Project: IEEE 802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Panasonic PHY and MAC Proposal to IEEE802.15 TG3c CFP]
Date Submitted: [07 May, 07]
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Re: [In response to TG3c Call for Proposals (IEEE P802.15-07-0586-02-003c)]]
Abstract: [Panasonic PHY and MAC proposal for portable applications]
Purpose: [To be considered in TG3C baseline document.]

Panasonic PHY&MAC Proposal to IEEE802.15 TG3c for Portable Applications

Panasonic Team

Contents

- General Overview
- PHY Layer Design
  - Channelization
  - Frame formats
  - BER and PER performances
- Implementation Feasibility
  - Non-coherent architecture as a simplest radio
- MAC Layer
  - Coexistence among different modulated signals
- Summary

General Overview

- PHY & MAC partial proposal
- Fulfill the UM5 in TG3C UMD
  - Kiosk file down/uploading: typical range is 1m, point-to-point
- PHY layer:
  - Single carrier OOK, BPSK and QPSK modulations used in each band
  - Reed-Solomon code mandatory for FEC
- Implementation feasibility:
  - Coherent and Non-coherent architectures
  - Simple hardware design with low power consumption, very suitable for portable devices applications
  - Quick to the market
- MAC layer:
  - Modification based on IEEE802.15.3 centralized MAC
  - Adaptive dual beaconing mode for coexistence

Problems for CE Applications by using Millimeter Wave

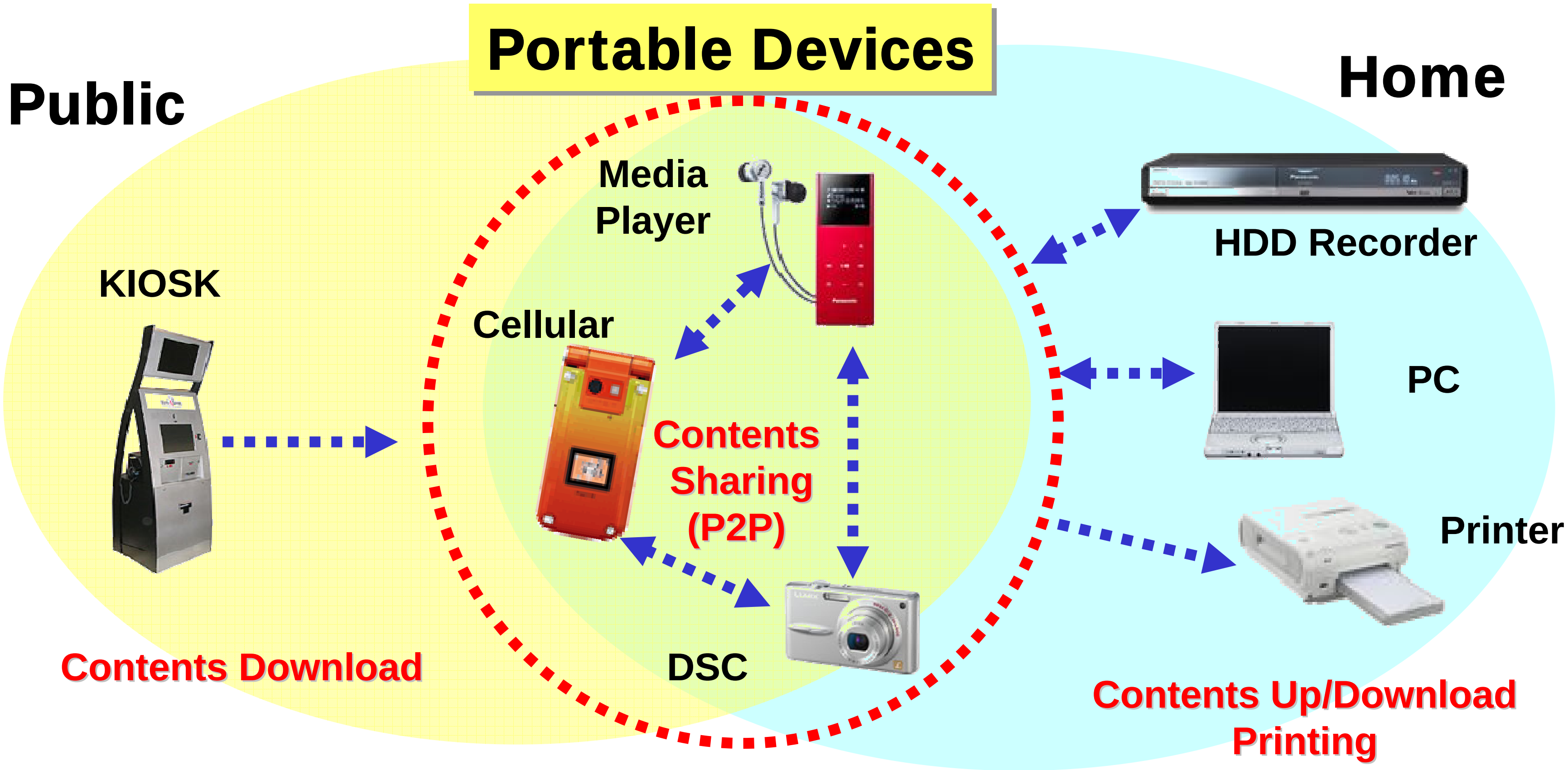
- Cost
- Power Consumption
- Shape Factor
- Mass Productivity

Low Complexity is Most Important Factor!

