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

Submission Title: [Merged Proposal of DS-UWB with Optional CS-UWB on UWB Band for IEEE 802.15.4a]

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Re: [Response to Call for Proposals]

Abstract [This document describes a merged proposal using DS-UWB with optional CS-UWB on UWB band for IEEE802.15.4a.]

Purpose: [Providing technical contributions for standardization by IEEE 802.15.4a.]

Merged Proposal of DS-UWB with Optional CS-UWB on UWB Band for IEEE 802.15.4a

NICT-Fujitsu-OKI,
Hitachi-YRP_UNL,
Freescale Semiconductor,
Wideband Access

Outline

- **Requirements of TG4a**
- **UWB and ISM dual-band proposal using DS-UWB and chirp signaling (CS) mode**
    1. Proposed system
    2. Performance examples
    3. Multiple access and SOP
    4. PHY frame structure
    5. Ranging issue
    6. 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) >= 1 kbps.

- High bit rate (aggregated) >= 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.

- By enabling dual-band operation, we can take advantage of the "huge" UWB frequency band to serve for IEEE 802.15.4a. On the other hand, in areas where regulation for UWB is not ready, we can use the "free" ISM band as an alternative to serve for 802.15.4a.

1. The proposed system

- DS-UWB with optional CS-UWB at UWB band

    - Will be described in detail hereafter including transceiver structure, system advantage, performance, etc.

- CS mode at ISM band

    - Skip most description because of the similarity to those of CS-UWB.

DS-UWB With Optional CS-UWB at UWB band

- Transceiver structures and waveforms
- Default and optional pulse shaping
- Frequency band
- Link budget
- Scalability and optional SS operation
- Advantages
- Proposed UWB antenna
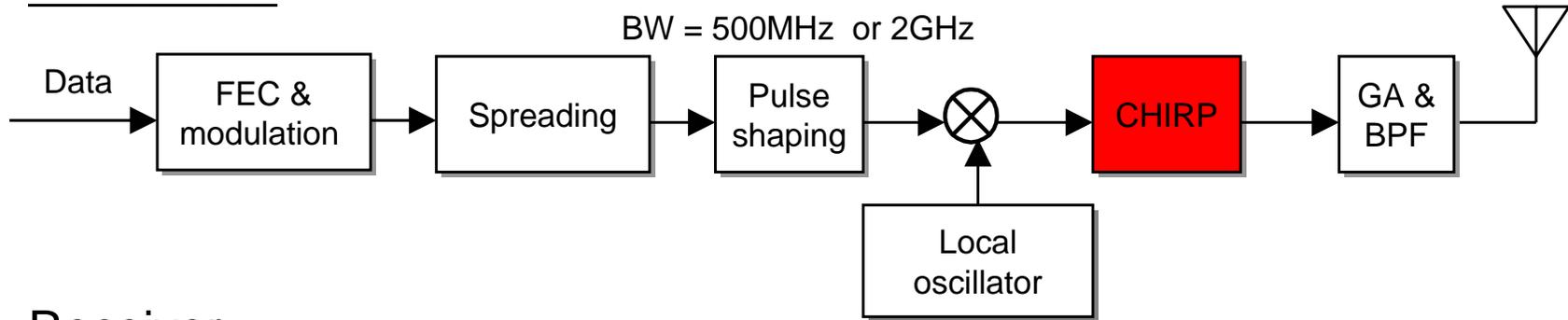
An Overview on the Proposal

- <u>Spectrum Spreading</u>: Direct sequence (DS) with spreading sequence of variable lengths. In option, additional chirp signaling (CS-UWB).

- <u>Pulse Shaping</u>: Gaussian, Raised cosine, and optionally variable pulse shapes with SSA (Soft Spectrum Adaptation#).

- <u>Frequency Band</u>: 500MHz and 2GHz in bandwidth over 3.1-10.6GHz. In addition, 2.4GHz ISM band.

- <u>Data Modulation</u>: Phase differentially encoded BPSK

- <u>Demodulation</u>: Coherent detection or Differential detection
  Low bit rate (individual link) >= 1 kbps.
  High bit rate (aggregated) >= 1 Mbps.
  Possibly several 10 Mbps

- <u>Channel Coding & Decoding</u>: Simple FEC codes.
  (# see 15-03-0334-05-003a)

