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

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

Impulsive Direct-Sequence UWB Wireless Networks with Node Cooperation Relaying

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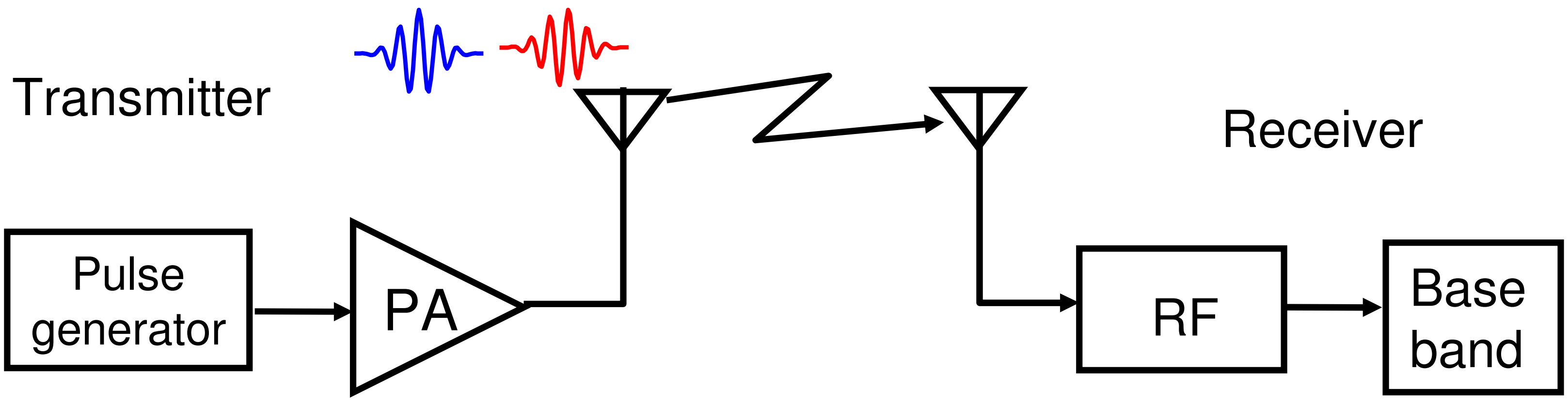
Presentation outline

- 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

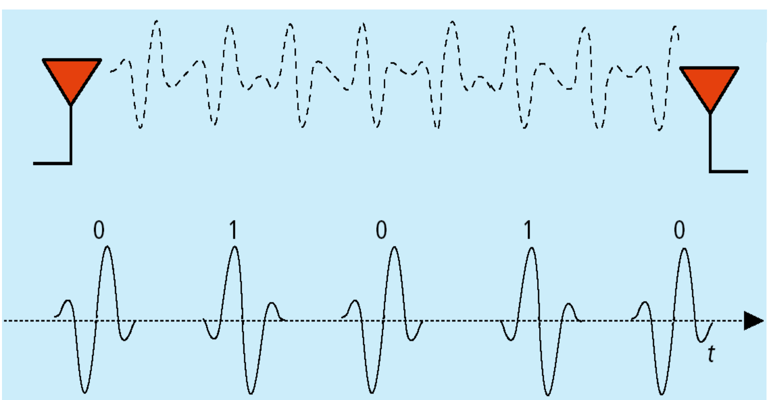
Technical background and technical requirements of IEEE 802.15.4a

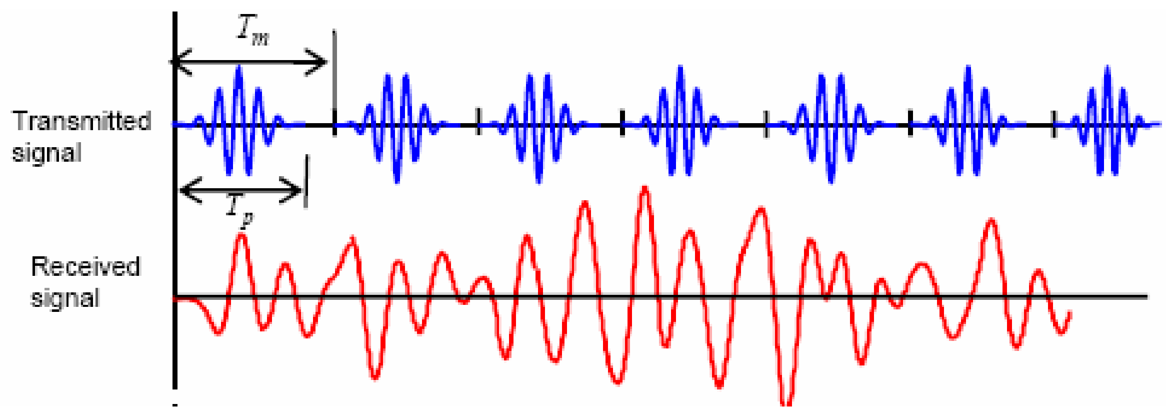
- Typical link bit rate shall be 1 kb/s (low data rate) at least, while the aggregated bit rate at a data collector shall be 1 Mb/s (high data rate).
- Communication range – 30 meters, optionally up to longer range.
- Low cost, low power and low complexity - power consumption is a crucial requirement 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

