Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)
Submission Title: [Pulsed DS-UWB with optional CS-UWB for Various Applications]
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Source: [Huan-Bang Li(1), Kenichi Takizawa(1), Kamya Yekeh Yazdandoost(1), Akifumi Kasamatsu(1), Shigenobu Sasaki(1), Shinsuke Hara(1), Makoto Itami(1), Tetsushi Ikekami(1), Ryuji Kohno(1), Toshiaki Sakane(2), Kiyohito Tokuda(3)]
Company [(1)National Institute of Information and Communications Technology (NICT), (2)Fujitsu Limited, (3)Oki Electric Industry Co., Ltd.]
E-Mail: [lee@nict.go.jp]
Re: [Response to Call For Proposal by IEEE 802.15.4a]
Abstract [This document has been submitted for an official proposal in January 2005. Two possible technologies of direct-sequence UWB(DS-UWB) and chirp-signal UWB(CS-UWB) are combined to be optimized for various application of IEEE802.15.4a. Pulsed DS-UWB with optional CS-UWB is proposed and investigated in performance on BER, ranging resolution, complexity, power consumption, SOP and so on. The proposed system is matched with requirements.]
Purpose: [Providing technical contributions for standardization by IEEE 802.15.4a.]
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Pulsed DS-UWB with Optional CS-UWB for Various Applications

Huan-Bang Li, Kenichi Takizawa, Kamya Yekeh Yazdandoost, Akifumi Kasamatsu, Shigenobu Sasaki, Shinsuke Hara, Makoto Itami, Tetsushi Ikegami, and Ryuji Kohno

National Institute of Information and Communications Technology (NICT), Japan

Toshiaki Sakane
Fujitsu Limited

Kiyohito Tokuda
Oki Electric Industry Co. Ltd.
Outline

- Requirements of TG4a
- Proposed system: Pulsed DS-UWB with optional CS-UWB (Chirp Signaling UWB)
  1. General advantages of DS-UWB and CS-UWB
  2. Proposed DS-UWB with optional CS-UWB
  3. Performance examples
  4. Multiple access and SOP
  5. PHY frame structure
  6. Ranging issue
  7. Complexity and power consumption
  8. Technical feasibility
- Concluding remarks
Primary Technical Requirements for 15.4a

- Low complexity, low cost, and low power consumption.
- Precision ranging by PHY --- tens of centimeters.
- Communication distance is ~30m (can be extended).
- Better robustness and mobility than 802.15.4.
- Low bit rate (individual link) $\geq$ 1 kbps.
- High bit rate (aggregated) $\geq$ 1 Mbps.
Aims of the Proposal

• By using DS-UWB with optional CS-UWB, the proposed system is conscientiously designed so that it can be easily customized and generally used for various applications, while keeping low complexity with low power consumption.

• Meet all requirements of 15.4a.
1. General Advantages of DS-UWB and CS-UWB

Both DS-UWB and CS-UWB are available for

- **High frequency efficiency**
  - Uniform use of frequency within the band

- **High robustness against noise and multipath**
  - Correlated processing

- **High compatibility with other existing systems**
  - Low interference level

- **High feasibility for SOP**
  - Use of DS codes or chirp pulses
Modulation/Demodulation for DS-UWB

- Modulation.

- Demodulation.
Chirp/De-chirp Processing for CS-UWB

• Chirp can be done by passing a pulse signal through a DDL.

- Chirp can be done by passing a pulse signal through a DDL.

- De-chirp is realized by doing correlated processing.

  B: 3-dB bandwidth of chirp
  T: time interval of chirp
## Comparison between DS-UWB and CS-UWB

<table>
<thead>
<tr>
<th>Feature</th>
<th>DS-UWB</th>
<th>CS-UWB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low complexity</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>Peak-to-average ratio</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Effect of SOP</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Ranging resolution</td>
<td>++</td>
<td>+</td>
</tr>
</tbody>
</table>
2. Proposed DS-UWB With Optional CS-UWB

- Transceiver structures and waveforms
- Default and optional pulse shaping
- Frequency band
- Link budget
- Scalability and optional SS operation
- Advantages
- Proposed UWB antenna
Pulsed DS-UWB System Proposal

