - Device supporting 480 Mbps has higher complexity & power consumption
    - MB-OFDM can reduce ADC to 3 bits with corresponding performance loss
    - It is not clear how to scale MB-OFDM to >480 Mbps without resorting to higher-order modulation such as 16-QAM or 16-PSK
      - Would result in significant loss in modulation efficiency and complexity increase

Scalability to Varying Multipath Conditions

- Critical for handheld (battery operated) devices
  - Support operation in severe channel conditions, but also…
  - Ability to use less processing (& battery power) in less severe environments
- Multipath conditions determine the processing required for acceptable performance
  - Collection of time-dispersed signal energy (using either FFT or rake processing)
  - Forward error correction decoding & Signal equalization
- Poor: receiver always operates using worst-case assumptions for multipath
  - Performs far more processing than necessary when conditions are less severe
  - Likely unable to provide low-power operation at high data rates (500-1000+ Mbps)
- DS-UWB device
  - Energy capture (rake) and equalization are performed at symbol rate
  - Processing in receiver can be scaled to match existing multipath conditions
- MB-OFDM device
  - Always requires full FFT computation – regardless of multipath conditions
  - Channel fading has Rayleigh distribution – even in very short channels
  - CP length is chosen at design time, fixed at 60 ns, regardless of actual multipath

Scalability to Other Portions of UWB Bands



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  - Low band (below U-NII, 3.1 to 4.9 GHz) – Mandatory
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Performance in Higher Bands

- DS-UWB
  - Center frequency is twice as high => lose 6dB.
  - 2 x Bandwidth => 2 x Total power => gain 3dB
  - Expect overall loss of 3dB w.r.t. low band in AWGN.
  - 3dB loss equates to a distance loss factor of $\sqrt{2}$.
  - AWGN distance for 220Mbps in low band is 16.5m => 11.7m AWGN in high band.
  - Although there is a loss of 3dB in AWGN, the loss turns out to be less in multipath because of the greater frequency diversity (see backup slides or 04/483 for details)
- MB-OFDM
  - No specific simulations or even estimates of performance in higher bands
  - Does not scale to wider bandwidths, this would cause even greater "burst" interference effects using the "TFC" approach

DS-UWB: The Best Solution

- We have presented a proposal superior to any others considered by TG3a
  - Lower complexity
  - Higher performance
  - Satisfies all applications requirements to 1+ Gbps
  - Scalable to other application spaces and regulatory requirements
    - Multi-Gbps for uncompressed video/transfer applications
    - Low rate/low complexity applications – many DS-type approaches are under consideration by TG4a
  - Compliant with all established regulations & proposed regulations
    - Lowest interference effects for other systems
    - OOB emissions well below any proposed limits
    - Capability to support other regulatory restrictions

Compromise: No other Options

- We have made significant improvements to the DS-UWB proposal over the last two years to address voter concerns
  - Multiple mergers
  - Significant improvements in March 2004 based on comments of Merger #1 (MB-OFDM) authors
  - Multiple cycles of resolving “No” comments
- Nevertheless, a number of voters have not voted to confirm this proposal
  - However, 54% approval was achieved on the last confirmation vote
- Given this, the prospects for Merger#1 proposal to be selected as the sole technology in the TG3a baseline draft are very low

Previous Compromise Efforts

- The DS-UWB authors & supporters have proposed multiple approaches to achieve a compromise standard for TG3a
  - Two optional independent PHYs in one standard
  - Two optional PHYs with a common signaling mode to coordinate & interoperate
  - A singly PHY with a required (TBD) base mode and two high rates modes
- In the past, all compromise proposal have been rejected by the authors of Merged Proposal #1
  - Little meaningful feedback, no counter-proposals offered
  - Only response is “Customers have indicated preference for a single PHY standard” (04/0641r1)
  - This position defies the reality that there will be multiple forms of UWB technology in the marketplace
  - This position will not lead to any path forward for TG3a

A Commitment to Compromise

- The DS-UWB authors are committed to working for compromise between the two differing approaches under consideration
- We will consider all reasonable proposals for compromise submitted by any TG3a voters
  - Examples of unreasonable compromise suggestions:
    - “Drop all DS-UWB and use only MB-OFDM,” or
    - “MB-OFDM is mandatory, DS-UWB is optional”
- We urge all TG3a voters to hold ***both*** proposal teams accountable to active and meaningful participation in compromise discussions and/or activities