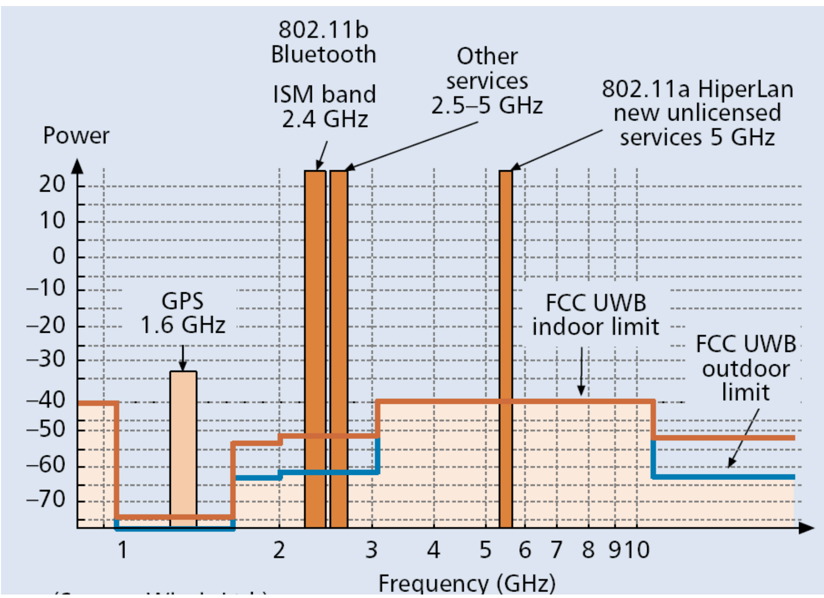


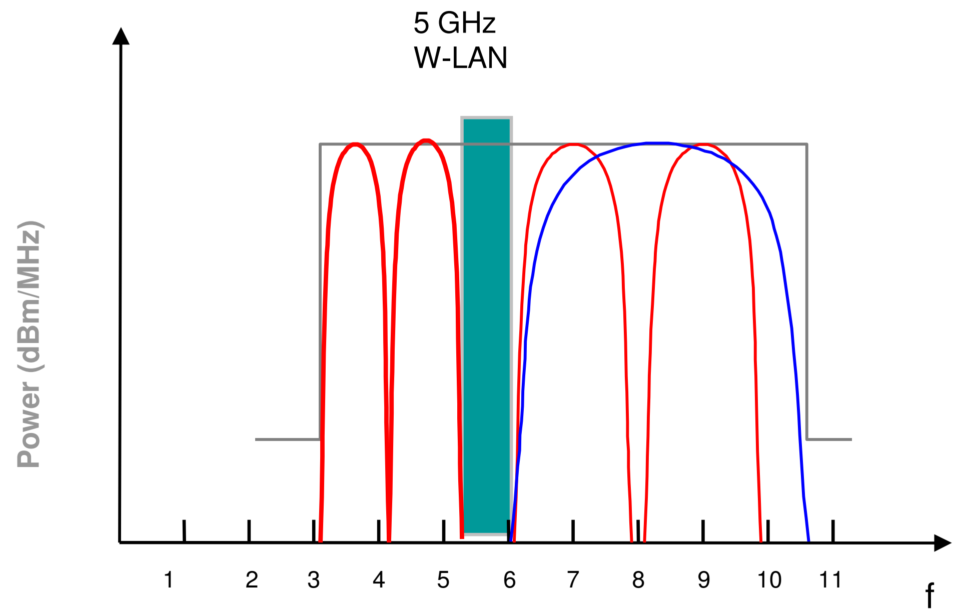
PRF (pulse repetition frequency)=Tens of MHz





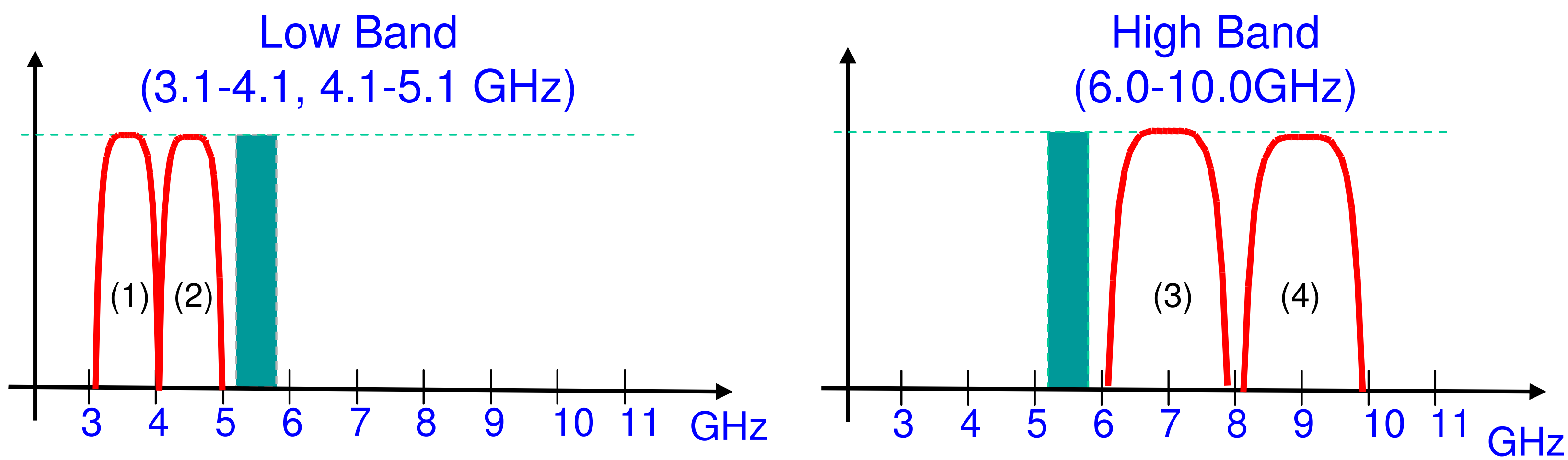
Frequency band plan for the proposed impulsive DS-UWB wireless networks