Outstanding Features of the Proposal
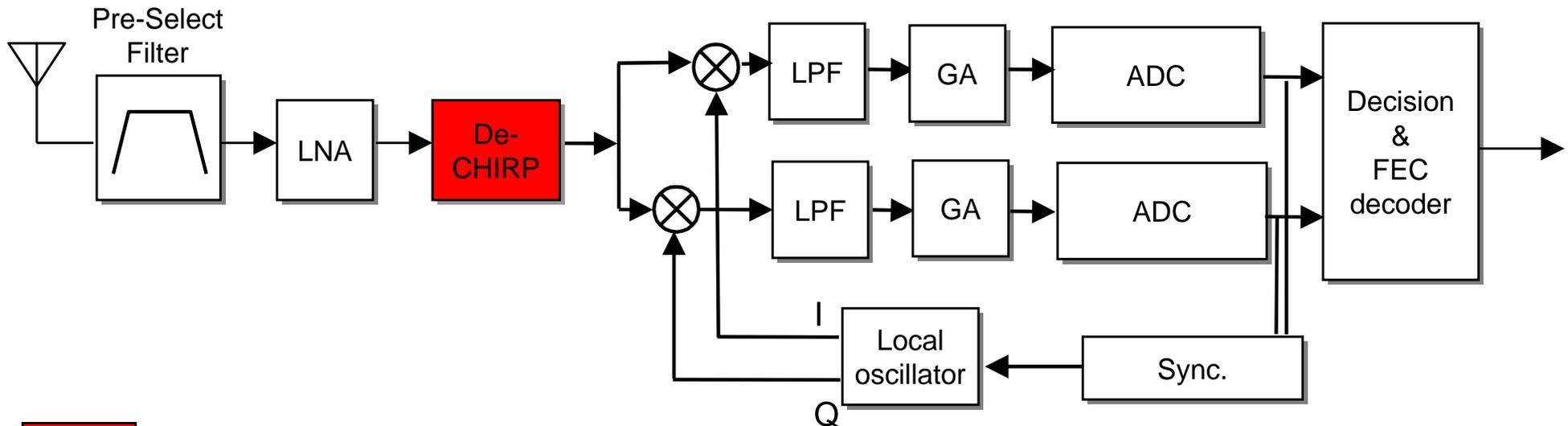
- **High capacity for SOP**
  - By independent DS codes or chirp pulses
  - By combined DS codes and chirp pulses

- **Multiple selectivity for FFD and RFD as well as for various Customization**
  - Chirp vs. Non chirp
  - High bit rate vs. Low bit rate
  - Coherent detection vs. differential detection

- **Interoperability**
  - Simplified structure from high rate DS-UWB of 15.3a

Overall Block Diagram With Optional CS

Transmitter

BW = 500MHz or 2GHz

Data → FEC & modulation → Spreading → Pulse shaping → ⊗ → CHIRP → GA & BPF

Local oscillator

Receiver

Pre-Select Filter → LNA → De-CHIRP → ⊗ → LPF → GA → ADC → Decision & FEC decoder

⊗ → LPF → GA → ADC

I / Q Local oscillator ← Sync.

Additional circuits to DS-UWB as an option

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.

- **Raised cosine and other simple pulse shapes for better fitting FCC mask.**
  - trade-off between performance, complexity and cost.

Frequency Band

- **Two operating bandwidths at UWB band(3.1-10.6GHz).**
  #1: BW=2GHz, and #2: BW=500MHz.
  Center frequency is selectable within the UWB band.

- **In addition, 2.4 GHz ISM band.**
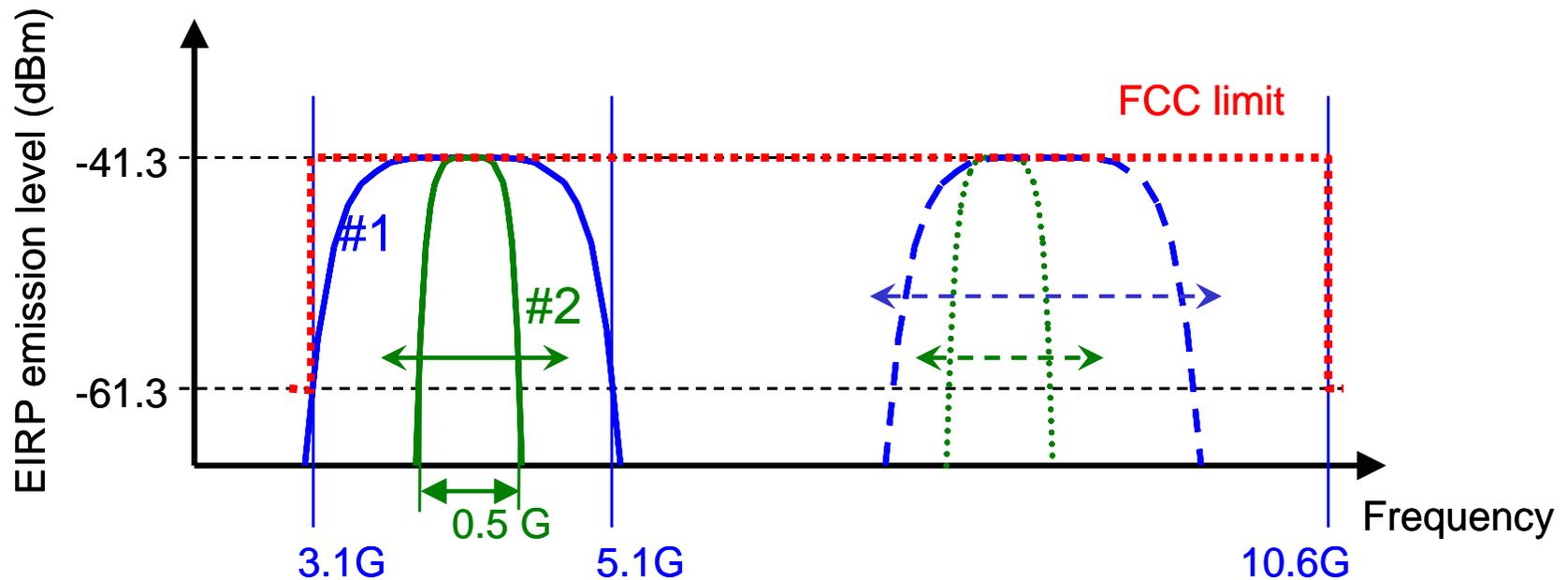
DS-UWB Link Budget (BW=2GHz)

