Submission Title: [DS-UWB Proposal Update]
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Source: [Reed Fisher(1), Ryuji Kohno(2), Hiroyo Ogawa(2), Honggang Zhang(3), Kenichi Takizawa(2)]
Company [(1) Oki Industry Co.,Inc.,(2)National Institute of Information and Communications Technology (NICT) & NICT-UWB Consortium (3) Create-Net ]Connector’s Address [(1)2415E. Maddox Rd., Buford, GA 30519,USA, (2)3-4, Hikaruno-oka, Yokosuka, 239-0847, Japan (3) Via Soletieri, 38, Trento, Italy]
Voice: [(1)+1-770-271-0529, (2)+81-468-47-5101], FAX: [(2)+81-468-47-5431],
E-Mail: [(1)reedfisher@juno.com, (2)kohno@nict.go.jp, honggang@create-net.it, takizawa@nict.go.jp ]
Source: [Michael Mc Laughlin] Company [decaWave, Ltd.]
Voice: [+353-1-295-4937], FAX: [-], E-Mail: [michael@decawave.com]
Source: [Matt Welborn] Company [Freescale Semiconductor, Inc]
Address [8133 Leesburg Pike Vienna, VA USA]
Voice: [703-269-3000], E-Mail: [matt.welborn @freescale.com]

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
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

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>FEC Rate</th>
<th>Code Length</th>
<th>Symbol Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 Mbps</td>
<td>$\frac{1}{2}$</td>
<td>24</td>
<td>55 MHz</td>
</tr>
<tr>
<td>55 Mbps</td>
<td>$\frac{1}{2}$</td>
<td>12</td>
<td>110 MHz</td>
</tr>
<tr>
<td>110 Mbps</td>
<td>$\frac{1}{2}$</td>
<td>6</td>
<td>220 MHz</td>
</tr>
<tr>
<td>220 Mbps</td>
<td>$\frac{1}{2}$</td>
<td>3</td>
<td>440 MHz</td>
</tr>
<tr>
<td>330 Mbps</td>
<td>$\frac{1}{2}$</td>
<td>2</td>
<td>660 MHz</td>
</tr>
<tr>
<td>500 Mbps</td>
<td>$\frac{3}{4}$</td>
<td>2</td>
<td>660 MHz</td>
</tr>
<tr>
<td>660 Mbps</td>
<td>1</td>
<td>2</td>
<td>660 MHz</td>
</tr>
<tr>
<td>1000 Mbps</td>
<td>$\frac{3}{4}$</td>
<td>1</td>
<td>1320 MHz</td>
</tr>
</tbody>
</table>

Similar Modes defined for high band
Range for 110 and 220 Mbps

<table>
<thead>
<tr>
<th>Channel Model</th>
<th>90% outage range 110Mbps</th>
<th>90% outage range 220Mbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWGN</td>
<td>23.4m</td>
<td>16.5m</td>
</tr>
<tr>
<td>CM1</td>
<td>14.0m</td>
<td>9.7m</td>
</tr>
<tr>
<td>CM2</td>
<td>11.9m</td>
<td>8.1m</td>
</tr>
<tr>
<td>CM3</td>
<td>12.4m</td>
<td>7.9m</td>
</tr>
<tr>
<td>CM4</td>
<td>11.8m</td>
<td>7.4m</td>
</tr>
</tbody>
</table>
## Range for 500 and 660 Mbps

<table>
<thead>
<tr>
<th>Channel Model</th>
<th>500Mbps 90% outage range</th>
<th>660Mbps 90% outage range*</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWGN</td>
<td>8.5m</td>
<td>9.1m</td>
</tr>
<tr>
<td>CM1</td>
<td>4.3m</td>
<td>4.2m</td>
</tr>
<tr>
<td>CM2</td>
<td>3.7m</td>
<td>3.2m</td>
</tr>
</tbody>
</table>

- This result if for code length = 1, rate $\frac{1}{2}$ $k=6$ FEC
- Additional simulation details and results in 15-04-483-r5
# Ultra High Rates

<table>
<thead>
<tr>
<th>Channel Model</th>
<th>Range 1Gbps</th>
<th>Range 1.33Gbps</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWGN</td>
<td>5.2m</td>
<td>2.5m</td>
</tr>
<tr>
<td>CM1 mean</td>
<td>2.7m</td>
<td>-</td>
</tr>
<tr>
<td>CM1-90%</td>
<td>0.0m</td>
<td>-</td>
</tr>
<tr>
<td>CM1-85%</td>
<td>1.7m</td>
<td>-</td>
</tr>
<tr>
<td>CM1-80%</td>
<td>2.3m</td>
<td>-</td>
</tr>
<tr>
<td>CM1-70%</td>
<td>3.1m</td>
<td>-</td>
</tr>
</tbody>
</table>
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 \( \approx 2x \) 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 \( \approx 2x \) the baseline \( k=7 \) decoder (twice the complexity of \( k=6 \) decoder, \textbf{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

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

- Prevent interference
- Enable interoperation

- Exchange your music & data
- Stream presentation from laptop/PDA to projector
- Data to/from storage/network
- Print

- MP3 titles to music player
- Stream DV or MPEG to display
What Does CSM Look Like?
One of the MB-OFDM bands!

- Proposed Common Signaling Mode Band (500+ MHz bandwidth)
  9-cycles per BPSK “chip”
- DS-UWB Low Band Pulse Shape (RRC)
  3-cycles per BPSK “chip”

MB-OFDM (3-band) Theoretical Spectrum
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

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>FEC Rate</th>
<th>Code Length</th>
<th>Symbol Time</th>
<th>Link Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.2 Mbps</td>
<td>½</td>
<td>24</td>
<td>55 ns</td>
<td>9.3 dB at 10 m</td>
</tr>
<tr>
<td>27 Mbps</td>
<td>½</td>
<td>8</td>
<td>18 ns</td>
<td>6.5 dB at 10 m</td>
</tr>
<tr>
<td>55 Mbps</td>
<td>½</td>
<td>4</td>
<td>9 ns</td>
<td>3.5 dB at 10 m</td>
</tr>
<tr>
<td>110 Mbps</td>
<td>½</td>
<td>2</td>
<td>5 ns</td>
<td>0.4 dB at 10 m</td>
</tr>
<tr>
<td>220 Mbps</td>
<td>1</td>
<td>2</td>
<td>5 ns</td>
<td>0.8 dB at 4 m</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Rate</th>
<th>Low Band: AWGN Range</th>
<th>High Band: AWGN Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>220 Mbps</td>
<td>16.5 m</td>
<td>11.8 m</td>
</tr>
<tr>
<td>440 Mbps</td>
<td>N/A</td>
<td>8.5 m</td>
</tr>
<tr>
<td>500 Mbps</td>
<td>8.5 m</td>
<td>6.3 m</td>
</tr>
<tr>
<td>660 Mbps</td>
<td>9.1 m</td>
<td>6.7 m</td>
</tr>
<tr>
<td>1.0 Gbps</td>
<td>5.2 m</td>
<td>4.2 m</td>
</tr>
<tr>
<td>1.3 Gbps</td>
<td>2.5 m</td>
<td>4.7 m</td>
</tr>
<tr>
<td>2.0 Gbps</td>
<td>N/A</td>
<td>2.6 m</td>
</tr>
</tbody>
</table>
### Multipath range comparison

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