- **Spectrum Spreading**: Direct sequence (DS) with spreading sequence of variable lengths. In option, additional chirp signaling (CS-UWB).
- **Pulse Shaping**: Gaussian monocycle and optionally variable pulse shapes with SSA (Soft Spectrum Adaptation#).
- **Frequency Band**: 500MHz or 2GHz in bandwidth over 3.1-10.6GHz. In option, 2.4GHz ISM band.
- **Data Modulation**: BPSK or others.
  - Low bit rate (individual link) >= 1 kbps.
  - High bit rate (aggregated) >= 1 Mbps.
- **Channel Coding & Decoding**: (24, 12) extended Golay code.
  - In option, CIDD (combined iterative demapping/decoding#)

(# see 15-03-0334-05-003a)
Outstanding Features of the Proposal

• High capacity for SOP
  – Use of independent DS codes or chirp pulses
  – Use of combined DS codes and chirp pulses

• Multiple selectivity for FFD and RFD as well as for various Customization
  – Chirp vs. Non chirp
  – High bit rate vs. Low bit rate
  – Optional SSA vs. Gaussian monocycle

• Interoperability
  – Simplified structure from high rate DS-UWB of 15.3a
Overall Block Diagram With Optional CS

Transmitter

Comm. data
Ranging data

(24,12)-Golay encoder
BPSK
Spreading
Pulse shaping
CHIRP
GA

BW = 500MHz or 2GHz

Local oscillator

Receiver

Pre-Select Filter

LNA
De-CHIRP

LPF
GA

1 or 2-bit ADC

Decision/ FEC decoder

Comm. data
Ranging data

1 or 2-bit ADC

Sync.

Peak detection

Time base
Calculation

Ranging processing

Local oscillator

Additional circuits to DS-UWB as an option
Block diagram Without Optional CS

Transmitter

Comm. data

(24,12)-Golay encoder → BPSK → Spreading → BPSK → GA

Pre-Select Filter

LNA → LPF → GA → LPF → GA → 1 or 2-bit ADC

Local oscillator

Decision/ FEC decoder

Comm. data

Ranging data

Ranging processing

Receiver

Pulse waveform: Variable(SSA)
BW = 500MHz or 2GHz

Comm. data

Sync.

Peak detection

Calculation

Time base

Ranging data

Decision/ FEC decoder

Comm. data

1 or 2-bit ADC

1 or 2-bit ADC

Local oscillator

I

Q
Waveforms With & Without Optional CS

- Gaussian pulse
- Gaussian pulse
- Gaussian pulse
- Gaussian pulse
- Gaussian pulse

- (24,12)-Golay encoder
- BPSK
- Spreading
- Pulse shaping
- CHIRP
- GA

- Local oscillator

- linear-chirp
- linear-chirp
- linear-chirp
- linear-chirp
- linear-chirp
Pulse shaping

• Gaussian monocycle is default.
  – Easy implementation of transceiver.
  – The ratio of chip rate to carrier frequency is an integer.
  – Drawback is less efficiency in utilizing FCC mask.

• Optional soft spectrum adaptation (SSA; see 15-03-0334-05-003a).
  – Adaptive spectrum by considering trade-off between performance and complexity/cost.
Frequency Band

- We consider two operating bandwidths of UWB. 
  #1: BW=2GHz, and #2: BW=500MHz. 
  Both are selected within 3.1 - 10.6 GHz frequency band.

