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

Submission Title: [Preliminary WBAN proposal using IR-UWB(ETRI)]
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Re: [Proposal to IEEE 802.15.6 Meeting, March 2009]

Abstract: [We propose a WBAN system which supports scalable data-rate modes and is based on the IR-UWB technique. We propose two modulation schemes; BPM + BPSK and Group PPM.

Purpose: [To be considered in IEEE 802.15.6]

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- Why IR-UWB ?
- Overview of IEEE 802.15.4a
  - Alternative PHY (BPM + BPSK)
- Proposed PHY (Group PPM)
- MAC Channel Access Mechanism
- Summary

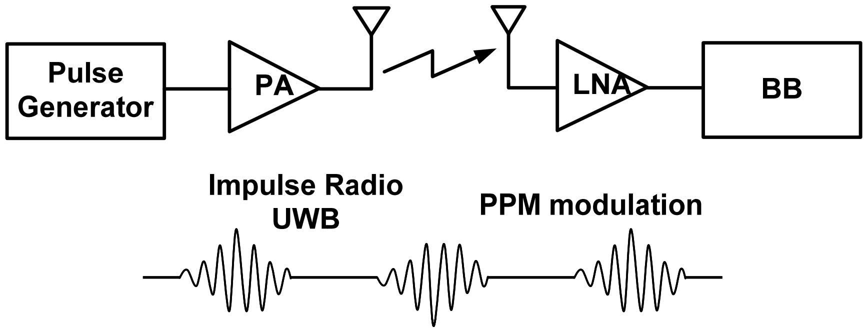
WBAN PHY Requirement

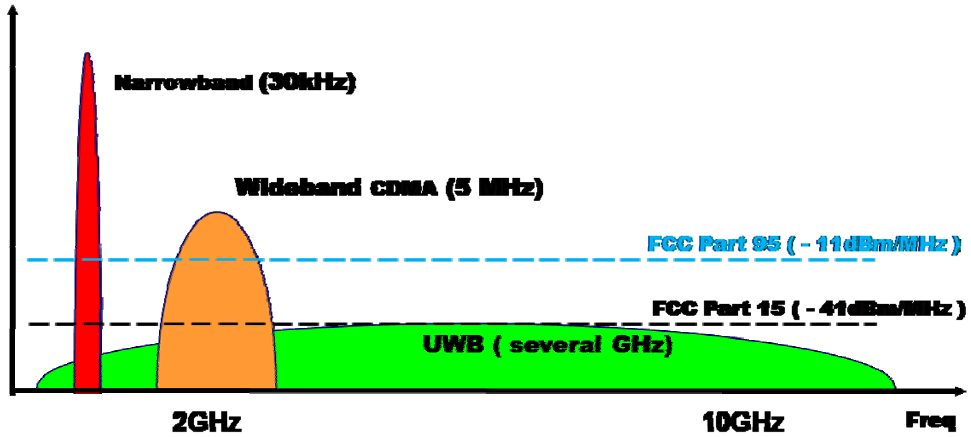
- Low Power Consumption
- PHY data-rate (Scalability)
  - Scalability for data rate
  - 10Kbps(low data) ~10Mbps(raw data)
- Range (3 meters)
- Link budget for proposed PHY
- Human safety (Low RF emission power)

Why IR-UWB ?

- Low implementation complexity
  - Low power consumption
- Low transmitting power
  - Coexistence (Underlay)
  - Human safety

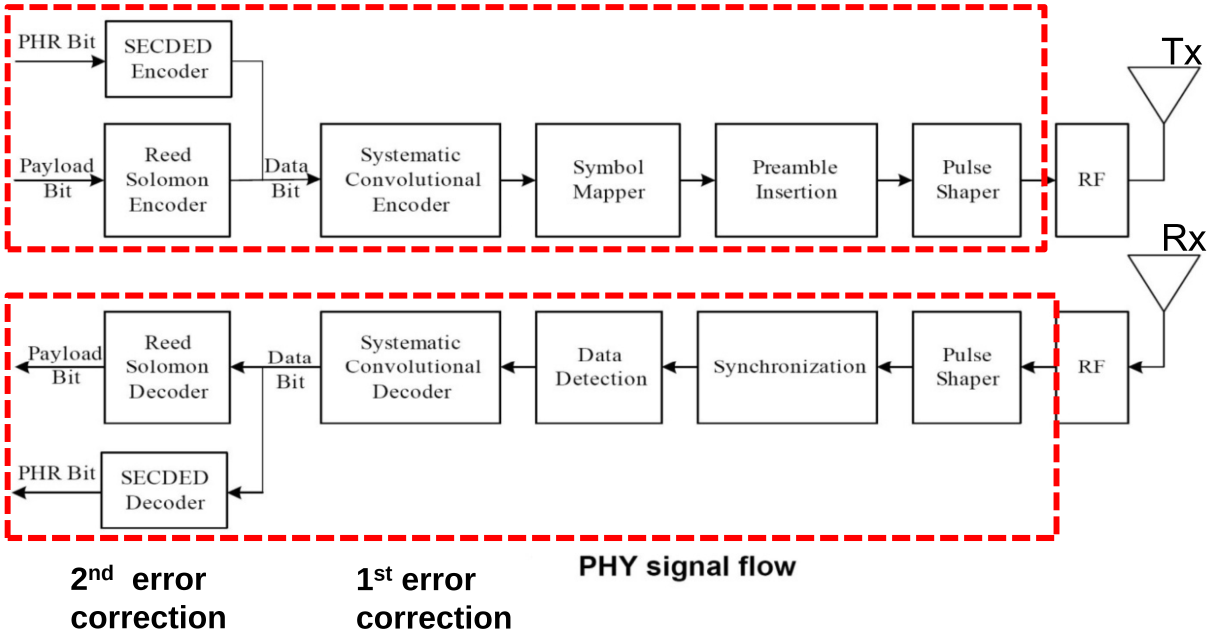
  (RF power = -41.3dBm/MHz)
- Scalable data rate
  - 10Kbps ~ 10Mbps