Parameter	Value	Value	Notes
Data rate (Rb)	1	1024	(kbps)
Modulation	BPSK		Coherent detection
Coding rate (R)	1/2		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	Rs=Rb/R (ksymbol/s)
Pulse duration (Tp)	0.662		(ns)
Spreading code length (Ns)	1024	64	
Chip rate (Rc)	2.048	131.072	=Rs*Ns (MHz)
Chip duration	488.3	7.63	=1/Rc (nsec)

Parameter	Value	Value	Unit
Distance (d)	30	10	m
Peak payload bit rate (Rb)	1	1024	kbps
Average Tx power (Pt)	-10.5		dBm
Tx antenna gain (Gt)	0		dBi
Frequency Band	3.1 - 5.1		GHz
Geometric center frequency (fc)	3.98		GHz
Path loss @ 1m (L1)	44.43		dB
Path loss @ d m (Ld)	29.54	20.00	dB
Rx antenna gain (Gr)	0		dBi
Rx power (Pr)	-90.47	-80.93	dBm
Average noise power per bit (N)	-144.00	-113.90	dBm
Rx Noise Figure (Nf)	7.00		dB
Average noise power per bit (Pn)	-137.00	-106.90	dBm
Minimum required Eb/N0 (S)	6.25		dB
Implementation loss (I)	3.00		dB
Link Margin	43.28	22.72	dB
Min. Rx Sensitivity Level	-127.75	-97.65	dBm

– In this calculation, (24,12) Golay code is assumed. There will be several dB change if different codes are used.

– Coherent detection is assumed. There is a maximum of 3dB loss if differential detection is used.

CS-UWB Link Budget (BW=2GHz)

Parameter	Value	Value	Notes
Data rate (Rb)	1	1024	(kbps)
Modulation	BPSK		Coherent detection
Coding rate (R)	1/2		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	Rs=Rb/R (ksymbol/s)
Chirp signal duration (Tc)	100		(ns)
Spreading code length (Ns)	1024	4	
Chip rate (Rc)	2.048	8.192	=Rs*Ns (MHz)
Chip duration	488.3	122.1	=1/Rc (nsec)

Parameter	Value	Value	Unit
Distance (d)	30	10	m
Peak payload bit rate (Rb)	1	1024	kbps
Average Tx power (Pt)	-8.89		dBm
Tx antenna gain (Gt)	0		dBi
Frequency band	3.1 - 5.1		GHz
Geometric center frequency (fc)	3.98		GHz
Path loss @ 1m (L1)	44.43		dB
Path loss @ d m (Ld)	29.54	20.00	dB
Rx antenna gain (Gr)	0		dBi
Rx power (Pr)	-90.47	-80.93	dBm
Average noise power per bit (N)	-144.00	-113.90	dBm
Rx Noise figure (Nf)	7.00		dB
Average noise power per bit (Pn)	-137.00	-106.90	dBm
Minimum required Eb/N0 (S)	6.25		dB
Implementation loss (I)	3.50		dB
Link Margin	44.39	23.83	dB
Min. Rx Sensitivity Level	-127.25	-97.15	dBm

- – In this calculation, (24,12) Golay code is assumed. There will be several dB change if different codes are used.
- – Coherent detection is assumed. There is a maximum of 3dB loss if differential detection is used.

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

DS-UWB Link Budget (BW=500MHz)

Parameter	Value	Value	Notes
Data rate (Rb)	1	1024	(kbps)
Modulation	BPSK		Coherent detection
Coding rate (R)	1/2		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	Rs=Rb/R (ksymbol/s)
Pulse duration (Tp)	2.649	2.649	(ns)
Spreading code length (Ns)	1024	64	
Chip rate (Rc)	2.048	131.072	=Rs*Ns (MHz)
Chip duration	488.3	7.63	=1/Rc (nsec)