- In addition, 2.4 GHz ISM band is also considered as an option.
**DS-UWB Link Budget (BW=2GHz)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Value</th>
<th>Notes</th>
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<tbody>
<tr>
<td>Data rate (Rb)</td>
<td>1</td>
<td>1024</td>
<td>(kbps)</td>
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<tr>
<td>Modulation</td>
<td>BPSK</td>
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<td>Coherent detection</td>
</tr>
<tr>
<td>Coding rate (R)</td>
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<td></td>
<td>(24,12)-Extended Golay Hard-decision decoding</td>
</tr>
<tr>
<td>Raw Symbol rate (Rs)</td>
<td>2</td>
<td>2048</td>
<td>Rs=Rb/R (ksymbol/s)</td>
</tr>
<tr>
<td>Pulse duration (Tp)</td>
<td>0.662</td>
<td></td>
<td>(ns)</td>
</tr>
<tr>
<td>Spreading code length (Ns)</td>
<td>1024</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>Chip rate (Rc)</td>
<td>2.048</td>
<td>131.072</td>
<td>=Rs*Ns (MHz)</td>
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<tr>
<td>Chip duration</td>
<td>488.3</td>
<td>7.63</td>
<td>=1/Rc (nsec)</td>
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Value</th>
<th>Unit</th>
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<tr>
<td>Distance (d)</td>
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<td>Frequency Band</td>
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<td>3.1 - 5.1</td>
<td>GHz</td>
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<tr>
<td>Geometric center frequency (fc)</td>
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<td>3.98</td>
<td>GHz</td>
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<tr>
<td>Path loss @ 1m (L1)</td>
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<td>dB</td>
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<tr>
<td>Path loss @ d m (Ld)</td>
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<td>20.00</td>
<td>dB</td>
</tr>
<tr>
<td>Rx antenna gain (Gr)</td>
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<td>dBi</td>
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<tr>
<td>Rx power (Pr)</td>
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<td>-80.93</td>
<td>dBm</td>
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<tr>
<td>Average noise power per bit (N)</td>
<td>-144.00</td>
<td>-113.90</td>
<td>dBm</td>
</tr>
<tr>
<td>Rx Noise Figure (NF)</td>
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<td>7.00</td>
<td>dB</td>
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<tr>
<td>Average noise power per bit (Pn)</td>
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<td>-106.90</td>
<td>dBm</td>
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<tr>
<td>Minimum required Eb/N0 (S)</td>
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<td>6.25</td>
<td>dB</td>
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<td>Implementation loss (I)</td>
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<td>3.00</td>
<td>dB</td>
</tr>
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<td>Link Margin</td>
<td>43.28</td>
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<td>Min. Rx Sensitivity Level</td>
<td>-127.75</td>
<td>-97.65</td>
<td>dBm</td>
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</table>
# CS-UWB Link Budget (BW=2GHz)

<table>
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<th>Parameter</th>
<th>Value</th>
<th>Value</th>
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<td>Data rate (Rb)</td>
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<tr>
<td>Coding rate (R)</td>
<td>1/2</td>
<td></td>
<td>Coherent detection</td>
</tr>
<tr>
<td>Raw Symbol rate (Rs)</td>
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<td>2048</td>
<td>Rs=Rb/R (ksymbol/s)</td>
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<tr>
<td>Chirp signal duration (Tc)</td>
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<td>(ns)</td>
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<tr>
<td>Spreading code length (Ns)</td>
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<tr>
<td>Chip rate (Rc)</td>
<td>2.048</td>
<td>8.192</td>
<td>=Rs*Ns (MHz)</td>
</tr>
<tr>
<td>Chip duration</td>
<td>488.3</td>
<td>122.1</td>
<td>=1/Rc (nsec)</td>
</tr>
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</table>

The items given in red characters have different values from those of DS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Value</th>
<th>Unit</th>
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<tr>
<td>Distance (d)</td>
<td>30</td>
<td>10</td>
<td>m</td>
</tr>
<tr>
<td>Peak payload bit rate (Rb)</td>
<td>1</td>
<td>1024</td>
<td>kbps</td>
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<tr>
<td>Average Tx power (Pt)</td>
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<td>dBm</td>
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<tr>
<td>Tx antenna gain (Gt)</td>
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<tr>
<td>Frequency band</td>
<td>3.1 - 5.1</td>
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<td>GHz</td>
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<tr>
<td>Geometric center frequency (fc)</td>
<td>3.98</td>
<td></td>
<td>GHz</td>
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<tr>
<td>Path loss @ 1m (L1)</td>
<td>44.43</td>
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<td>dB</td>
</tr>
<tr>
<td>Path loss @ d m (Ld)</td>
<td>29.54</td>
<td>20.00</td>
<td>dB</td>
</tr>
<tr>
<td>Rx antenna gain (Gr)</td>
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<td></td>
<td>dBi</td>
</tr>
<tr>
<td>Rx power (Pr)</td>
<td>-90.47</td>
<td>-80.93</td>
<td>dBm</td>
</tr>
<tr>
<td>Average noise power per bit (N)</td>
<td>-144.00</td>
<td>-113.90</td>
<td>dBm</td>
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<tr>
<td>Rx Noise figure (Nf)</td>
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<td></td>
<td>dB</td>
</tr>
<tr>
<td>Average noise power per bit (Pn)</td>
<td>-137.00</td>
<td>-106.90</td>
<td>dBm</td>
</tr>
<tr>
<td>Minimum required Eb/N0 (S)</td>
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<td>dB</td>
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<td>Implementation loss (I)</td>
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<td>dB</td>
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<td>Link Margin</td>
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<td>23.83</td>
<td>dB</td>
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<tr>
<td>Min. Rx Sensitivity Level</td>
<td>-127.25</td>
<td>-97.15</td>
<td>dBm</td>
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### DS-UWB Link Budget (BW=500MHz)