IEEE 802.15.4a IR-UWB

- Concatenated code (RS code& Convolutional code)
- Modulation (Combination of BPM+BPSK)
- Data rate mode
  - Mandatory : 0.85Mbps
  - Optional : 0.11, 6.81, 27.24 Mbps



IEEE 802.15.4a PHY Parameters

- Symbol Parameter
  - Preamble Code length : 31
  - Bandwidth : 499.2 MHz
  - Chip Duration : 2.024 nsec

Channel Coding Rate			Data Symbol Structure			Data Rate	
Viterbi rate	RS rate	Overall FEC rate	#chips per Symbol	#chips per burst	# Hop burst	symbol rate (Mbps)	bit rate (Mbps)
0.5	0.87	0.435	4096	128	8	0.12	0.11
0.5	0.87	0.435	512	16	8	0.98	0.85
0.5	0.87	0.435	64	2	8	7.8	6.81
1	0.87	0.87	32	1	8	15.6	27.24

Mandatory

Alternative PHY : BPM + BPSK

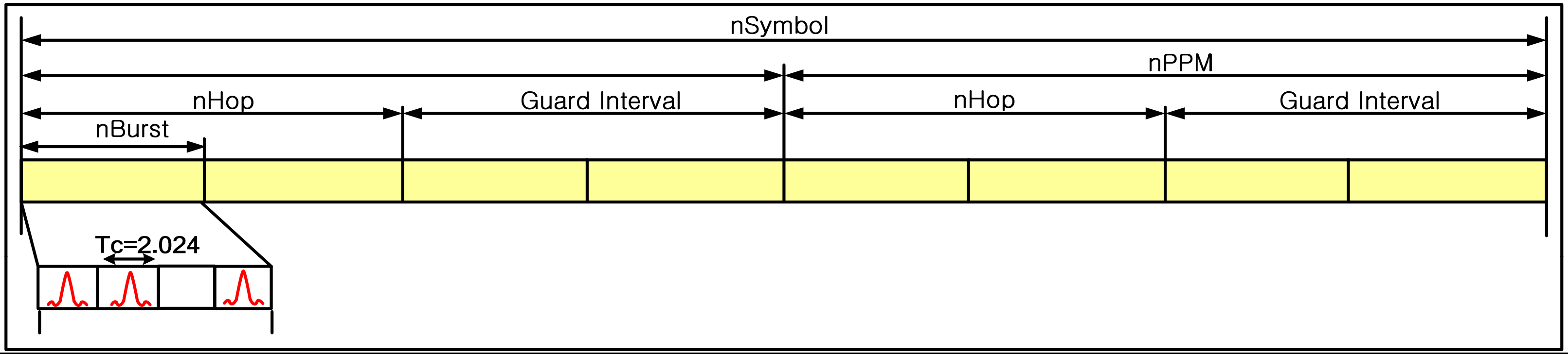
- Modified version of IEEE 802.15.4a frame structure
- Concatenated code
  - Convolutional code, Reed Solomon code
- Modulation method
  - BPM+ BPSK
- Scalable data-rate
  - 10Kbps(low data) ~10Mbps(high data)

Alternative PHY : BPM+BPSK

- PHY Symbol Table
  - Scale data rate for WBAN

Data Rate Mode	Channel Coding Rate			Data Frame Structure			Data Rate (Mbps)	
	Viterbi	RS	Overall	nSymbol	nBurst	nHop	symbol rate	bit rate
10 Kbps	0.5	0.87	0.435	32768	1024	8	0.015078	0.01312
100 Kbps	0.5	0.87	0.435	4096	128	8	0.120623	0.10494
1 Mbps	0.5	0.87	0.435	256	8	8	1.929965	1.67907
10 Mbps	0.5	0.87	0.435	32	1	8	15.43972	13.4326