Parameter	Value	Value	Unit
Distance (d)	30	10	m
Peak payload bit rate (Rb)	1	1024	kbps
Average Tx power (Pt)	-16.9		dBm
Tx antenna gain (Gt)	0		dBi
Frequency band	3.85 - 4.35		GHz
Geometric center frequency (fc)	4.09		GHz
Path loss @ 1m (L1)	44.68		dB
Path loss @ d m (Ld)	29.54	20.00	dB
Rx antenna gain (Gr)	0		dBi
Rx power (Pr)	-91.12	-81.58	dBm
Average noise power per bit (N)	-144.00	-114.00	dBm
Rx Noise figure (Nf)	7.00		dB
Average noise power per bit (Pn)	-137.00	-106.90	dBm
Minimum required Eb/N0 (S)	6.25		dB
Implementation loss (I)	3.00		dB
Link Margin	36.63	16.07	dB
Min. Rx Sensitivity Level	-127.75	-97.65	dBm

- – In this calculation, (24,12) Golay code is assumed. There will be several dB change if different codes are used.
- – Coherent detection is assumed. There is a maximum of 3dB loss if differential detection is used.

CS-UWB Link Budget (BW=500MHz)

Parameter	Value	Value	Notes
Data rate (Rb)	1	1024	(kbps)
Modulation	BPSK		Coherent detection
Coding rate (R)	1/2		(24,12)-Extended Golay Hard-decision decoding
Raw Symbol rate (Rs)	2	2048	Rs=Rb/R (ksymbol/s)
Chirp signal duration (Tc)	25		(ns)
Spreading code length (Ns)	1024	4	
Chip rate (Rc)	2.048	8.192	=Rs*Ns (MHz)
Chip duration	488.3	122.1	=1/Rc (nsec)

Parameter	Value	Value	Unit
Distance (d)	30	10	m
Peak payload bit rate (Rb)	1	1024	kbps
Average Tx power (Pt)	-15.38		dBm
Tx antenna gain (Gt)	0		dBi
Frequency band	3.85 – 4.35		GHz
Geometric center frequency (fc)	4.09		GHz
Path loss @ 1m (L1)	44.68		dB
Path loss @ d m (Ld)	29.54	20.00	dB
Rx antenna gain (Gr)	0		dBi
Rx power (Pr)	-89.60	-80.06	dBm
Average noise power per bit (N)	-144.00	-114.0	dBm
Rx Noise figure (Nf)	7.00		dB
Average noise power per bit (Pn)	-137.00	-106.90	dBm
Minimum required Eb/N0 (S)	6.25		dB
Implementation loss (I)	3.50		dB
Link Margin	37.65	17.09	dB
Min. Rx Sensitivity Level	-127.25	-97.15	dBm

– In this calculation, (24,12) Golay code is assumed. There will be several dB change if different codes are used.

– Coherent detection is assumed. There is a maximum of 3dB loss if differential detection is used.

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

Scalability With DS Lengths (Examples)

Data rate (kbps)	Raw Symbol rate (ksps)	DS Code length (chip)	Chip rate (Mcps)	Link margin at 10m (dB)	Notes
DS-UWB					
1	2	1024	2.048	52.8	0.662 (ns) pulse width
16	32	1024	32.768	40.8	
32	64	1024	65.536	37.8	
128	256	256	65.536	31.8	
256	512	256	131.072	28.7	
1024	2048	64	131.072	22.7	
2048	4096	64	131.072	19.7	Optional, use 4BOK
4096	8192	64	131.072	16.7	Optional, use 16BOK
CS-UWB (optional)					
1	2	1024	2.048	53.9	100 (ns) chirp duration
16	32	64	2.048	41.9	100 (ns) chirp duration
1024	2048	4	8.192	23.8	100 (ns) chirp duration

# Advantages of 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.

2. Performance Examples

- Performance with 15.4a channel models

- Anti-interference performance (IEEE802.11a and MB-OFDM)