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

Impulsive DS-UWB operating bands

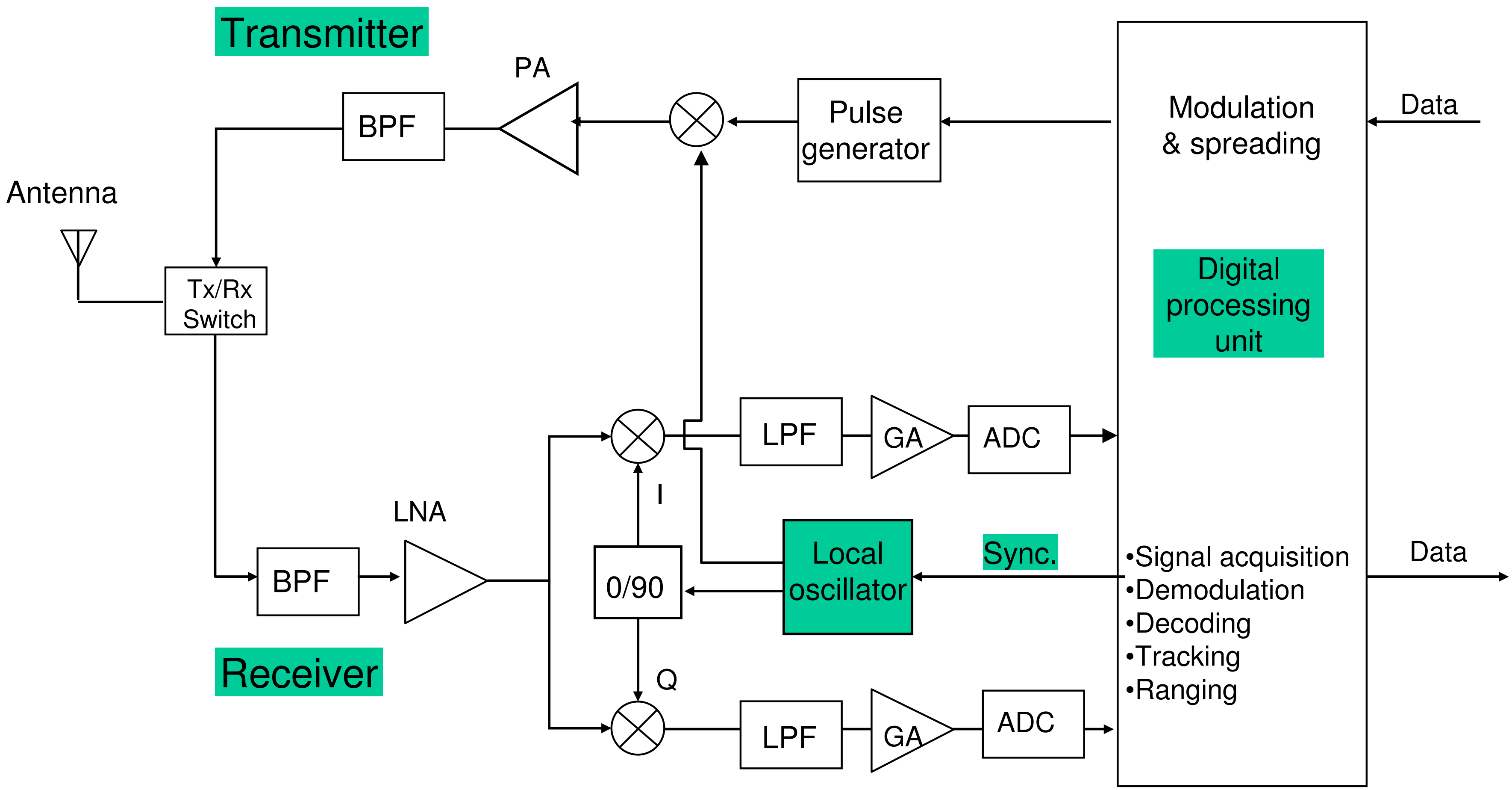


- Each 802.15.4a transceiver operates in one of two bands
  - Low band (below U-NII, 3.1 to 4.1 and 4.1 to 5.1 GHz)
  - High band (optional, above U-NII, 6.0 to 10.0 GHz)
  - Bandwidth of low band: 1 GHz
  - Bandwidth of high band: 2 GHz