- Frame Structure



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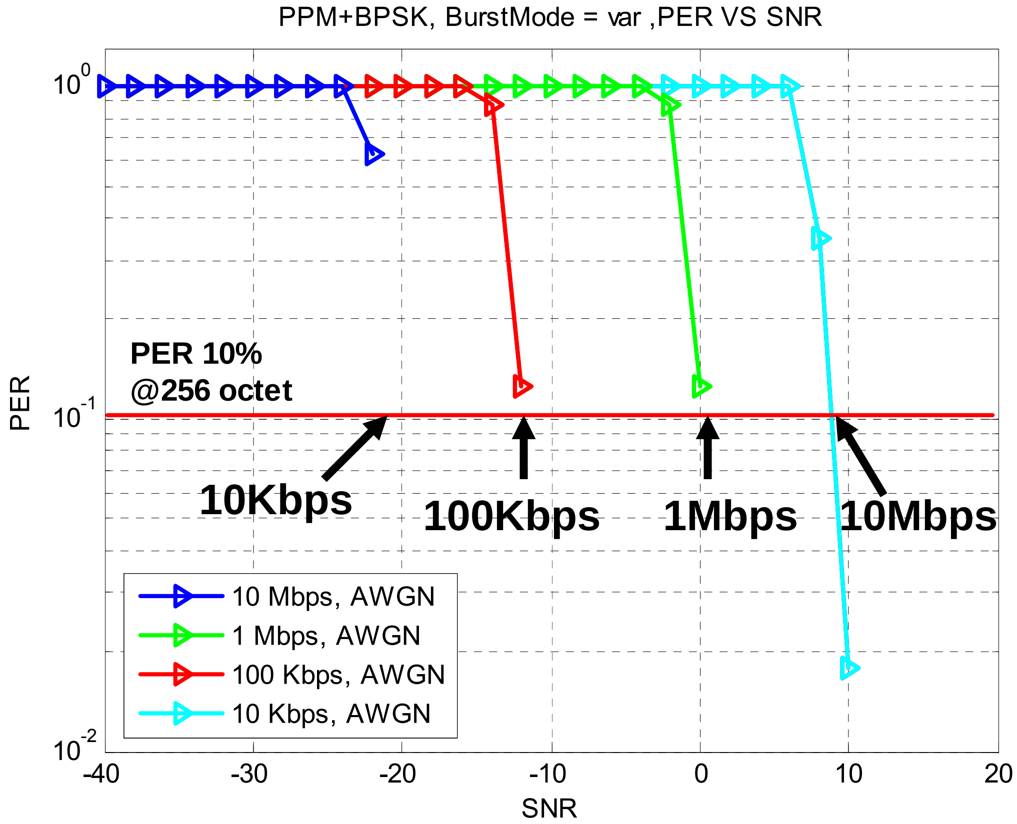
Performance of BPM+BPSK

- AWGN Channel



Minimum SNR at PER (10% @ 256 octet)

→SNR_{min} of 10Mbps = 9dB

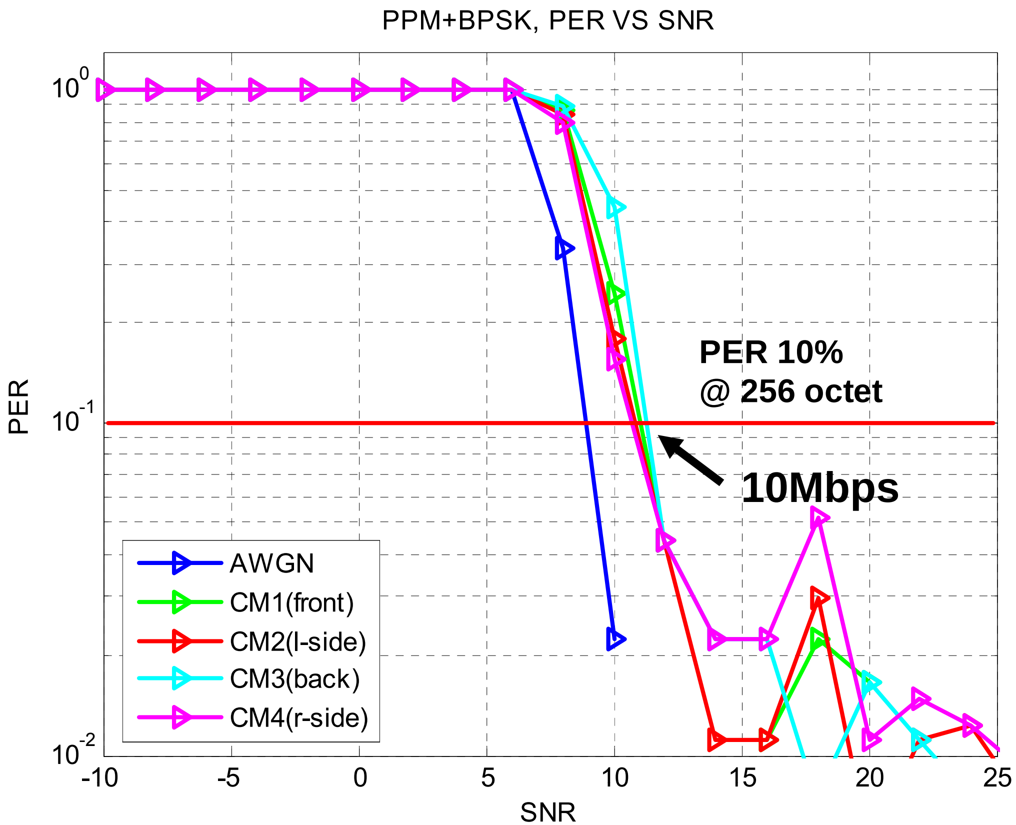
→SNR_{min} of 1Mbps = 0 dB

→SNR_{min} of 100Kbps = -11dB

→SNR_{min} of 10Kbps = -20dB

Performance of BPM + BPSK

- WBAN channel (front, L-side, back, R-side)