Future Compromise Activities

- Possible compromise activities to pursue closure
  - Extended compromise discussions this week – ~4 hours of agenda time available during “Technical Contributions” period
  - Teleconferences between meetings
- Accountability options?
  - “Expiration date”:
    - Select 2-option approach if no better approach is developed by a specific date, or
    - More drastic: terminate PAR if no compromise found
  - Other penalties for “non-participation”

A Framework for Compromise

- A Base Mode common to all 15.3a devices
- Negligible impact on native MB-OFDM or DS-UWB piconet performance
- Negligible complexity increase over baseline MB-OFDM-only or DS-UWB-only implementations
- Advantages
  - Moving the TG3a process to completion
  - Mechanism to avoid inter-PHY interference when these high rate UWB PHYs exist in the marketplace
  - Potential for interoperation at higher data rates

Conclusions: DS-UWB

- DS-UWB has superior performance in all multipath conditions
- Scalability to ultra-high data rates of 1+ Gbps
- High performance / low complexity implementation supports all WPAN applications
  - Mobile and handheld device applications
  - WPAN & multimedia applications
- Full & committed support for compromise efforts to reach consensus for a baseline draft

Back up slides

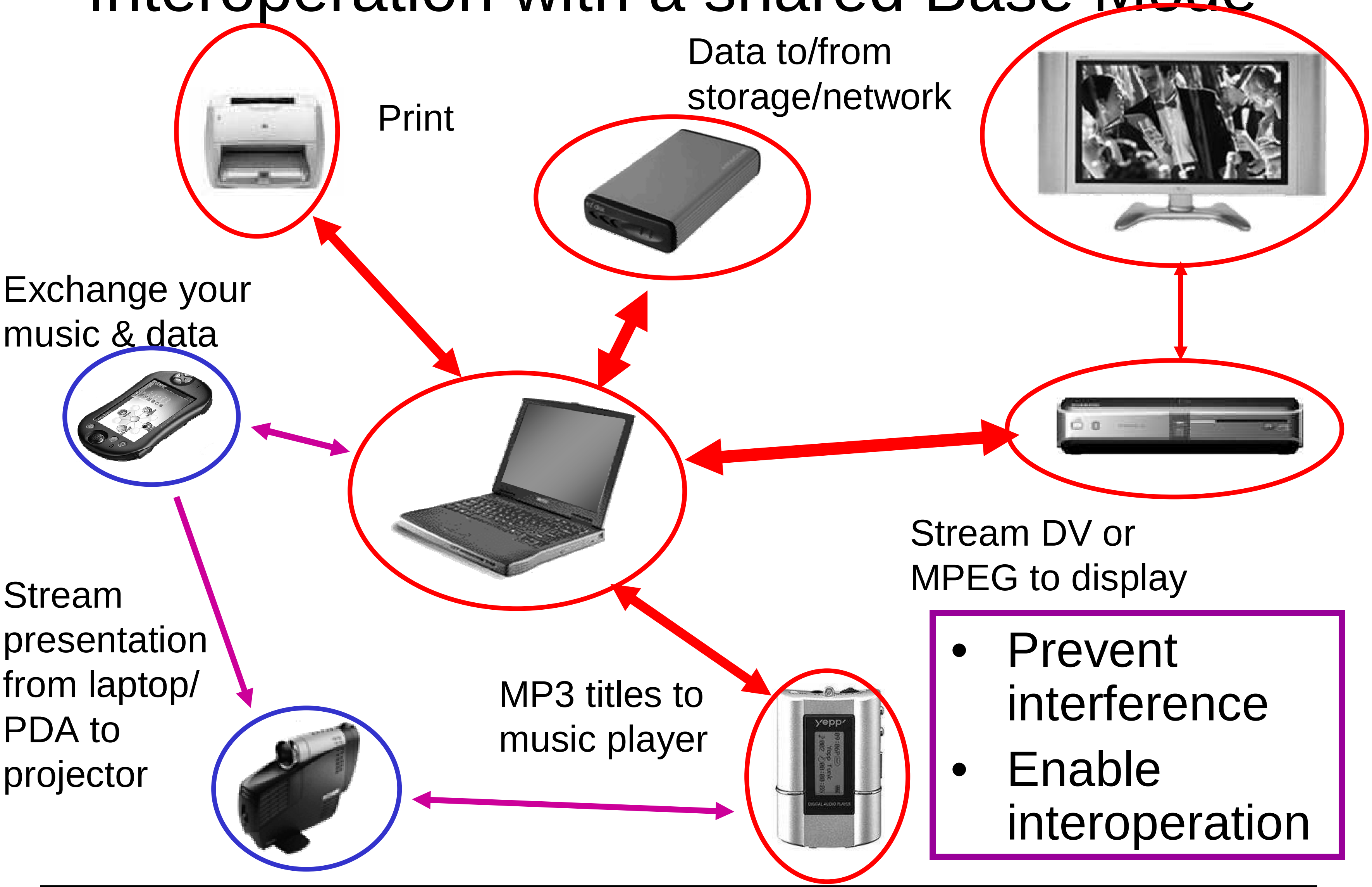
Impact on MB-OFDM Performance of a Base Mode for Coordination