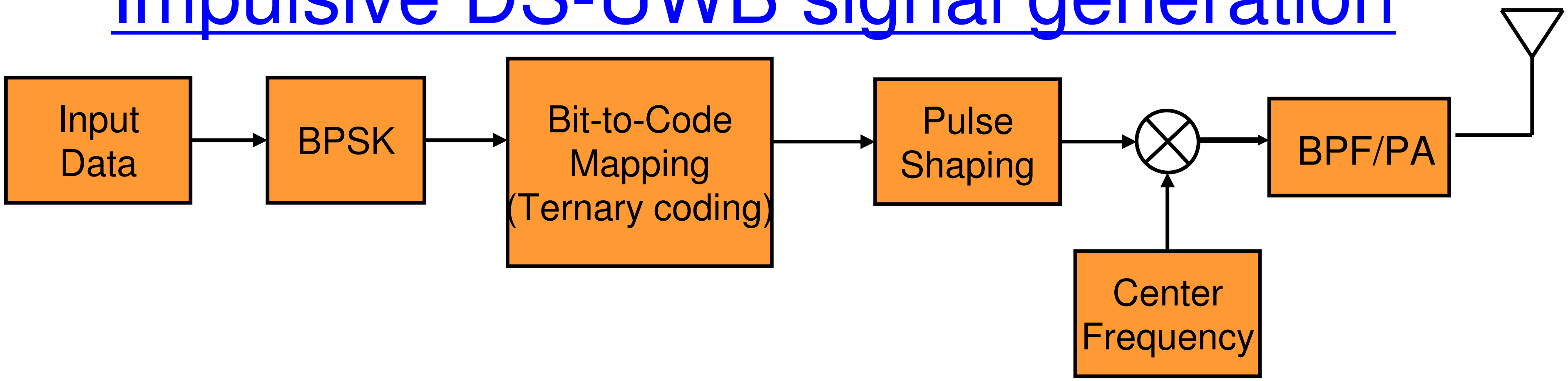
Key points of impulsive DS-UWB proposal

- 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



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

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

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

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

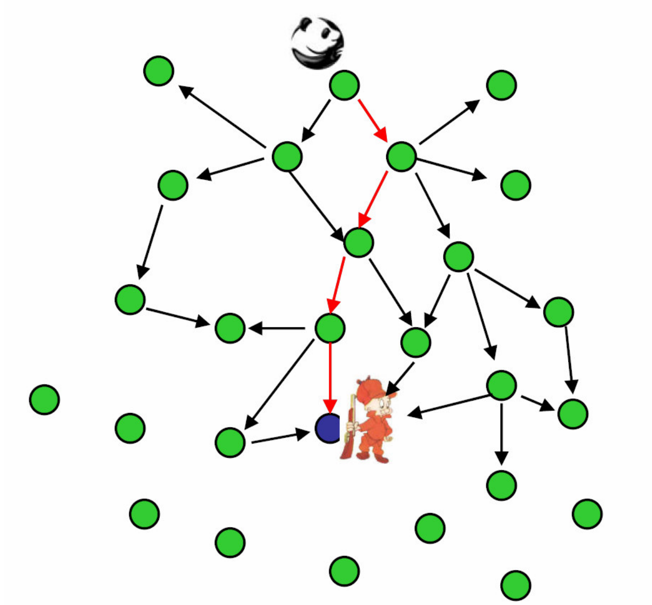
Link budget

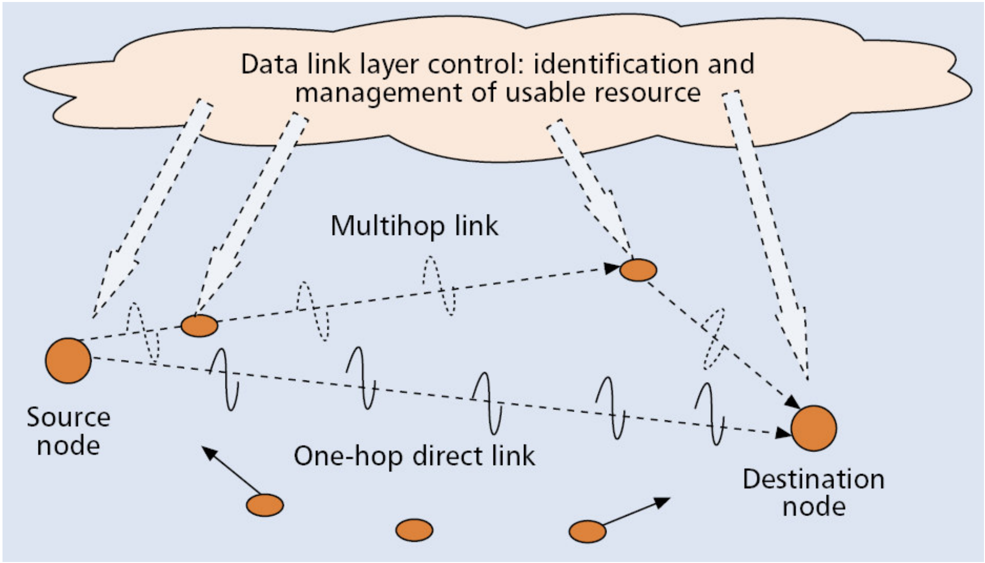
Parameter	Values	Values
Raw bit rate (R_b)	1.0 kbps	1 Mbps
Average Tx power (P_t)	-12.8 dBm	-12.8 dBm
Tx antenna gain (G_t)	0 dBi	0 dBi
Geometric center frequency of low band (f_c)	3.6 GHz	3.6 GHz
Path loss at 1 meter (L_1)	43.57 dB	43.57 dB
Path loss at d m (L_d)	36.9 dB at 70 m	29.54 dB at 30 m
Rx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