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<th>Value</th>
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<tr>
<td>Data rate (Rb)</td>
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<td>(kbps)</td>
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<tr>
<td>Modulation</td>
<td>BPSK</td>
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<td>Coherent detection</td>
</tr>
<tr>
<td>Coding rate (R)</td>
<td>1/2</td>
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<td>(24,12)-Extended Golay Hard-decision decoding</td>
</tr>
<tr>
<td>Raw Symbol rate (Rs)</td>
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<td>2048</td>
<td>Rs=Rb/R (ksymbol/s)</td>
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<td>2.649</td>
<td>(ns)</td>
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<td>Spreading code length (Ns)</td>
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<tr>
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<td>131.072</td>
<td>=Rs*Ns (MHz)</td>
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<tr>
<td>Chip duration</td>
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<td>7.63</td>
<td>=1/Rc (nsec)</td>
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<table>
<thead>
<tr>
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<th>Value</th>
<th>Value</th>
<th>Unit</th>
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</thead>
<tbody>
<tr>
<td>Distance (d)</td>
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<td>10</td>
<td>m</td>
</tr>
<tr>
<td>Peak payload bit rate (Rb)</td>
<td>1</td>
<td>1024</td>
<td>kbps</td>
</tr>
<tr>
<td>Average Tx power (Pt)</td>
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<td>Tx antenna gain (Gt)</td>
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<td>dBi</td>
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<tr>
<td>Frequency band</td>
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<td>Geometric center frequency (fc)</td>
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<td>GHz</td>
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<td>Path loss @ 1m (L1)</td>
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<tr>
<td>Path loss @ d m (Ld)</td>
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<td>dB</td>
</tr>
<tr>
<td>Rx antenna gain (Gr)</td>
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<td>-114.00</td>
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<tr>
<td>Rx Noise figure (Nf)</td>
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<td>dB</td>
<td></td>
</tr>
<tr>
<td>Average noise power per bit (Pn)</td>
<td>-137.00</td>
<td>-106.90</td>
<td>dBm</td>
</tr>
<tr>
<td>Minimum required Eb/N0 (S)</td>
<td>6.25</td>
<td>dB</td>
<td></td>
</tr>
<tr>
<td>Implementation loss (I)</td>
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<td>dB</td>
<td></td>
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<tr>
<td>Link Margin</td>
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<tr>
<td>Min. Rx Sensitivity Level</td>
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<td>-97.65</td>
<td>dBm</td>
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## CS-UWB Link Budget (BW=500MHz)

<table>
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<th>Value</th>
<th>Value</th>
<th>Notes</th>
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<tr>
<td>Data rate (Rb)</td>
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<td>(kbps)</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
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<td>Coherent detection</td>
</tr>
<tr>
<td>Coding rate (R)</td>
<td>1/2</td>
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<td>(24,12)-Extended Golay Hard-decision decoding</td>
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<tr>
<td>Raw Symbol rate (Rs)</td>
<td>2</td>
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<td>Rs=Rb/R (ksymbol/s)</td>
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<td>Chirp signal duration (Tc)</td>
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<td>(ns)</td>
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<td>=Rs*Ns (MHz)</td>
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<td>Chip rate (Rc)</td>
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<tr>
<td>Chip duration</td>
<td>488.3</td>
<td>122.1</td>
<td>=1/Rc (nsec)</td>
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</tbody>
</table>