- Multiple piconet modes are proposed to control impact on MB-OFDM or DS-UWB piconet throughput
  - More details available in 15-04-0478-r1
- Native MB-OFDM mode for piconets enables full MB-OFDM performance without compromise
  - Beacons and control signaling uses MB-OFDM
  - Impact of BM signaling is carefully limited & controlled
    - Less than 1% impact on capacity from BM beaconing
    - Association and scheduling policies left to implementer
- Performance of BM receiver in MB-OFDM device
  - Does not constrain MB-OFDM device range performance
  - Does not limit association time or range for MB-OFDM devices

Impact on MB-OFDM Complexity of the Specific CSM Base Mode

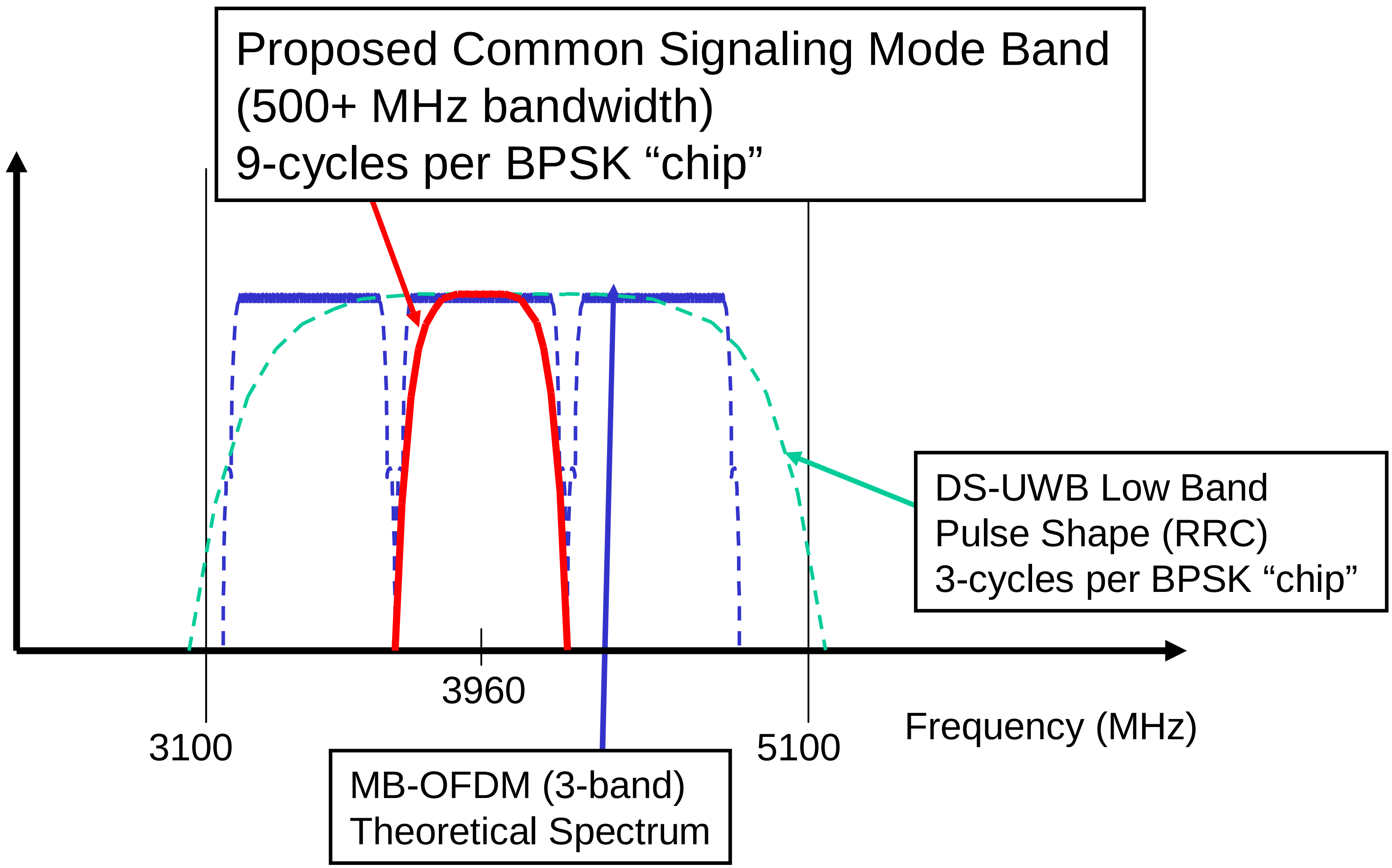
- The CSM proposal is one specific example of a possible shared Base Mode
  - Others are possible
- Very little change to the MB-OFDM receiver
  - Negligible change to RF front-end
  - No requirement to support 2 convolutional codes
    - No additional Viterbi decoder required
    - Non-directed CSM frames can use multiple codes
  - Low complexity for multipath mitigation
    - No requirement to add an equalizer
    - No requirement for rake
    - CSM receiver performance is acceptable without either