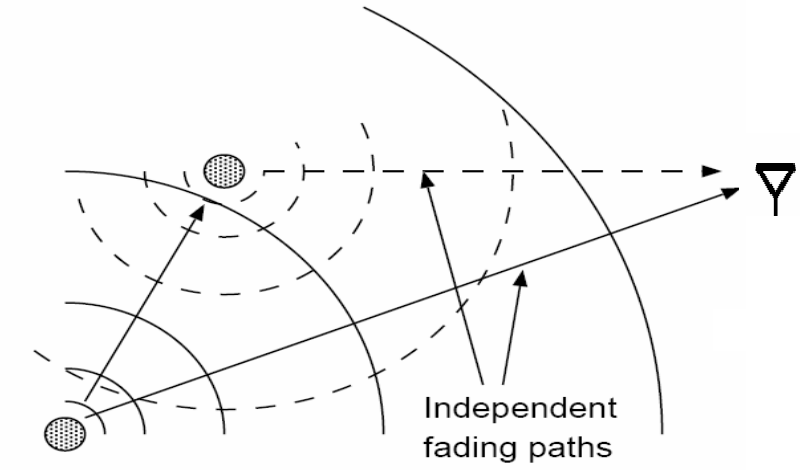
Multiple nodes cooperation strategies

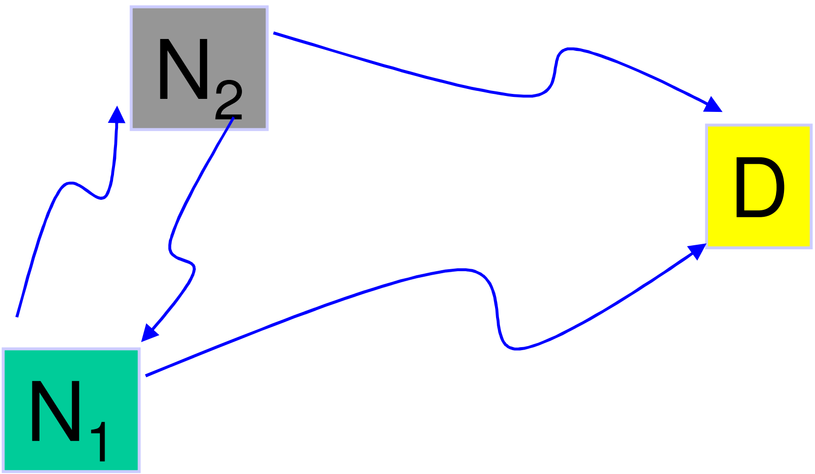
- Embedded UWB networks of sensors and actuators: Low cost, low power emission and consumption, disposable devices
    - Single antenna
    - Simple detection (e.g. non-coherent) and decoding (hard-decision)
    - High spatial density, but low node activity cycle
- Spatial diversity:
    - Multipath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

