Submission Title: [Impulsive Direct-Sequence UWB Wireless Networks with Node Cooperation Relaying]

Date Submitted: [January, 2005]

Source: [Honggang Zhang, Xiaofei Zhou, Iacopo Carreras, Sandro Pera, Imrich Chlamtac]

Company [Create-Net]
Address [Via Solteri 38, 38100 Trento, Italy], Voice: [+39-0461-828584], FAX: [+39-0461-421157]
E-Mail: [honggang.zhang@create-net.it, xiaofei.zhou@create-net.it, iacopo.carreras@create-net.it, sandro.pera@create-net.it, imrich.chlamtac@create-net.it]

Source: [(1) Zheng Zhou, (2) Frank Zheng]

Company [(1) China UWB Forum (CUF) & Beijing University of Posts and Telecommunications, (2) China UWB Forum (CUF) & Chinese Academy of Sciences]
Address [(1) Inner Box 96, BUPT, Beijing 100876, China, (2) No. 116-13, 572 Bibo Road, Pudong, Shanghai 201203, China]
Voice: [(1)86-01-62282463, (2) 86-021-50807211]
E-Mail: [(1) zzhou@bupt.edu.cn, (2) xjzheng@ict.ac.cn]

Re: [IEEE P802.15 Low Rate Alternative PHY Call For Proposals]

Abstract: [For the Low Rate Alternative PHY standardization in 802.15.4a task group, impulsive direct-sequence UWB wireless system with multiple node cooperation has been investigated.]

Purpose: [Proposal submission to IEEE 802.15.4a Task Group by Create-Net and China UWB Forum (C&C)]

Notice: This document has been prepared to assist the IEEE P802.15. It is offered as a basis for discussion and is not binding on the contributing individual(s) or organization(s). The material in this document is subject to change in form and content after further study. The contributor(s) reserve(s) the right to add, amend or withdraw material contained herein.

Release: The contributor acknowledges and accepts that this contribution becomes the property of IEEE and may be made publicly available by P802.15.
Impulsive Direct-Sequence UWB Wireless Networks with Node Cooperation Relaying

Honggang ZHANG, Xiaofei ZHOU, Iacopo CARRERAS, Sandro PERA, and Imrich CHLAMTAC
Create-Net

Zheng ZHOU
China UWB Forum & Beijing University of Posts and Telecommunications

Frank ZHENG
China UWB Forum & Chinese Academy of Sciences
Presentation outline

- Technical background and requirements of IEEE 802.15.4a
- Impulsive direct-sequence UWB proposal for IEEE 802.15.4a
- Multiple nodes cooperation strategies
- Conclusion remarks
Typical link bit rate shall be 1 kb/s (low data rate) at least, while the aggregated bit rate at a data collector shall be 1 Mb/s (high data rate).

Communication range – 30 meters, optionally up to longer range.

Low cost, low power and low complexity - power consumption is a crucial requirement for which any device must operate while supporting a battery life of months or years without intervention.

Location-awareness (tens of centimeters) - a mandatory characteristic and precision ranging must be provided by the alt-PHY itself without support by external features.

Robustness and interference resistance - strongly desirable (better than 802.15.4.)

Mobility – a key feature for which the nodes shall be capable of reliable communication while in moving, at least for tracking.

Form factor – being compatible with the needs of sensor networks or RF tags applications.
Impulsive direct-sequence UWB transceiver

Transmitter

Pulse generator

PA

Receiver

RF

Base band

PRF (pulse repetition frequency) = Tens of MHz
Frequency band plan for the proposed impulsive DS-UWB wireless networks

- Multiple systems coexistence, robustness and interference resistance (e.g., 802.11 a/b/g, 802.15.3a, Bluetooth)
Impulsive DS-UWB operating bands

Each 802.15.4a transceiver operates in one of two bands

- Low band (below U-NII, 3.1 to 4.1 and 4.1 to 5.1 GHz)
- High band (optional, above U-NII, 6.0 to 10.0 GHz)
- Bandwidth of low band: 1 GHz
- Bandwidth of high band: 2 GHz
Key points of impulsive DS-UWB proposal

- Data modulation scheme: BPSK
  - Low data rate > 1 Kbps
  - High data rate (aggregated) > 1 Mbps

- Classical spread spectrum approach: Direct-sequence with ternary spreading codes
  - Ternary complementary codes achieving spread gain, coding and space diversity
  - Mutually orthogonal ternary code sets for multiple users scenario

- Operating frequency bandwidth: 1 GHz in low band group and 2 GHz in high band group

- Pulse shaping: general RRC pulse with advanced PSWF (Prolate Spheroidal Wave Functions) pulses as options
Impulsive DS-UWB transceiver architecture

Transmitter

Antenna

Tx/Rx Switch

BPF

PA

Pulse generator

0/90

Local oscillator

Receiver

LNA

BPF

Data

Modulation & spreading

Digital processing unit

• Signal acquisition
• Demodulation
• Decoding
• Tracking
• Ranging

Sync.