Performance With 15.4a CMs
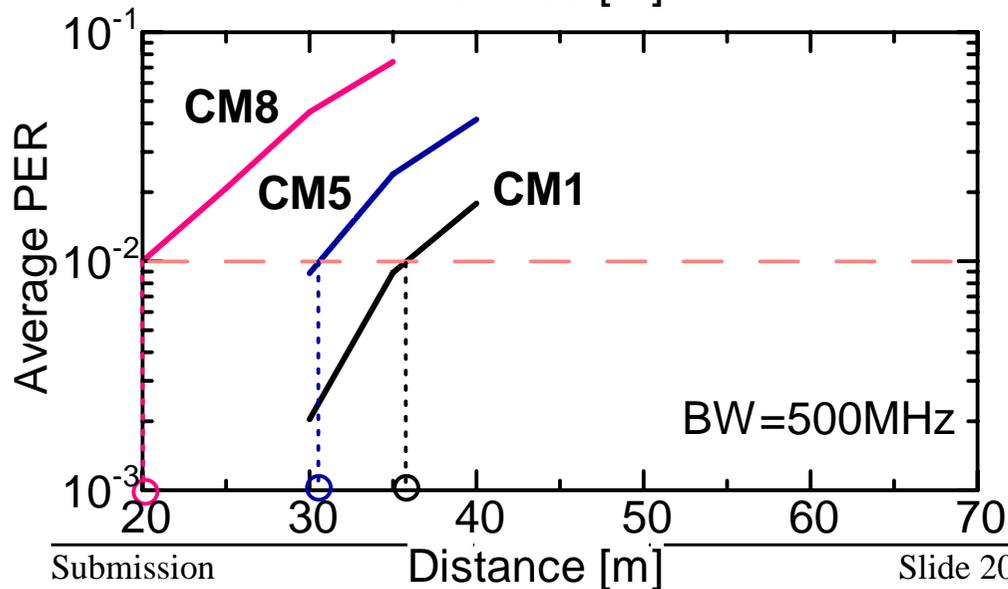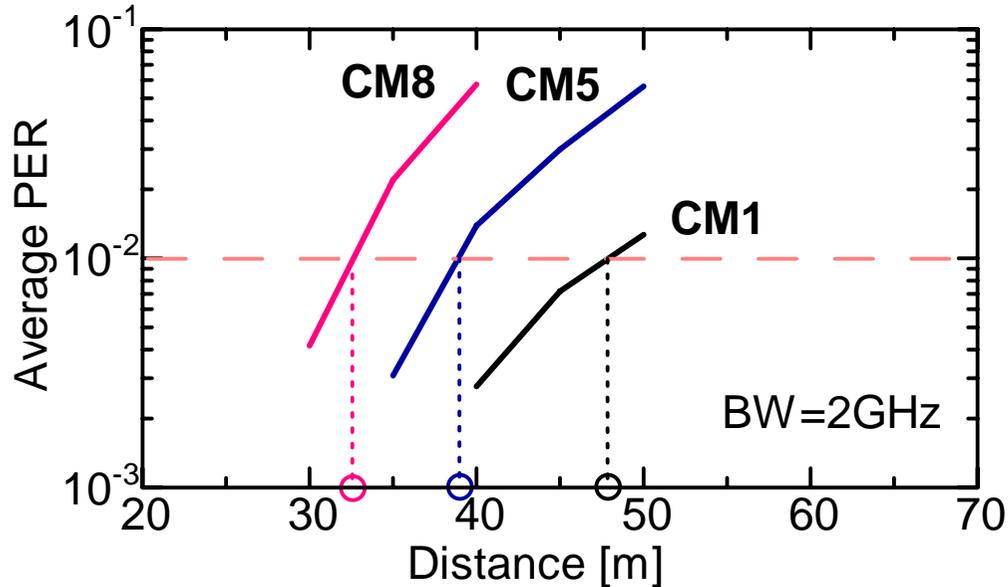
DS-UWB

- – 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 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

Interference models		Tolerable distance to achieve PER<1%
IEEE802.11a		
BW = 2GHz	Eb/N0 = inf.	0.52 m
	Eb/N0 = 10 dB	0.80 m
MB-OFDM		
BW = 2GHz	Eb/N0 = inf.	0.012
	Eb/N0 = 10 dB	0.022
BW = 500MHz	Eb/N0 = inf.	0.104
	Eb/N0 = 10 dB	0.115