Minimum SNR at PER (10% @ 256 octet)

→SNR_{min} of 10Mbps = 11dB

WBAN Link budget

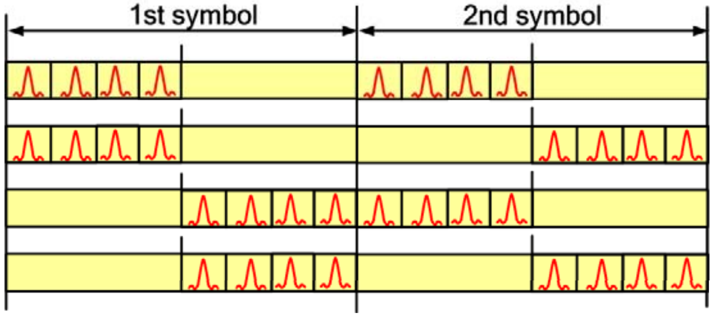
Parameter	10Mbps
peak payload bit rate	13.4 (Mbps)
Distance	3m
Average Tx power	-14.3 (dBm)
Tx antenna gain	0 (dBi)
geometric center frequency of waveform	4.4928×10^9 (Hz)
Path loss at 1 meter	-45.5 (dB)
Path loss at *d* m	-9.5 (dB)
Rx antenna gain	0 (dBi)
Rx power	-69.3 (dBm)
Rx Noise Floor	-87.0 (dBm)
Rx Noise Figure	10 (dB)
Noise Reduction by Duty Gain	15.1
Average noise power per bit	-92.1 (dBm)
Minimum Eb/N0 (*S*) [Ep/N0]	11 (dB)
Implementation Loss (I)	5 (dB)
Link Margin	6.8 (dB)
Proposed Min. Rx Sensitivity Level	−76.1

Proposed PHY : Group PPM

- Modified version of IEEE 802.15.4a frame structure for BPM modulation
- Proposed Group PPM method
  - Increase throughput
  - Error check algorithm
  - Data encryption algorithm
- Scalable data-rate
  - Up to 10Mbps(high data)

Entropy comparison

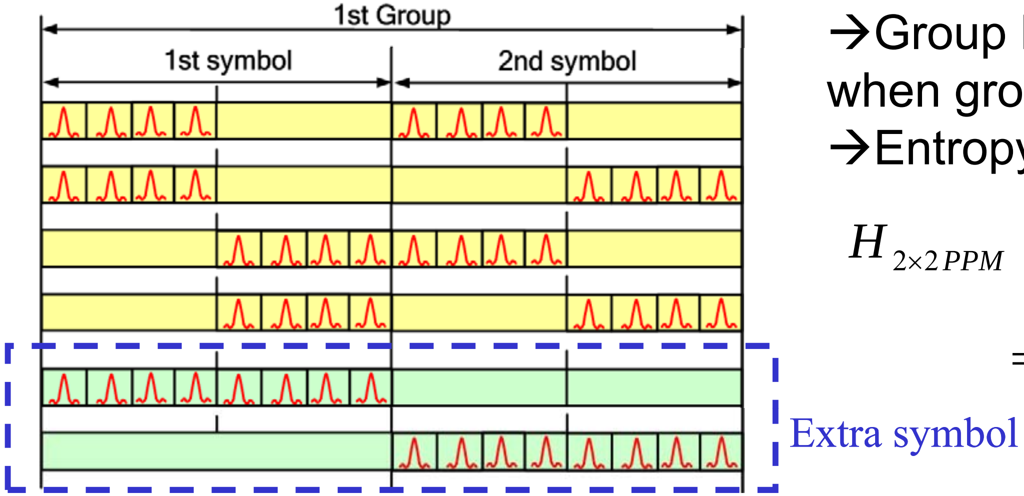
- Conventional PPM symbols



→PPM has only 4 case of stream
→Entropy is only 2, that is transmit 2bit in binary systems

$$H_{2\times 2PPM} = \sum P_{2\times 2PPM} \log 2(1/P_{2\times 2PPM})$$
$$= 4\times\frac{1}{4}\log 2(4) = 2$$

- Proposed PPM symbols



→Group PPM has 6 case of stream when group 2 symbols
→Entropy increase to 2.634,

$$H_{2\times 2PPM} = \sum P_{2\times 2PPM} \log 2(1/P_{2\times 2PPM})$$
$$= 6\times\frac{1}{6}\log 2(6) = 2.634$$

Entropy in Group PPM

- Calculate the Entropy and the number of cases both conventional PPM and group PPM
- Increased Entropy values can be used to increase data-rate
- 3GPPM : 4/3 = 1.33%