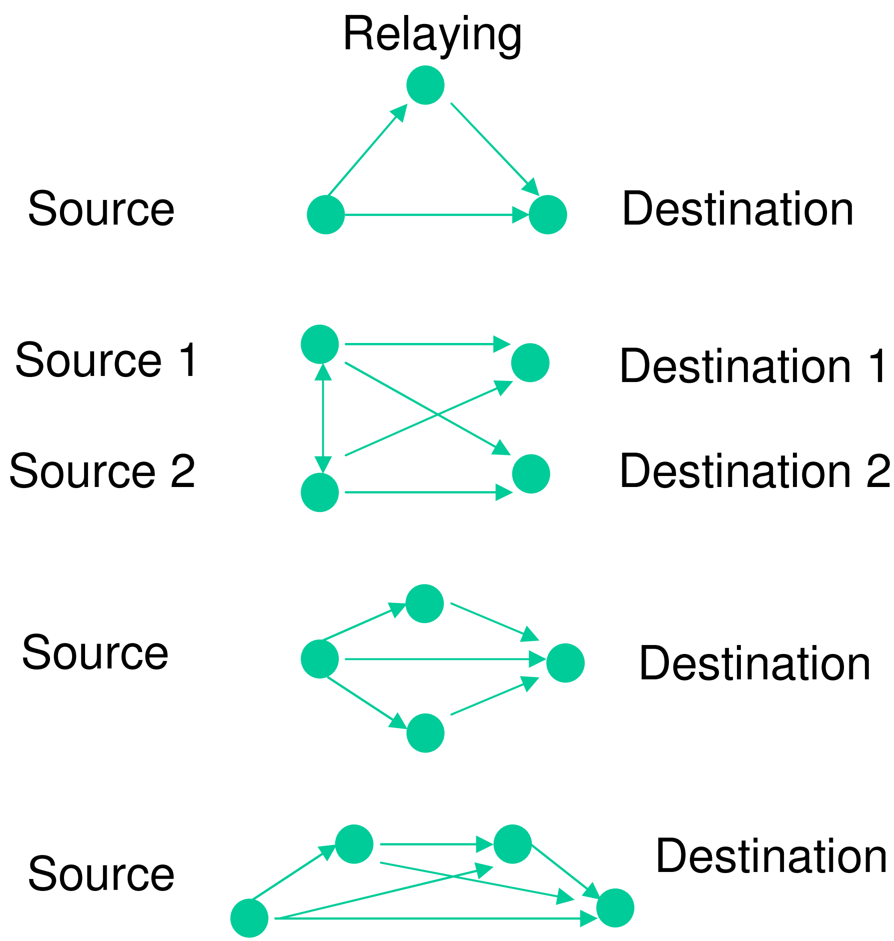








Various nodes cooperation schemes



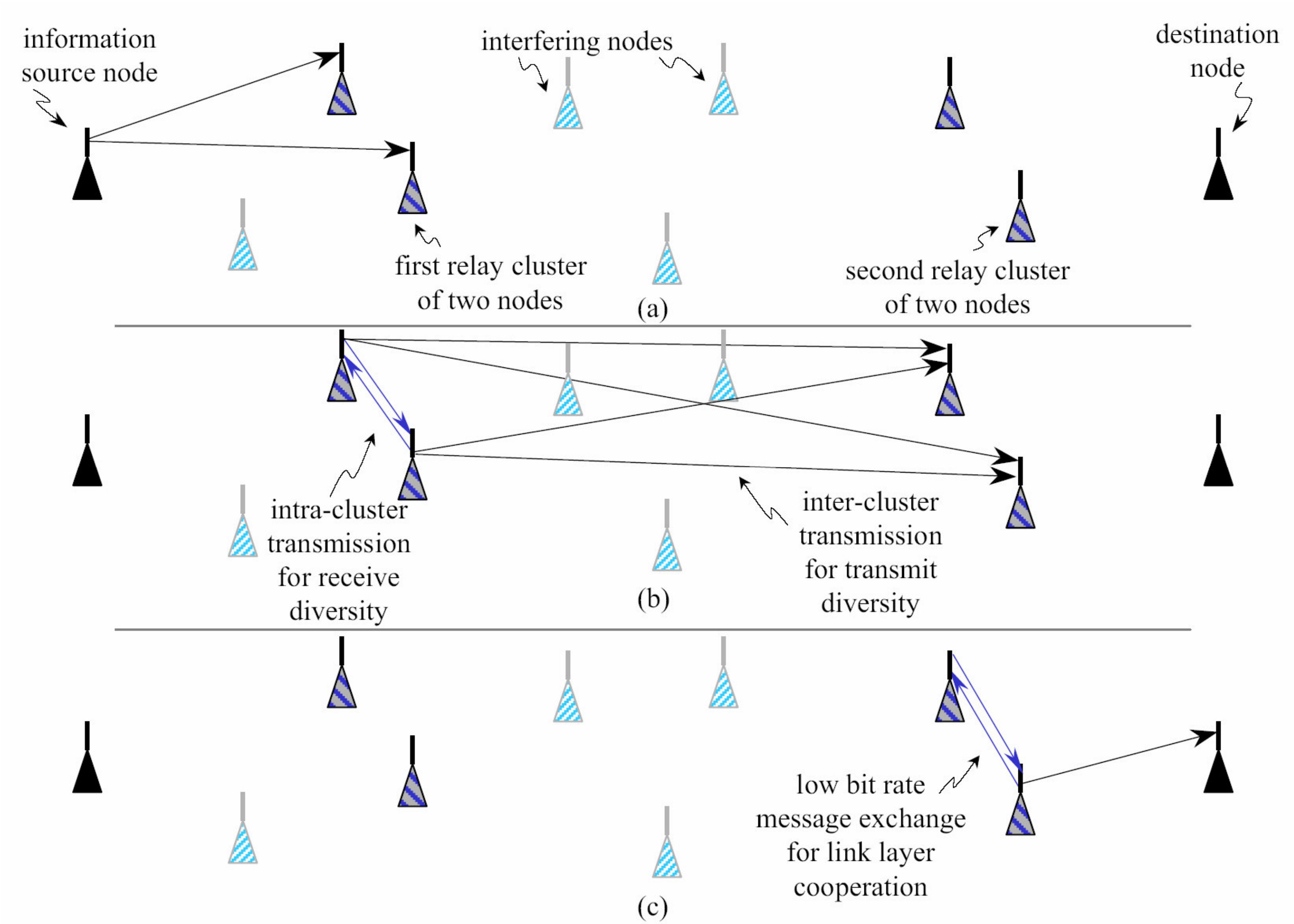
Multipath relay channel

Cooperative diversity with cooperative coding

Parallel relay channel

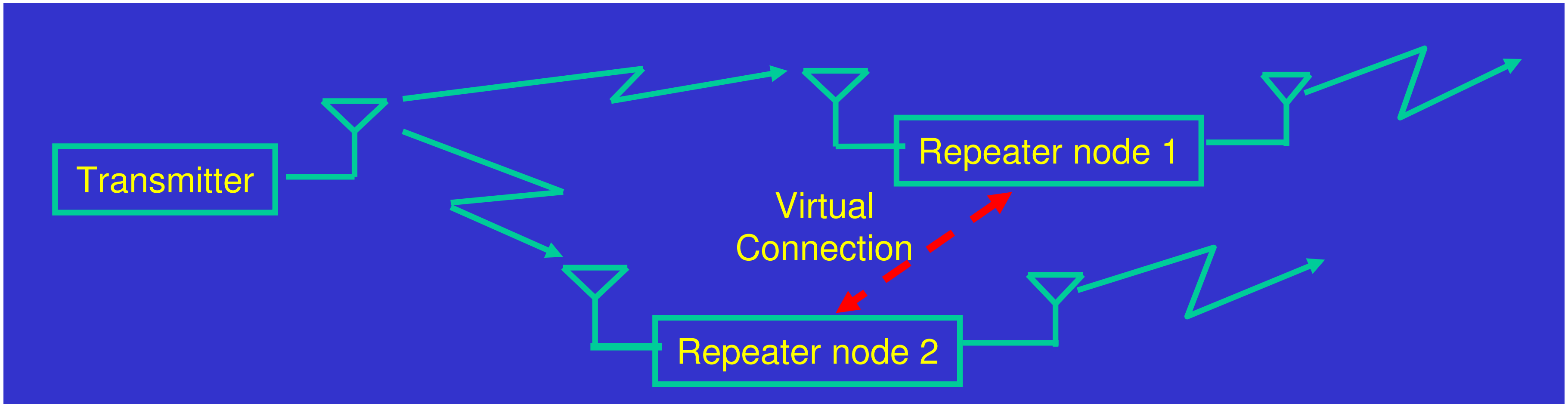
Multi-hop diversity

Various nodes cooperation schemes (cont.)