- **Value**
  - Min. Rx Sensitivity Level: -127.25 dBm
  - Average power per bit (Pn): -80.06 dBm
  - Peak payload bit rate (Rb): 1024 kbps
  - Geometric center frequency (fc): 3.85 – 4.35 GHz
  - Tx antenna gain (Gt): 0 dBi
  - Average noise power per bit (N): -144.0 dBm
  - Rx power (Pr): -89.60 dBm
  - Minimum required Eb/N0 (S): 6.25 dB
  - Implementation loss (I): 3.50 dB
  - Link Margin: 37.65 dB
  - Rx Noise figure (Nf): 7.00 dB

- **Unit**
  - Distance (d): m
  - Path loss @ d m (Ld): dB
  - Path loss @ 1 m (L1): dB
  - Frequency band: GHz
  - Coordination center frequency (fc): GHz

- **Notes**
  - The items given in red characters have different values from those of DS
## Scalability With DS Lengths

<table>
<thead>
<tr>
<th>Data rate (kbps)</th>
<th>Raw Symbol rate (ksp)</th>
<th>DS Code length (chip)</th>
<th>Chip rate (Mcps)</th>
<th>Link margin at 10m (dB)</th>
<th>Notes</th>
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<td><strong>DS-UWB</strong></td>
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</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1024</td>
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<td>52.8</td>
<td>0.662 (ns) pulse width</td>
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<td>512</td>
<td>256</td>
<td>131.072</td>
<td>28.7</td>
<td></td>
</tr>
<tr>
<td>1024</td>
<td>2048</td>
<td>64</td>
<td>131.072</td>
<td>22.7</td>
<td></td>
</tr>
<tr>
<td>2048</td>
<td>4096</td>
<td>64</td>
<td>131.072</td>
<td>19.7</td>
<td>Optional, use 4BOK</td>
</tr>
<tr>
<td>4096</td>
<td>8192</td>
<td>64</td>
<td>131.072</td>
<td>16.7</td>
<td>Optional, use 16BOK</td>
</tr>
<tr>
<td><strong>CS-UWB (optional)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1024</td>
<td>2.048</td>
<td>53.9</td>
<td>100 (ns) chirp duration</td>
</tr>
<tr>
<td>16</td>
<td>32</td>
<td>64</td>
<td>2.048</td>
<td>41.9</td>
<td>100 (ns) chirp duration</td>
</tr>
<tr>
<td>1024</td>
<td>2048</td>
<td>4</td>
<td>8.192</td>
<td>23.8</td>
<td>100 (ns) chirp duration</td>
</tr>
</tbody>
</table>
Optional SS Operation & Pulse Shaping

- These optional operations provide choice for FFD and RFD, and allow energy-rich codes to obtain better QoS and/or higher throughput.
Advantages of Pulsed DS-UWB with Optional CS-UWB

The proposed system can be widely customized for various applications but less complex with low power consumption.

- **Low complexity**
  - Simple ADC (1 or 2-bit) is enough.
  - Optional CS-UWB can be carried out with simple chirp and de-chirp circuits in addition to the basic DS-UWB (see system diagram).

- **Variable Transmission**
  - Chirped DS-UWB signals can be demodulated by both FFD and RFD.
  - Variable data rates is realized by selecting the length of DS codes.

- **High robustness against noise, multipath, and interference**
  - Correlated processing provides robustness against noise and multipath.
  - Reduction of interference from other nodes, e.g. SOP or from other operating systems.

- **Interoperability & Coexistence**
  - Simplified structure from high rate DS-UWB of 15.3a may enable active coexistence.
**UWB Antenna**

- Very small antenna with excellent radiation pattern.
  - Antenna size is smaller than SD memory card size.

![Diagram of UWB Antenna](image)

- Substrate: Silicon
- Patch: Copper

Radiation Pattern

19 mm
17 mm
0.7 mm
19 mm
Antenna Characteristics

- VSWR <= 2 in total band and nearly linear gain.