ENTROPY OF METHOD EACH GROUP

Number of Group	Conventional PPM		Proposed PPM	
	Number of cases	Entropy	Number of cases	Entropy
1	2	1	2	1
2	4	2	6	2.5849
3	8	3	20	4.3219
4	16	4	70	6.1292
5	32	5	252	7.9772

Entropy increase

Entropy increase, the values of integer number increases

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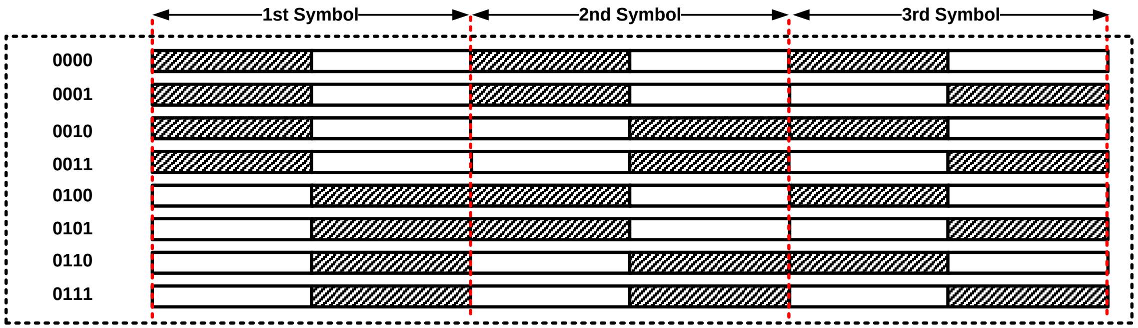
Concept of Group PPM (3 Group GPPM)