Interoperation with a shared Base Mode



- Prevent interference
- Enable interoperation

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



Higher Data Rates Possible for CSM

- CSM waveform can provide higher data rates for interoperability
  - Shorter ranges
  - Higher rates require complexity than base CSM rate
  - Some rake or equalizer may be helpful at higher rates

Data Rate	FEC Rate	Code Length	Symbol Time	Link Margin
9.2 Mbps	½	24	55 ns	9.3 dB at 10 m
27 Mbps	½	8	18 ns	6.5 dB at 10 m
55 Mbps	½	4	9 ns	3.5 dB at 10 m
110 Mbps	½	2	5 ns	0.4 dB at 10 m
220 Mbps	1	2	5 ns	0.8 dB at 4 m

Margin computed using k=6 code, slightly higher for k=7 code

Conclusions: Compromise

- A single PHY with multiple modes to provide a complete solution for TG3a
  - Base mode required in all devices, used for control signaling
  - Higher rate mode also required to support 110+ Mbps
  - Compliant device can implement *either* DS-UWB or MB-OFDM (or both)
- Advantage relative to uncoordinated DS-UWB and MB-OFDM deployment is usability
  - Mechanism to avoid inter-PHY interference
  - Potential for higher rate interoperation
- Increases options for innovation and regulatory flexibility to better address all applications and markets
  - Smaller spectral footprint than either DS-UWB or MB-OFDM

AWGN range comparison

Rate	Low Band: AWGN Range	High Band: AWGN Range
220 Mbps	16.5 m	11.8 m
440 Mbps	N/A	8.5 m
500 Mbps	8.5 m	6.3 m
660 Mbps	9.1 m	6.7 m
1.0 Gbps	5.2 m	4.2 m
1.3 Gbps	2.5 m	4.7 m
2.0 Gbps	N/A	2.6 m

Multipath range comparison

Rate	Low Band: CM1 Range	High Band: CM1 Range	Low Band: CM2 Range	High Band: CM2 Range
220 Mbps	9.7 m	6.6 m	8.1 m	5.7 m
440 Mbps	N/A	4.4 m	N/A	m
500 Mbps	4.3 m	m	3.7 m	m
660 Mbps	4.2 m	3.4 m	3.2 m	2.7 m
1.0 Gbps	1.7 m*	2.0 m	0 m	1.0m
1.3 Gbps	0 m	1.7m	0 m	1.1m
2.0 Gbps	N/A	1 m	N/A	0 m