![VSWR and Gain Graphs](image-url)
3. Performance Examples

- Performance under AWGN channel
- Performance with 15.4a channel models
- Anti-interference performance (IEEE802.11a and MB-OFDM)
Simulation results (Single link, AWGN)

One Packet includes 32 bytes.
Simulation results (Single link, AWGN)
Performance With 15.4a CMs

**DS-UWB**
- Data rate: 1kbps (nominal)
- Modulation: BPSK
- Pulse shape: Gaussian monocycle
- Spreading code: 1024 chips
- ADC: 1Gs and 1bit
- Channel models
  - CM1: Indoor residential LOS
  - CM5: Outdoor LOS
  - CM8: Industrial environments
  - CM8: NLOS
Interference Models Considered

- **IEEE802.11a**
  - Center frequency: 5.18 GHz
  - Emission power: 15 dBm
  - Antenna gain: 0 dBi

- **MB-OFDM**
  - Frequency band: Group 1, lower three bands
  - Emission power: -41.3dBm*528MHz*Duty cycle
  - Antenna gain: 0 dBi
## Interference Evaluation Using Minimum Criteria

<table>
<thead>
<tr>
<th>Interference models</th>
<th>Tolerable distance to achieve PER&lt;1%</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IEEE802.11a</strong></td>
<td></td>
</tr>
<tr>
<td>BW = 2GHz</td>
<td></td>
</tr>
<tr>
<td>Eb/N0 = inf.</td>
<td>0.52 m</td>
</tr>
<tr>
<td>Eb/N0 = 10 dB</td>
<td>0.80 m</td>
</tr>
<tr>
<td><strong>MB-OFDM</strong></td>
<td></td>
</tr>
<tr>
<td>BW = 2GHz</td>
<td></td>
</tr>
<tr>
<td>Eb/N0 = inf.</td>
<td>0.012</td>
</tr>
<tr>
<td>Eb/N0 = 10 dB</td>
<td>0.022</td>
</tr>
<tr>
<td>BW = 500MHz</td>
<td></td>
</tr>
<tr>
<td>Eb/N0 = inf.</td>
<td>0.104</td>
</tr>
<tr>
<td>Eb/N0 = 10 dB</td>
<td>0.115</td>
</tr>
</tbody>
</table>

UWB: Propagation distance = 1m. BW = 2 GHz, fc = 4.1 GHz. Data rate = 2 Mbps, FEC off. BW = 500 MHz, fc = 3.35 GHz.
4. Multiple Access and SOP

- Multiple access method
- Simulation results
Multiple Access Method For SOP

• **DS-UWB**
  – Use different DS codes
    (and/or different frequency sub bands for BW = 500MHz).

• **CS-UWB (in option)**
  – Use different chirped pulses or combination of DS codes and chirped pulses.
Simulation block diagram for SOP

Desired transmitter → Channel → Receiver

Undesired transmitter A

Devices of Other piconets

Undesired transmitter B

Channel

Undesired transmitter C

Channel

Devices in the same piconet
Simulation results for SOP

BER vs. Number of SOP for different SIR and SNR conditions:

- SIR = -5 dB
- SIR = 0 dB
- SNR = 5 dB

Lines:
- DS-UWB (blue)
- CS-UWB (red)
Cross correlation coefficient

DS-UWB

CS-UWB
5. PHY Frame Structure

- Frame Format
- PHY header payload
PHY Frame Format

- Preamble
- Start Delimiter
- PHY Header
- PSDU

- DS Spreading
- DS-UWB or CS-UWB

- 1024 kbps (BPSK)
- PHY-SAP Payload Bit Rates
  - 1, 16, 32, 128, 256, 1024 kbps (BPSK)
  - 2048 kbps (4BOK)
  - 4096 kbps (16BOK)

- Coding rate = 1
- Coding rate = 1/2
Payload of PHY Header

- We can use the spreading type field bit in PHY header as an indicator to show which spreading scheme is employed in the payload, DS-UWB or CS-UWB.

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>Spreading Length</th>
<th>UWB Type</th>
<th>Modulation Type</th>
<th>PSDU Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>3bits</td>
<td>2bits</td>
<td>1bit</td>
<td>2bits</td>
<td>8bits</td>
</tr>
</tbody>
</table>

0: DS-UWB
1: CS-UWB
6. Ranging Issue

- Ranging circuit
- Ranging period
- Ranging accuracy
Ranging Processing with TOA

MAC

- Tx data/Ranging data
  - Coder
  - Pulse Generator
  - Tx Power Amp
  - Tx Chirp Filter
    (Option)
  - T/R Switch
  - ANT
  - BPF

- Tx-Chirp Filter Cont
- Rx-Chirp Filter Cont
  (Option)

- Rx data
  - Decoder
  - Comparator
  - Rx Chirp Filter
    (Option)
  - LNA

- Calculate Ranging

Ranging Circuit

- Rx data
  - Calculate Ranging

- Tx/Rx SW Cont

Submission

Slide 42

NIC, Fujitsu, and OKI
Period of Ranging with TOA

Period of ranging

- Long ranging period
  - 250 sec
- Short ranging period
  - 15 msec

The ranging period is decided by referring to the superframe structure of 15.4.
Ranging Accuracy with TOA

- Ranging precision depends on the bandwidth used.
- Using a simple TOA, DS-UWB provides better precision than CS-UWB in principle.