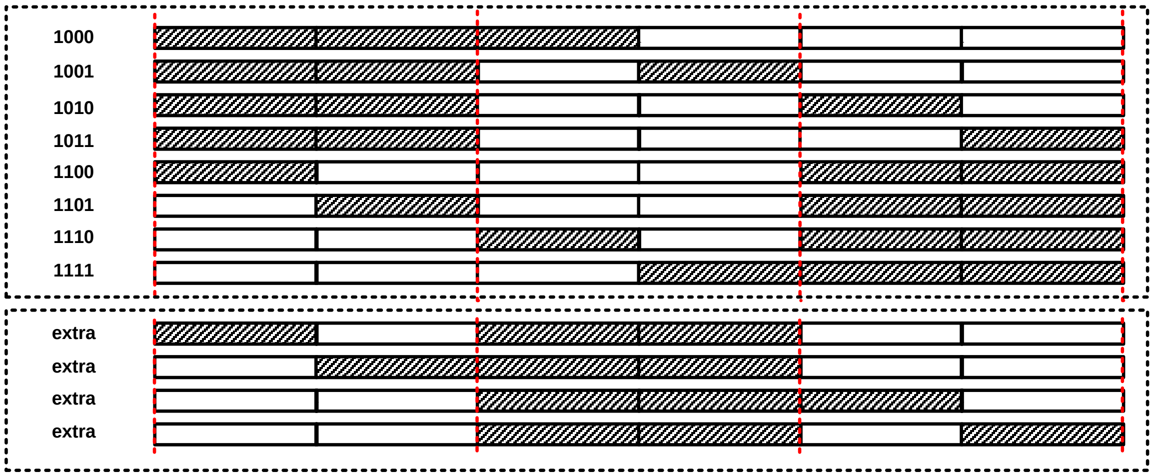
- Conventional PPM symbols



→ Usual
8 symbols

+

- Additional PPM symbols



→ Additional
8 symbols

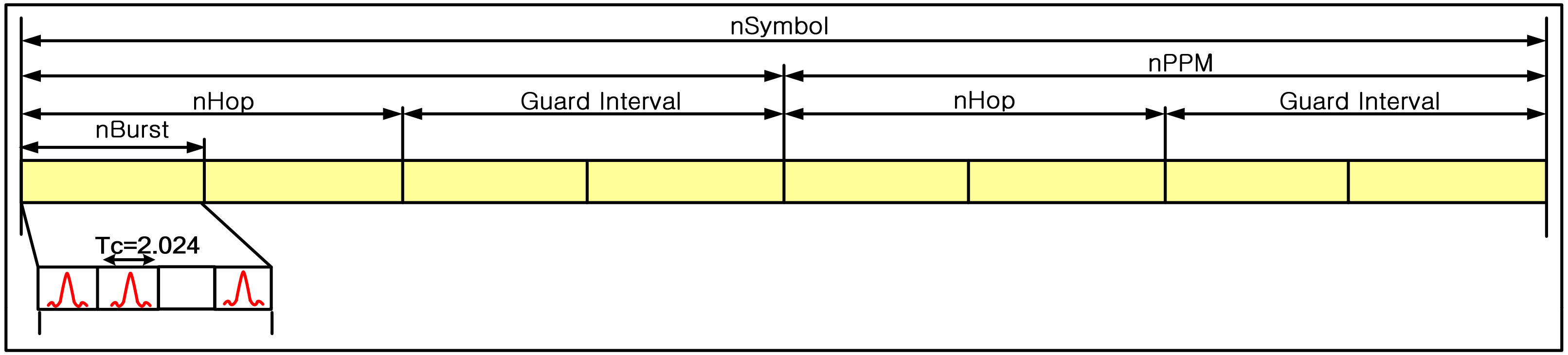
= 1bit increase

GPPM Scalability & Frame Parameter

- 3Group PPM, channel coding : Off

Data Rate Mode	Channel Coding Rate			Data Frame Structure			Data Rate (Mbps)	
	Viterbi	RS	Overall	nSymbol	nBurst	nHop	symbol rate	bit rate
10 Kbps	1	1	1	65536	2048	8	0.007539	0.01003
100 Kbps	1	1	1	4096	128	8	0.120623	0.16043
1 Mbps	1	1	1	512	16	8	0.964983	1.28343
10 Mbps	1	1	1	64	2	8	7.719862	10.2674

- Frame Structure



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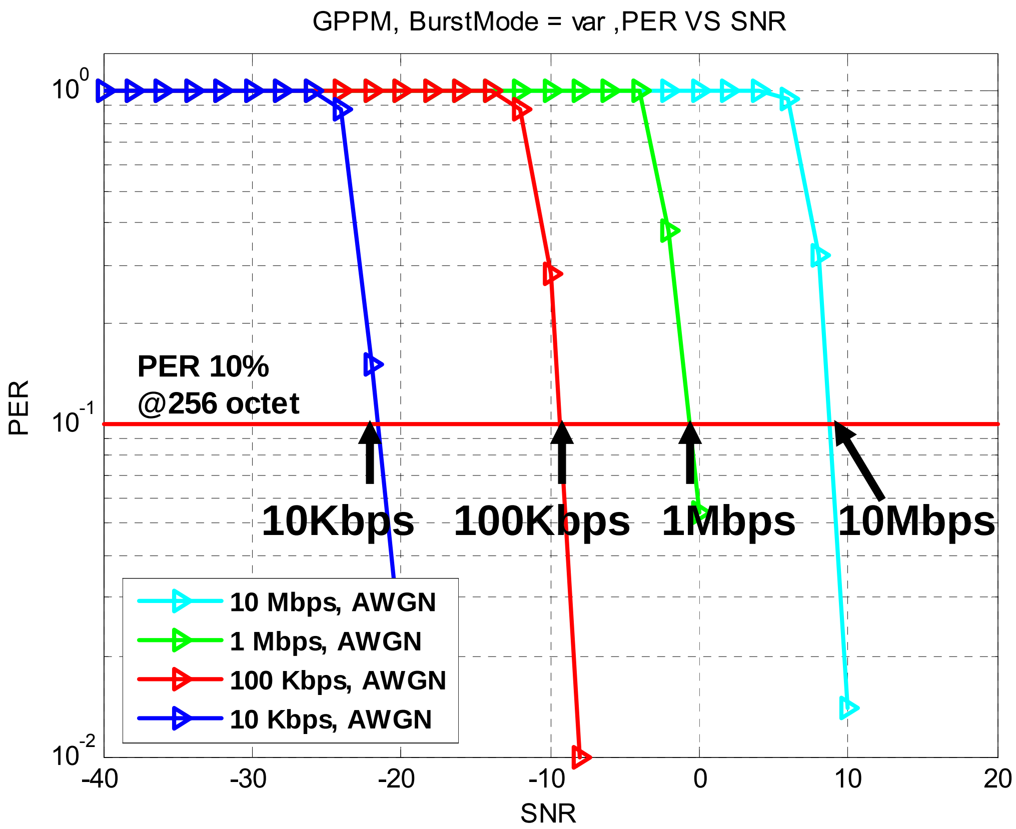
Performance of GPPM

- AWGN Channel



Minimum SNR at PER (10% @ 256 octet)