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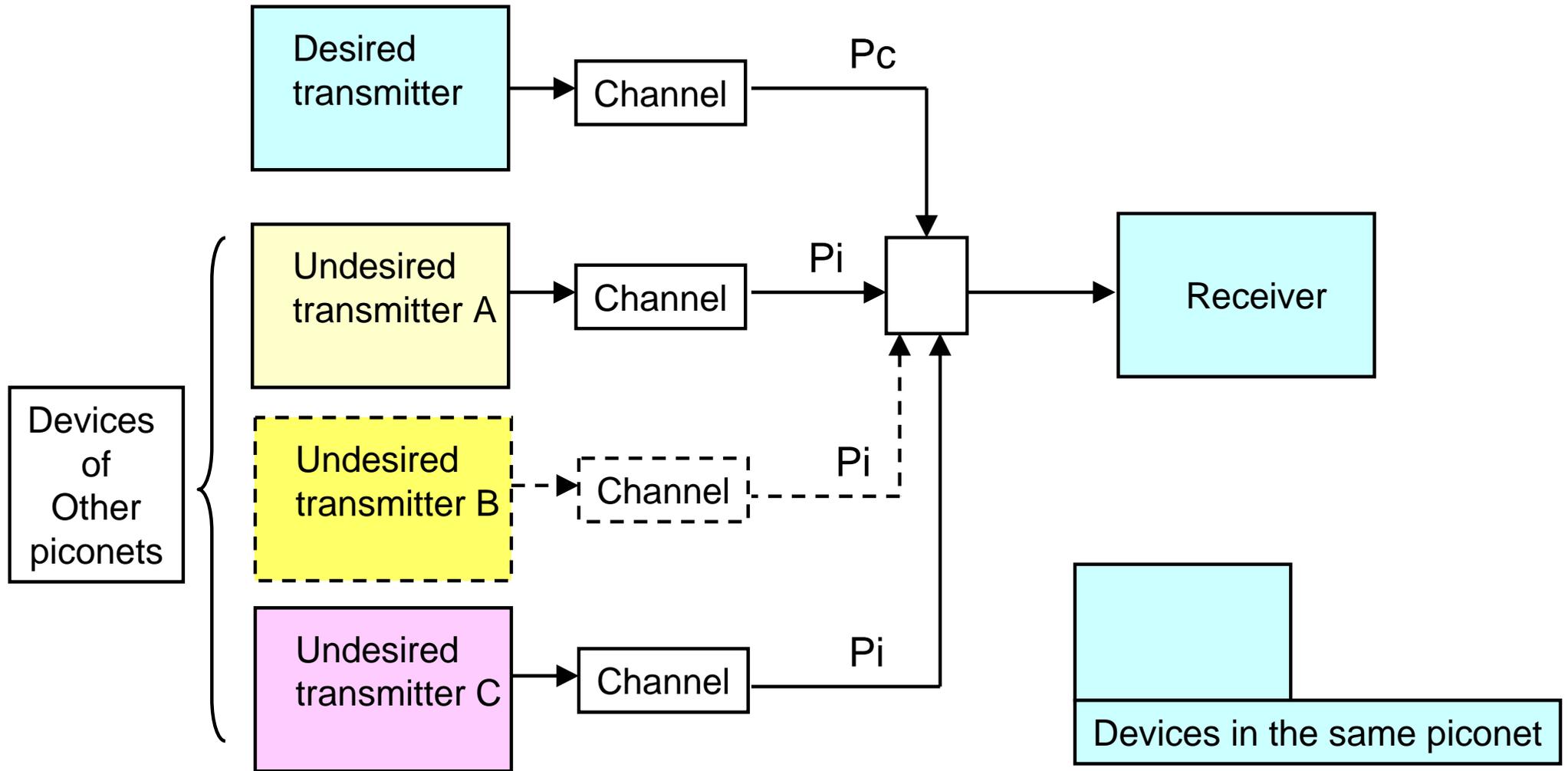Data rate = 2 Mbps, FEC off. BW = 500 MHz, fc = 3.35 GHz.

3. Multiple Access and SOP

- Multiple access method
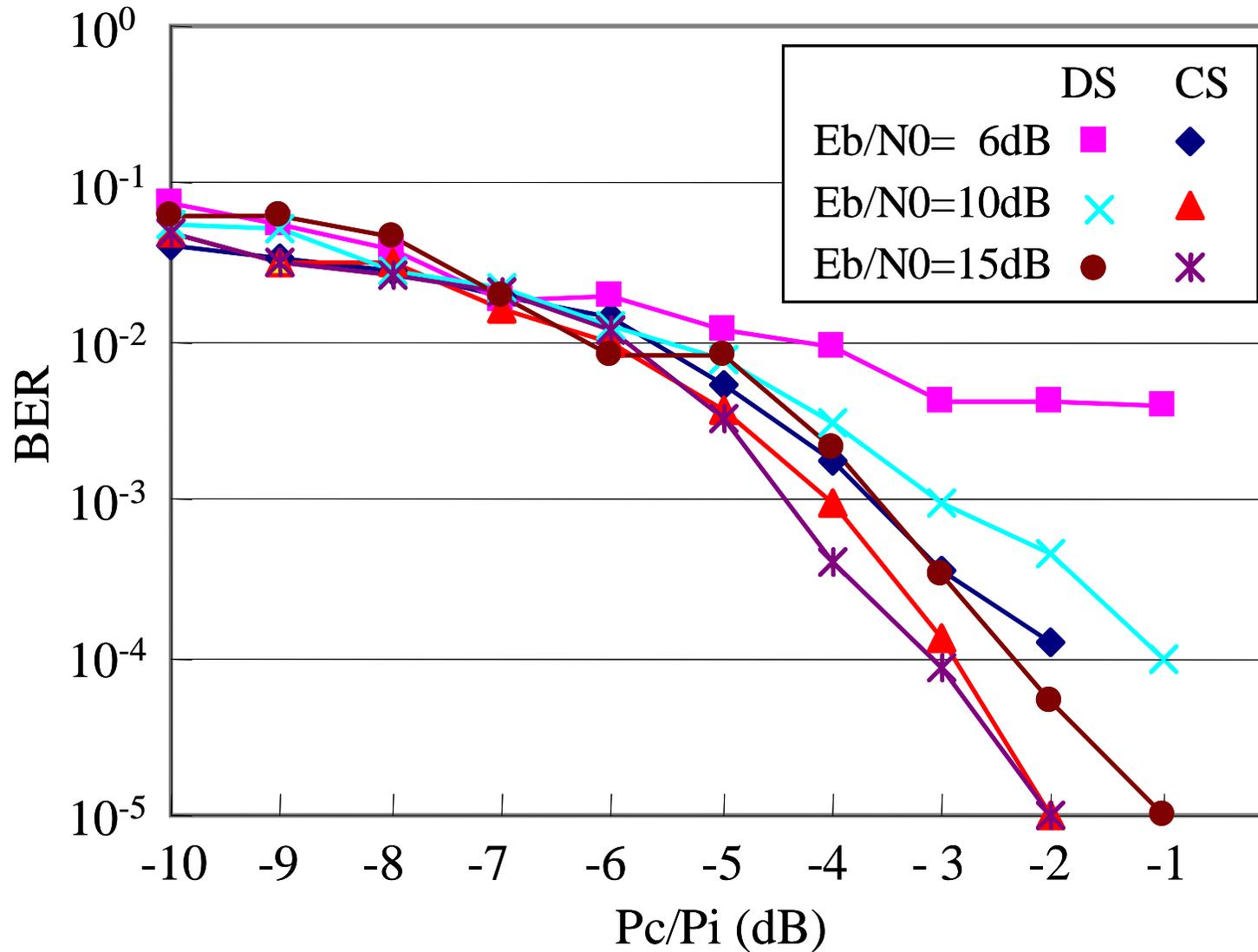
- Simulation results