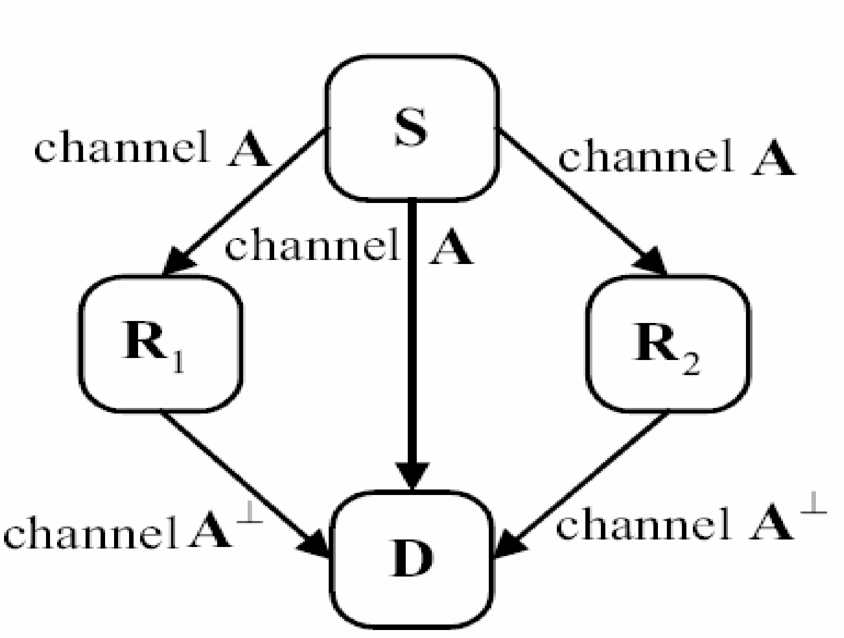


"Virtual" antenna array in impulsive DS-UWB

- 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



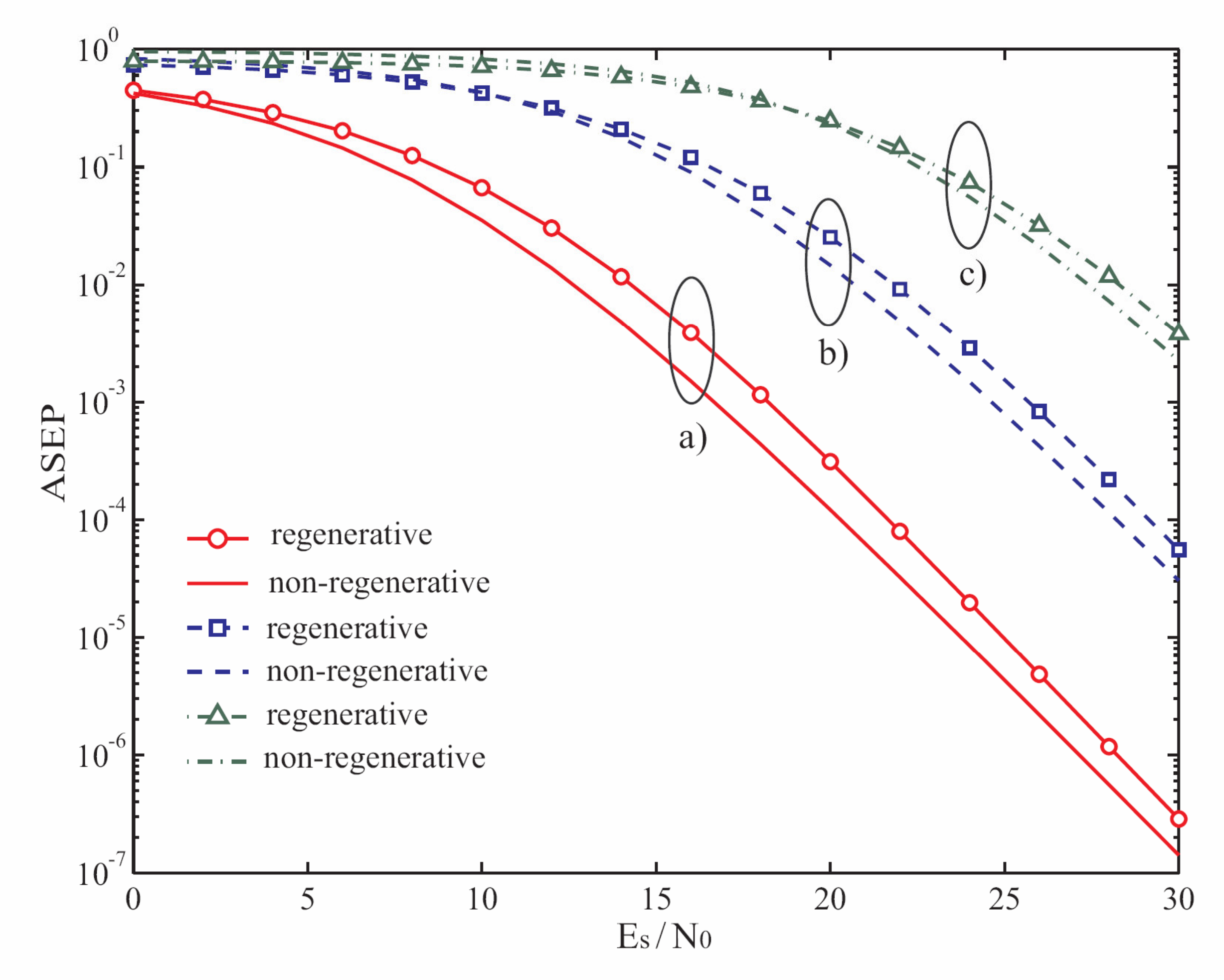
Alamouti STBC (two coded blocks are shown)