→ SNR_{min} of 10Mbps = 9 dB

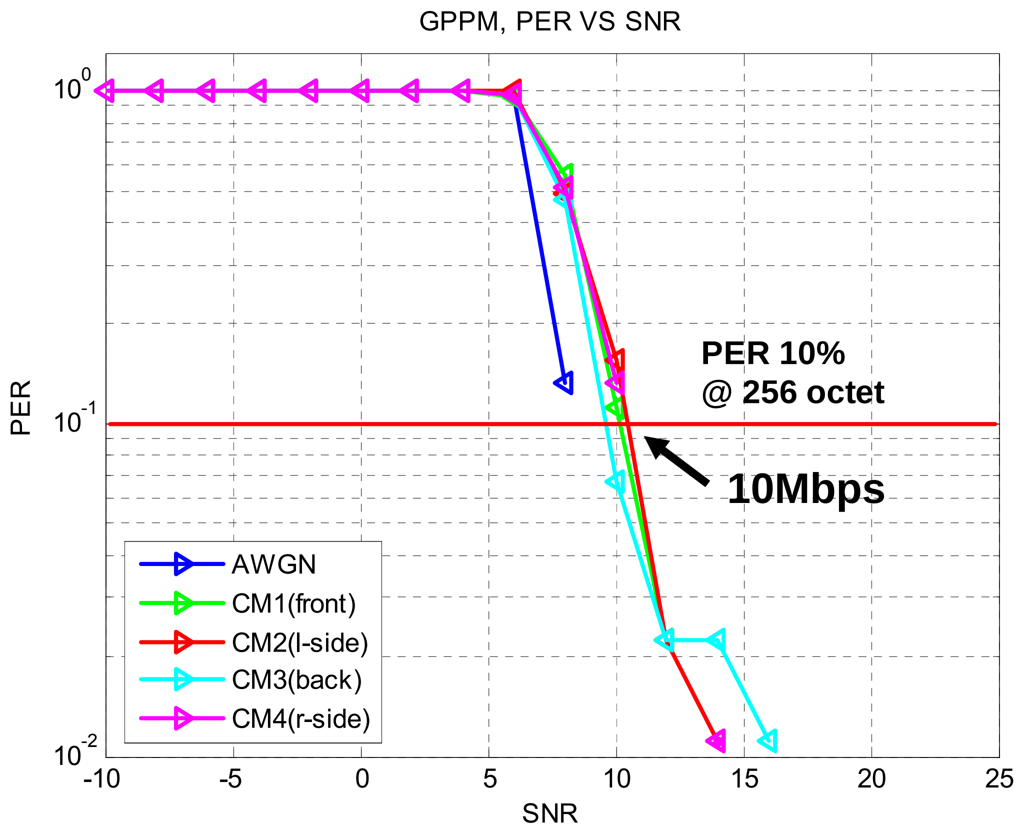
→ SNR_{min} of 1Mbps = 0 dB

→ SNR_{min} of 100Kbps = -10 dB

→ SNR_{min} of 10Kbps = -21dB

Performance of GPPM

- WBAN channel (front, L-side, back, R-side)



Minimum SNR at PER (10% @ 256 octet)

→SNR_{min} of 10Mbps = 10 dB

GPPM Link budget

Parameter	10Mbps
peak payload bit rate	10.2 (Mbps)
Distance	3m
Average Tx power	-14.3 (dBm)
Tx antenna gain	0 (dBi)
geometric center frequency of waveform	4.4928×10^9 (Hz)
Path loss at 1 meter	-45.5 (dB)
Path loss at *d* m	-9.5 (dB)
Rx antenna gain	0 (dBi)
Rx power	-69.3 (dBm)
Rx Noise Floor	-87.0 (dBm)
Rx Noise Figure	10 (dB)
Noise Reduction by Duty Gain	15.1
Average noise power per bit	-92.1 (dBm)
Minimum Eb/N0 (*S*) [Ep/N0]	10 (dB)
Implementation Loss (I)	5 (dB)
Link Margin	7.8 (dB)
Proposed Min. Rx Sensitivity Level	−77.1

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Characteristics of GPPM

- Simplicity :
  - IR-UWB scheme, low power
  - Non-Coherent structure
- Scalability :
  - Easy to convert data rate
- Error check :
  - Error check using extra symbol
- Efficiency enhancement :
  - Better efficiency at higher data-rate than BPM
- Security (data encryption) :
  - Scrambled mapping code

WBAN MAC Requirement

- Scalability for link connection between nodes
  - Accommodate several nodes in networks
  - Support efficient link connection and disconnection
  - Non periodic data communications
- QoS for secure data transmission
  - Scalable data rate from10kbps up to 10Mbps
  - Need to satisfy delay and throughput profile
  - Reliable communication for real time applications

Proposed MAC mechanism

- Support data rate scalability
  - Data rate from 10kbps up to 10Mbps
- Combination of CSMA and TDMA
  - Modified 802.15.4/4a MAC architecture
  - Superframe composed of Channel Contention Period (CCP) and Slot Allocation Period (SAP)
  - Efficient bandwidth utilization using adaptive slot allocation for multiple nodes

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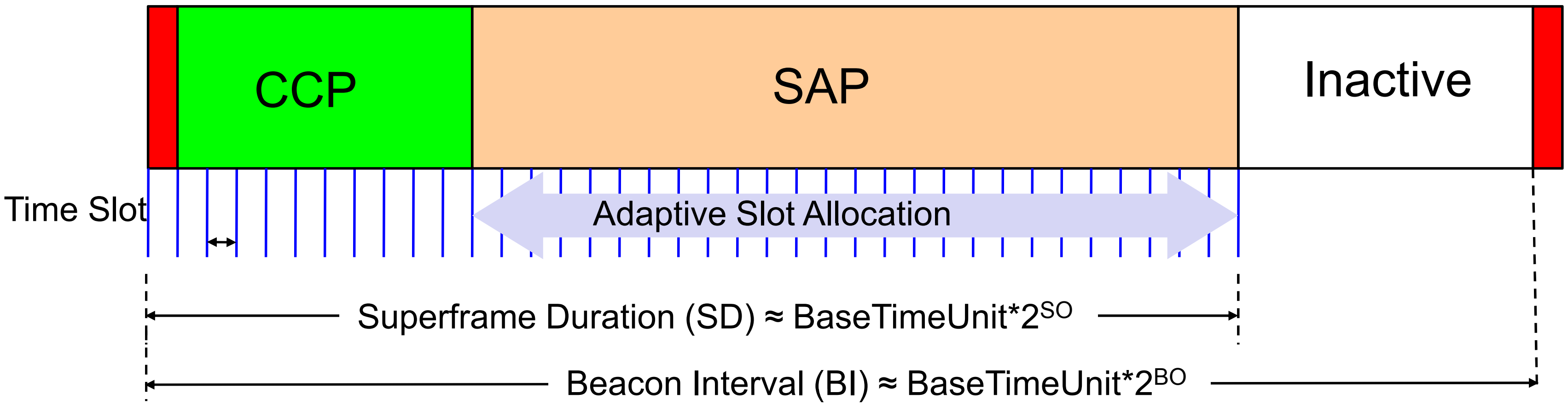
WBAN superframe structure