LNA

LPF

GA

ADC

ADC

Data
Impulsive DS-UWB signal generation

- Variable spread code lengths provide scalable data rates
- Variable spread codes are suitable for coexistence and robust to in-band interference
- Ternary complementary code sets
  - Ternary complementary code sets can be used to achieve processing gain as well as code cooperation diversity for enhanced performance.
  - Mutually orthogonal ternary complementary code sets can be used for multiple users environment.
- BPSK modulation scheme for simplified transmission and receiving processing
Design mutually orthogonal (MO) ternary complementary code sets

\[
\{c_{m,n}\}_{m=1}^4 = \begin{bmatrix}
1 & 1 & 1 & 1 & -1 & -1 \\
1 & 1 & 0 & 0 & 1 & 1 \\
-1 & 1 & -1 & 1 & 1 & -1 \\
-1 & 1 & 0 & 0 & -1 & 1 \\
\end{bmatrix}
\]

\[
\{c_{m,n}\}_{m=1}^4 = \begin{bmatrix}
1 & 1 & 0 & 0 & 1 & 1 \\
1 & 1 & -1 & -1 & -1 & -1 \\
-1 & 1 & 0 & 0 & -1 & 1 \\
-1 & 1 & 1 & -1 & 1 & -1 \\
\end{bmatrix}
\]

\[
\{c_{m,n}\}_{m=1}^4 = \begin{bmatrix}
-1 & 1 & -1 & 1 & 1 & -1 \\
-1 & 1 & 0 & 0 & -1 & 1 \\
1 & 1 & 1 & 1 & -1 & -1 \\
1 & 1 & 0 & 0 & 1 & 1 \\
\end{bmatrix}
\]

\[
\{c_{m,n}\}_{m=1}^4 = \begin{bmatrix}
-1 & 1 & 0 & 0 & -1 & 1 \\
-1 & 1 & 1 & -1 & 1 & -1 \\
1 & 1 & 0 & 0 & 1 & 1 \\
1 & 1 & -1 & -1 & -1 & -1 \\
\end{bmatrix}
\]
Design mutually orthogonal (MO) ternary complementary code sets (cont.)

\[
\{c_{m,n}\}_{m=1}^4 = \begin{bmatrix}
1 & 0 & 1 & 0 \\
0 & -1 & 0 & 1 \\
1 & 0 & -1 & 0 \\
0 & 1 & 0 & 1 \\
\end{bmatrix}
\]

\[
\{c_{m,n}\}_{m=1}^4 = \begin{bmatrix}
1 & 0 & 1 & 0 \\
0 & -1 & 0 & 1 \\
-1 & 0 & 1 & 0 \\
0 & -1 & 0 & -1 \\
\end{bmatrix}
\]

\[
\{c_{m,n}\}_{m=1}^4 = \begin{bmatrix}
-1 & 0 & 1 & 0 \\
0 & 1 & 0 & 1 \\
1 & 0 & 1 & 0 \\
0 & 1 & 0 & -1 \\
\end{bmatrix}
\]

\[
\{c_{m,n}\}_{m=1}^4 = \begin{bmatrix}
1 & 0 & -1 & 0 \\
0 & -1 & 0 & -1 \\
1 & 0 & 1 & 0 \\
0 & 1 & 0 & -1 \\
\end{bmatrix}
\]
Design mutually orthogonal (MO) ternary complementary code sets (cont.)

\[
\{c_{m,n}\}_{m=1}^7 = \begin{bmatrix}
1 & 0 & 0 & -1 & 0 & -1 & 1 \\
1 & 1 & 0 & 0 & -1 & 0 & -1 \\
-1 & 1 & 1 & 0 & 0 & -1 & 0 \\
0 & -1 & 1 & 1 & 0 & 0 & -1 \\
-1 & 0 & -1 & 1 & 1 & 0 & 0 \\
0 & -1 & 0 & -1 & 1 & 1 & 0 \\
0 & 0 & -1 & 0 & -1 & 1 & 1 \\
\end{bmatrix}
\]

Mutually orthogonal ternary codes can be further extended to code lengths of 16, 32, 64, 128, 256, 512 and 1024.
Advantages of the impulsive DS-UWB proposal

- High robustness against the noise, multipath fading and in-band interference
- Improved interoperability and coexistence with 802.11.a/b/g, Bluetooth and even 802.15.3a
- Frequency, code and space diversity for various QoS requirements
- Low complexity and low power consumption with simplified AD converter (1 or 2-bit)
- Variable data transmission for a number of application scenarios
- High ranging accuracy – related to effective pulse width
## Link budget