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.
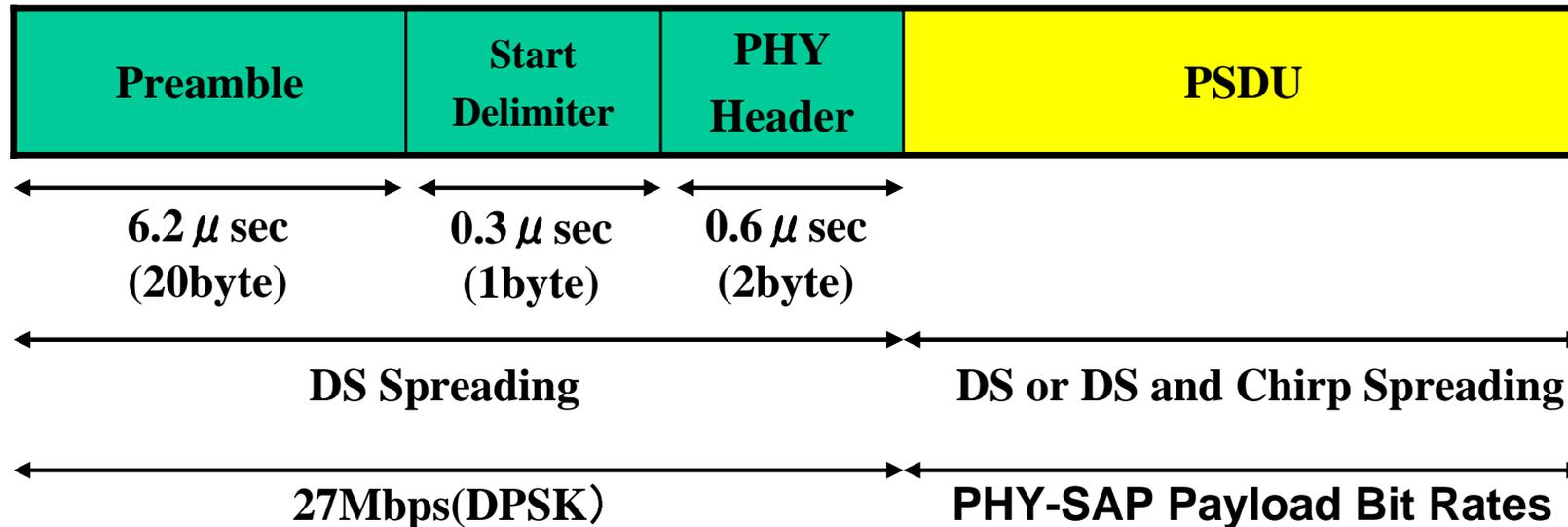
Simulation block diagram for SOP
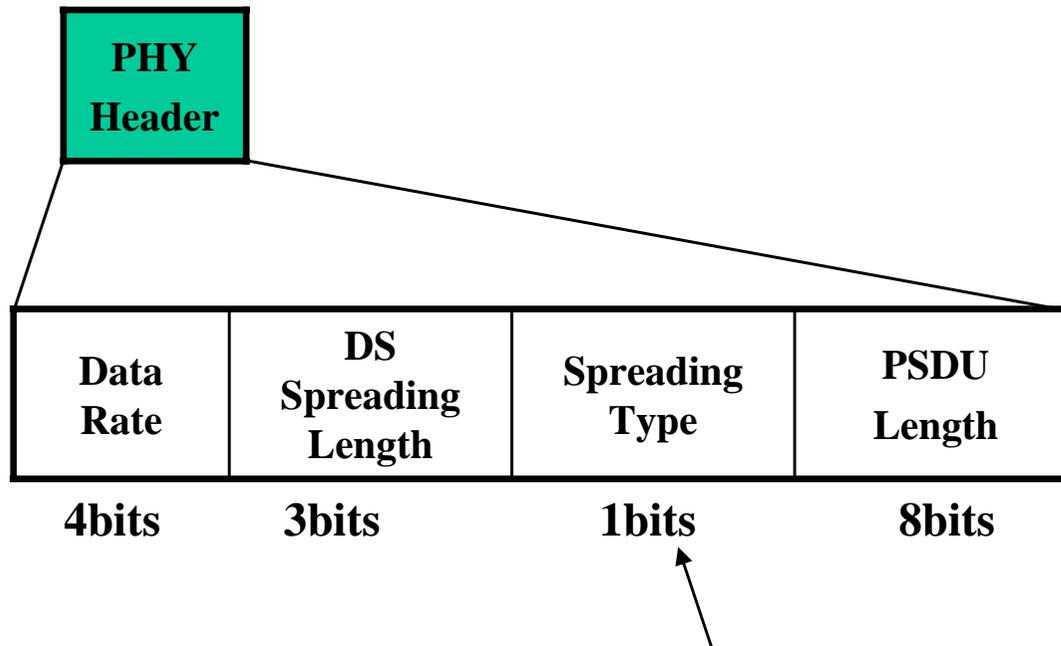
Simulation results for SOP