	t=0	t=1	t=2	t=3
Ant number 1	s_1	$-s_2^*$	s_3	$-s_4^*$
Ant number 2	s_2	s_1^*	s_4	s_3^*

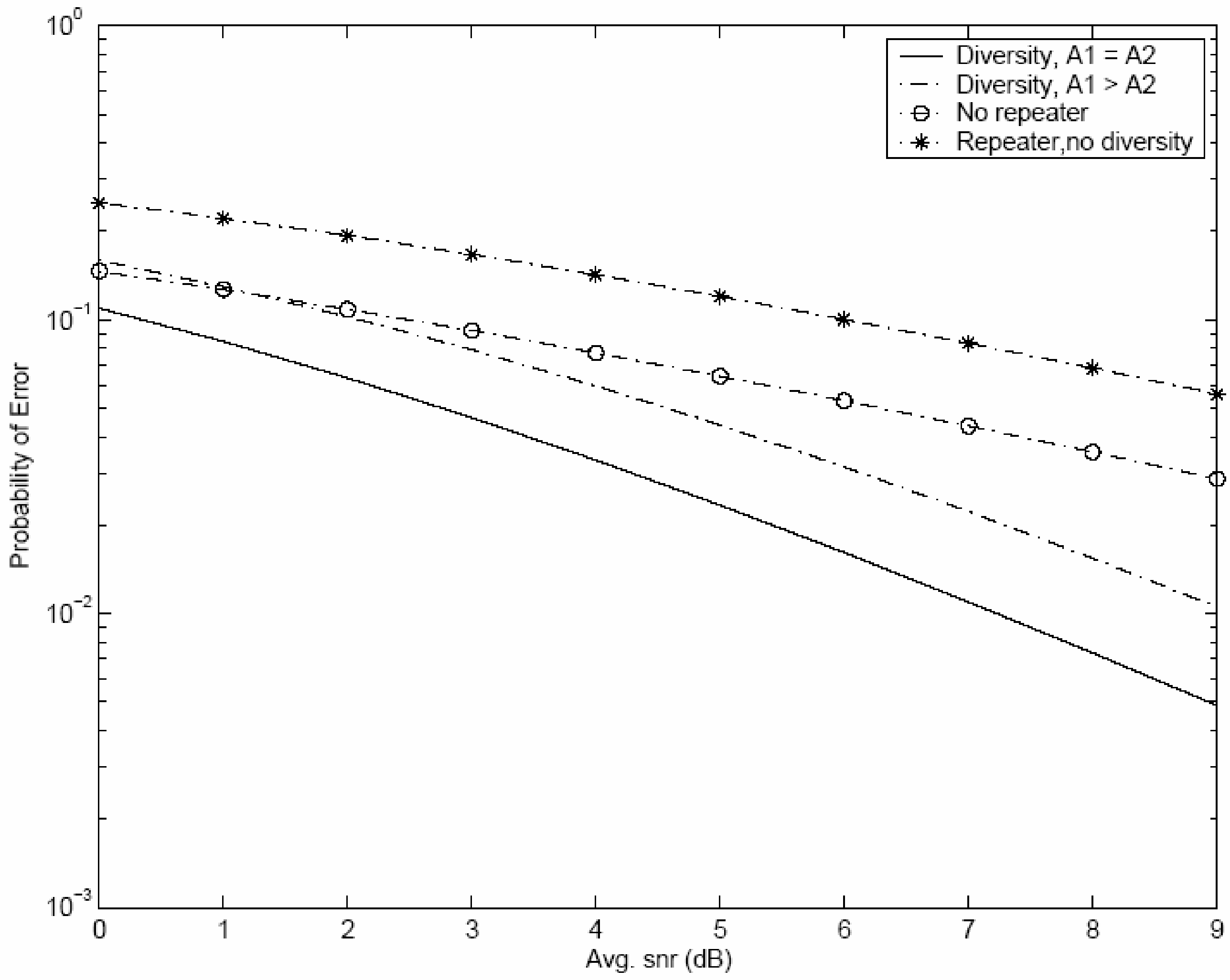
V-BLAST

	t = 0	t = 1	t = 2	t = 3
Ant number 1	s_1	s_3	s_5	s_7
Ant number 2	s_2	s_4	s_6	s_8

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.