<table>
<thead>
<tr>
<th></th>
<th>DS-UWB</th>
<th>CS-UWB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth (GHz)</td>
<td>2.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Ranging resolution (cm)</td>
<td>19.86</td>
<td>79.47</td>
</tr>
</tbody>
</table>
## 7. Complexity/Power Consumption

Assuming standard 0.13μm CMOS technology
With intermittent operation in analog section

<table>
<thead>
<tr>
<th>Component</th>
<th>Gate Counts (kgate)</th>
<th>Area (mm²)</th>
<th>Power @1kbps* (mW)</th>
<th>Power @1024kbps (mW)</th>
<th>Power@slow Cycle (mW)</th>
<th>Power@fast Cycle (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx and Rx Mix.</td>
<td>-</td>
<td>2.5</td>
<td>1.2</td>
<td>12</td>
<td>1.2</td>
<td>12</td>
</tr>
<tr>
<td>Center Freq. Gen.</td>
<td>-</td>
<td></td>
<td>2</td>
<td>20</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>Tx Amp.</td>
<td>-</td>
<td></td>
<td>0.8</td>
<td>8</td>
<td>0.8</td>
<td>8</td>
</tr>
<tr>
<td>LNA</td>
<td>-</td>
<td></td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>GA</td>
<td>-</td>
<td></td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>ADC (2-bit)</td>
<td>-</td>
<td></td>
<td>1.8</td>
<td>18</td>
<td>1.8</td>
<td>18</td>
</tr>
<tr>
<td>Sync and Clock</td>
<td>-</td>
<td></td>
<td>2</td>
<td>20</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Tx Digital</td>
<td>10</td>
<td>0.06</td>
<td>0.1</td>
<td>4</td>
<td>0.1</td>
<td>4</td>
</tr>
<tr>
<td>Rx Digital</td>
<td>50</td>
<td>0.3</td>
<td>0.3</td>
<td>20</td>
<td>0.2</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>60</strong></td>
<td><strong>2.5 (Analog)</strong></td>
<td><strong>10.2</strong></td>
<td><strong>122</strong></td>
<td><strong>9.0</strong></td>
<td><strong>102</strong></td>
</tr>
</tbody>
</table>

The consumption power will be dominated by ‘Communication’, if ‘Communication’ and ‘Ranging’ are operated simultaneously.
8. Technical Feasibility

- Power Management
- Manufacturability
- Time to market
Power Management Mode

- Functions similar to those of 15.4 are available,
  - Sleep
  - Wake up
  - Poll
Technical Feasibility

• **Manufacturability**
  – Proposed system can be manufactured right now by conventional standard CMOS technology such as 0.13\(\mu\)m.
  – Basics of the system have been demonstrated in DS-UWB 802.15.3a proposal.

• **Time to market**
  – There is no difficulty on research and technique.
  – Time for design and product is needed.
  – Regulation may be a factor.
Concluding Remarks

- The proposed DS-UWB with optional CS-UWB can be widely customized and perform excellent for various applications in 15.4a.
  - The proposed system can be widely customized for different applications with pre-optimized sets of parameters.
  - Full and reduced function devices (FFD and RFD) can make choice for each of the following pairs of parameters: chirped or non-chirped DS-UWB, default Gaussian pulse or SSA, and, high or low data rate, etc..
- Feasibility and scalability are guaranteed both.
  - Low complexity, low cost, and low power consumption.
  - Variable data rate and multiple dimensions for SOP.
  - Robustness against multipath and interference.
- Communication and ranging requirements in 15.4a are both satisfied for a wide range of applications.
- Excellent performance with 15.4a channel models is confirmed and more results will come.