4. PHY Frame Structure

- Frame Format

- PHY header payload

PHY Frame Format and PHY-SAP Payload Bit Rates

Preamble	Start Delimiter	PHY Header	PSDU

6.2 μ sec (20byte)   0.3 μ sec (1byte)   0.6 μ sec (2byte)

DS Spreading   DS or DS and Chirp Spreading

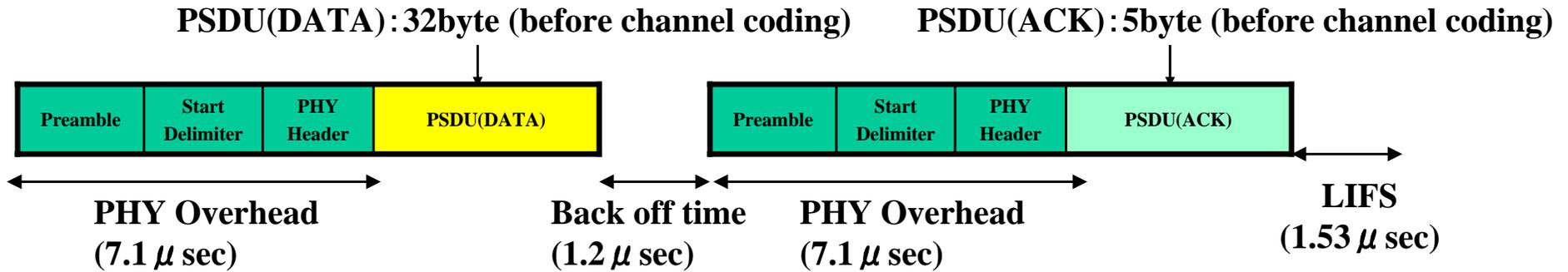27Mbps(DPSK)   PHY-SAP Payload Bit Rates

Payload of PHY Header

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

PHY Header

Data Rate	DS Spreading Length	Spreading Type	PSDU Length
4bits	3bits	1bits	8bits

0: DS Type
1: DS and Chirp Type

PHY-SAP Throughput

PSDU(DATA)：32byte (before channel coding)   PSDU(ACK)：5byte (before channel coding)

| Preamble | Start Delimiter | PHY Header | PSDU(DATA) |

| Preamble | Start Delimiter | PHY Header | PSDU(ACK) |

PHY Overhead
(7.1 μ sec)

Back off time
(1.2 μ sec)

PHY Overhead
(7.1 μ sec)

LIFS
(1.53 μ sec)

Bit Rate (kbps)	1	2.1	8.4	16.9	33.8	135	406	1083	3250	8666	27000
Pay Load (kbps)	1	2.1	8.4	16.9	33.8	134.9	401.7	1051	2982	6992	15127
Throughput (kbps)	0.9	1.8	7.3	14.6	29.2	116.2	343.4	882	2370	5012	9043

5. 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.

	DS-UWB		CS-UWB	
Bandwidth (GHz)	2.0	0.5	2.0	0.5
Ranging resolution (cm)	19.86	79.47	30	120

6. Technical Feasibility

A) Power Management

B) Manufacturability

C) Mobility

D) Time to market

A) Power Management Mode

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

B) Manufacturability

– Proposed system can be manufactured right now by conventional standard CMOS technology such as 0.13μm.

– Basics of the system have been demonstrated in DS-UWB 802.15.3a proposal.

C) Mobility

- ## Low data rate device tracking

- ## Assumptions

  -Distance resolution：0.3m

  -Date Rate : 1kbps

- ## Tolerable velocity

  (1) CSMA mode

   V_C<39km/H (=0.3m/28msec)

   (28msec: Data transfer duration time of 1kbps mode)

  (2) Beacon mode

   V_B<V_C/2

D) 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.