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw bit rate $(R_b)$</td>
<td>1.0 kbps</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>Average Tx power $(P_t)$</td>
<td>-12.8 dBm</td>
<td>-12.8 dBm</td>
</tr>
<tr>
<td>Tx antenna gain $(G_t)$</td>
<td>0 dBi</td>
<td>0 dBi</td>
</tr>
<tr>
<td>Geometric center frequency of low band $(f_c)$</td>
<td>3.6 GHz</td>
<td>3.6 GHz</td>
</tr>
<tr>
<td>Path loss at 1 meter $(L_1)$</td>
<td>43.57 dB</td>
<td>43.57 dB</td>
</tr>
<tr>
<td>Path loss at $d$ m $(L_d)$</td>
<td>36.9 dB at 70 m</td>
<td>29.54 dB at 30 m</td>
</tr>
<tr>
<td>Rx antenna gain $(G_r)$</td>
<td>0 dBi</td>
<td>0 dBi</td>
</tr>
<tr>
<td>Rx power $(P_r)$</td>
<td>-93.27 dBm</td>
<td>-85.91 dBm</td>
</tr>
<tr>
<td>Average noise power per bit: $N = -174 + 10 \log_{10}(R_b)$</td>
<td>-143.80 dBm</td>
<td>-113.80 dBm</td>
</tr>
<tr>
<td>Rx Noise Figure $(N_F)$</td>
<td>7 dB</td>
<td>7 dB</td>
</tr>
<tr>
<td>Average noise power per bit: $P_N = N + N_F$</td>
<td>-136.80 dBm</td>
<td>-106.80 dBm</td>
</tr>
<tr>
<td>Minimum $E_b/N_0$ $(S)$</td>
<td>10 dB</td>
<td>10 dB</td>
</tr>
<tr>
<td>Implementation Loss $(I)$</td>
<td>4 dB</td>
<td>4 dB</td>
</tr>
<tr>
<td>Link Margin</td>
<td>29.53 dB</td>
<td>6.89 dB</td>
</tr>
<tr>
<td>Proposed Min. Rx Sensitivity Level</td>
<td>-122.80 dBm</td>
<td>-92.80 dBm</td>
</tr>
</tbody>
</table>
**Multiple nodes cooperation strategies**

- Embedded UWB networks of sensors and actuators: Low cost, low power emission and consumption, disposable devices
  - Single antenna
  - Simple detection (e.g. non-coherent) and decoding (hard-decision)
  - High spatial density, but low node activity cycle

- Spatial diversity:
  - Multipath fading can be mitigated using space diversity (e.g. antenna arrays)
  - Multiple antenna system is too cumbersome for 802.15.4a

- Basic philosophy is to achieve cooperative **space, frequency and code diversity** in a dense network of low-cost devices, each with a single antenna
  - "Virtual" multiple antennas for a number of nodes
  - Cooperation relaying among the nodes by using distributed Space-Timing coding scheme
  - Emphasis on low cost solutions
  - A cross-layer (MAC/PHY) approach
Multiple nodes cooperation scenarios

Data link layer control: identification and management of usable resource

Source node

Multihop link

One-hop direct link

Destination node

Independent fading paths

N1

N2

D
Various nodes cooperation schemes

- **Relaying**: Source → Relaying → Destination
  - Multipath relay channel

- **Cooperative diversity with cooperative coding**
  - Source 1 → Destination 1
  - Source 2 → Destination 2

- **Parallel relay channel**
  - Source → Relaying → Destination

- **Multi-hop diversity**
  - Source → Relaying → Destination
Various nodes cooperation schemes (cont.)

- (a) First relay cluster of two nodes
- (b) Intra-cluster transmission for receive diversity
- (c) Inter-cluster transmission for transmit diversity
- (d) Low bit rate message exchange for link layer cooperation
“Virtual” antenna array in impulsive DS-UWB

- With “virtual” multiple antennas, the antenna elements are widely spaced (attached to different nodes) but are not connected by any backbone.
  - “Virtual” connection achieved by cross-layer design
  - Decentralized cooperation (relaying) achieving space diversity
Node cooperation by utilizing “virtual” distributed Space-Time coding scheme
Performance improvement realized by regenerative and non-regenerative relaying
Performance improvement realized by Space-Timing cooperation among multiple nodes
Conclusion remarks

- Impulsive direct-sequence UWB wireless networks proposal has been investigated for IEEE 802.15.4a task group.

- We have also proposed the multiple nodes cooperation scheme for the impulsive DS-UWB to achieve the space, frequency and code diversity.

- Scalable and adaptive performance improvement can be expected by utilizing the impulsive DS-UWB proposal as well as the node cooperation scheme.