Network beacon (red)	Periodically synchronize the communication among nodes and distribute network wide information
Channel Contention Period (green)	Channel access based on contention for any nodes (CSMA based approach)
Slot Allocation Period (orange)	Reserved for nodes requiring guaranteed Bandwidth to allocate an active slot (TDMA based approach)

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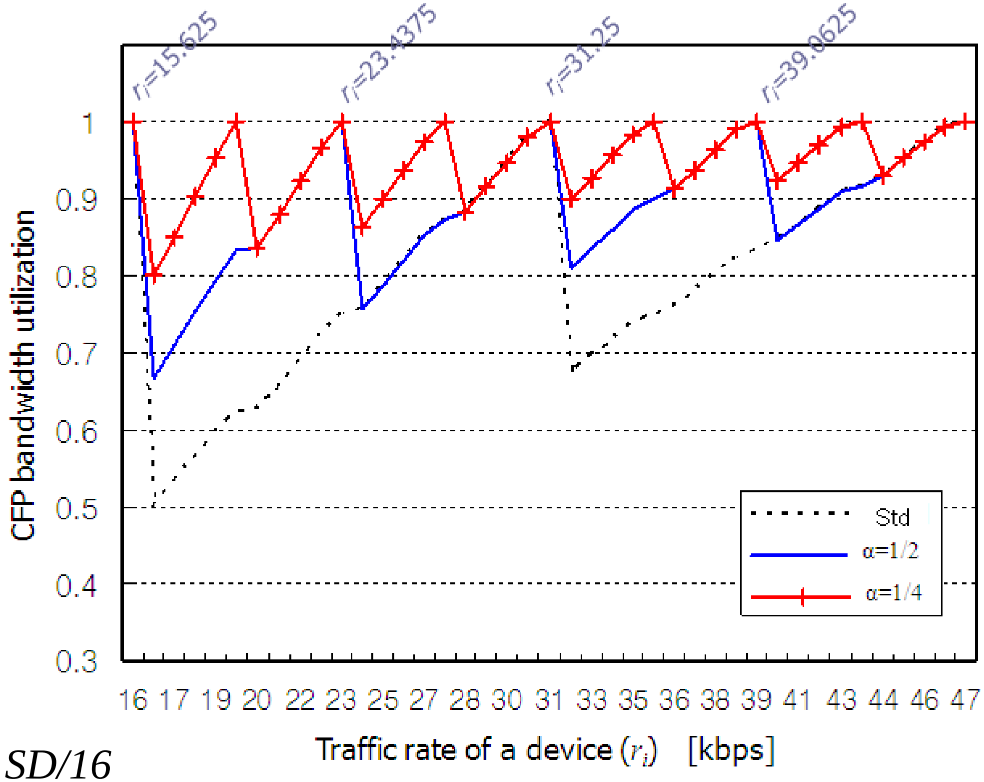
Adaptive Slot Allocation

- Bandwidth utilization using Adaptive Time Slot allocation in SAP
  - Higher bandwidth utilization than 802.15.4a
  - Proposed method

$$U'_{CFP} = \frac{2^{BO-SO+4}\sum_{i=1}^{m} r_i}{\alpha C \sum_{i=1}^{m}\left\lceil \frac{2^{BO-SO+4}\, r_i}{\alpha C}\right\rceil}$$

$$, \ where \quad \alpha = \frac{T'_s}{T_s} = \begin{cases} 1 & , 0 \le SO \le 2 \\ 1/2 & , 3 \le SO \le 5 \\ 1/4 & , 6 \le SO \le 8 \\ 1/8 & , 9 \le SO \le 11 \\ 1/16 & , 12 \le SO \le 14 \end{cases}$$



  - Example
    - *SO*=*BO*=4,*C*=850 kbps,*m=1*,*Ts* = *SD/16*
    - $N_i = \lceil t_i / T_s \rceil \quad t_i = (r_i \times BI)/C$

Summary

- GPPM PHY Proposal
  - Transmitted Signal : Impulse radio UWB
  - Support scalable data rate
  - Good efficiency in data rate of 10Mbps
  - Compatibility with IEEE 802.15.4a mechanism

- MAC Proposal
  - Combination of CSMA-CA and TDMA approach
  - Efficiency enhancement using adaptive slot allocation