- Killer Application

UM5 can be solved by only using MMW

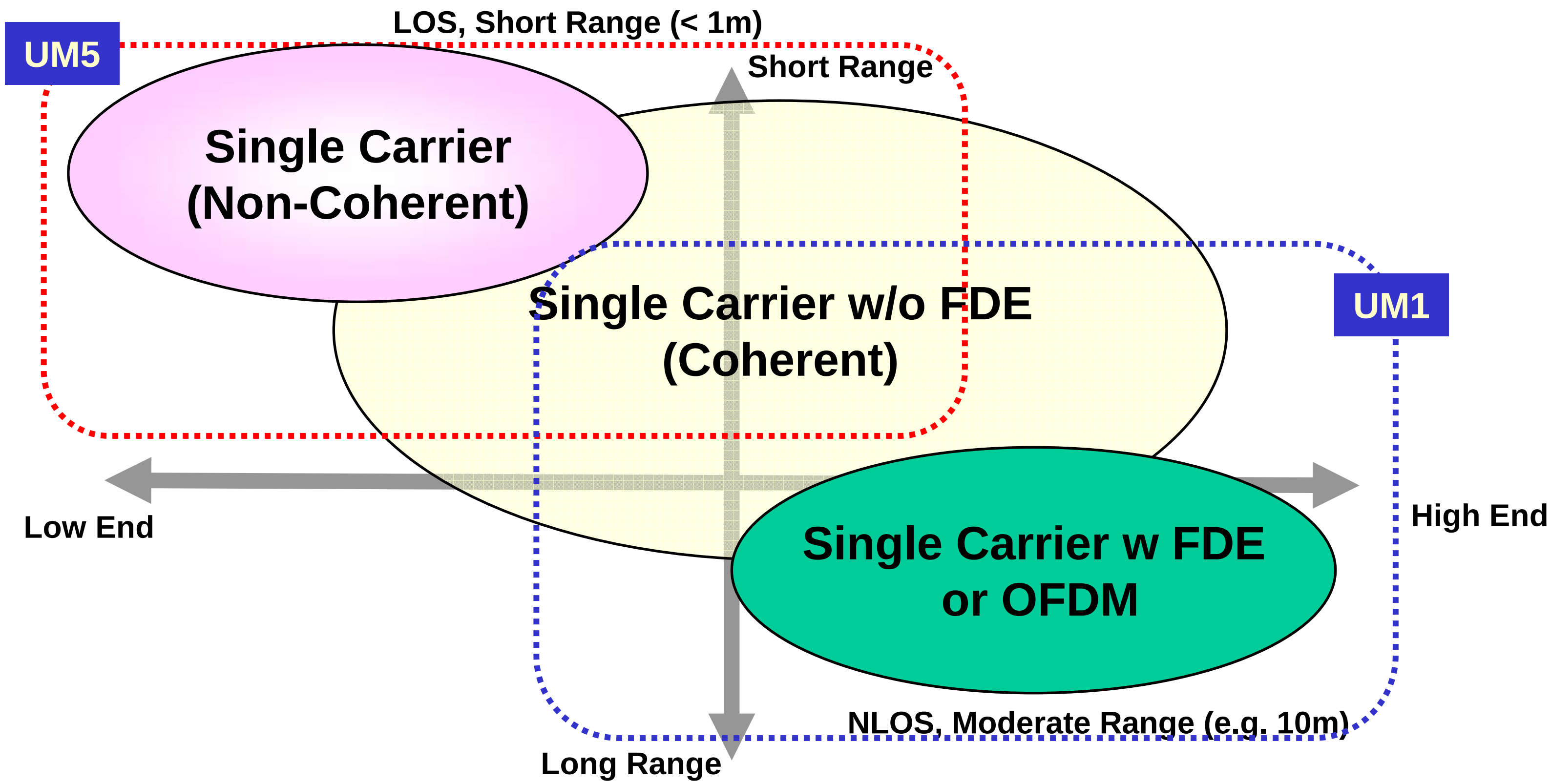
Application Scenario in UM5



- Requirements from portable devices
  - Low power consumption, Low cost and Compactness

Classified Solutions for UM1 and UM5

- UM1 and UM5 requirements are completely different.
- Suitable solution for each UMs should be chosen.
- Single Carrier with adaptive modulation can support all Application Scenarios

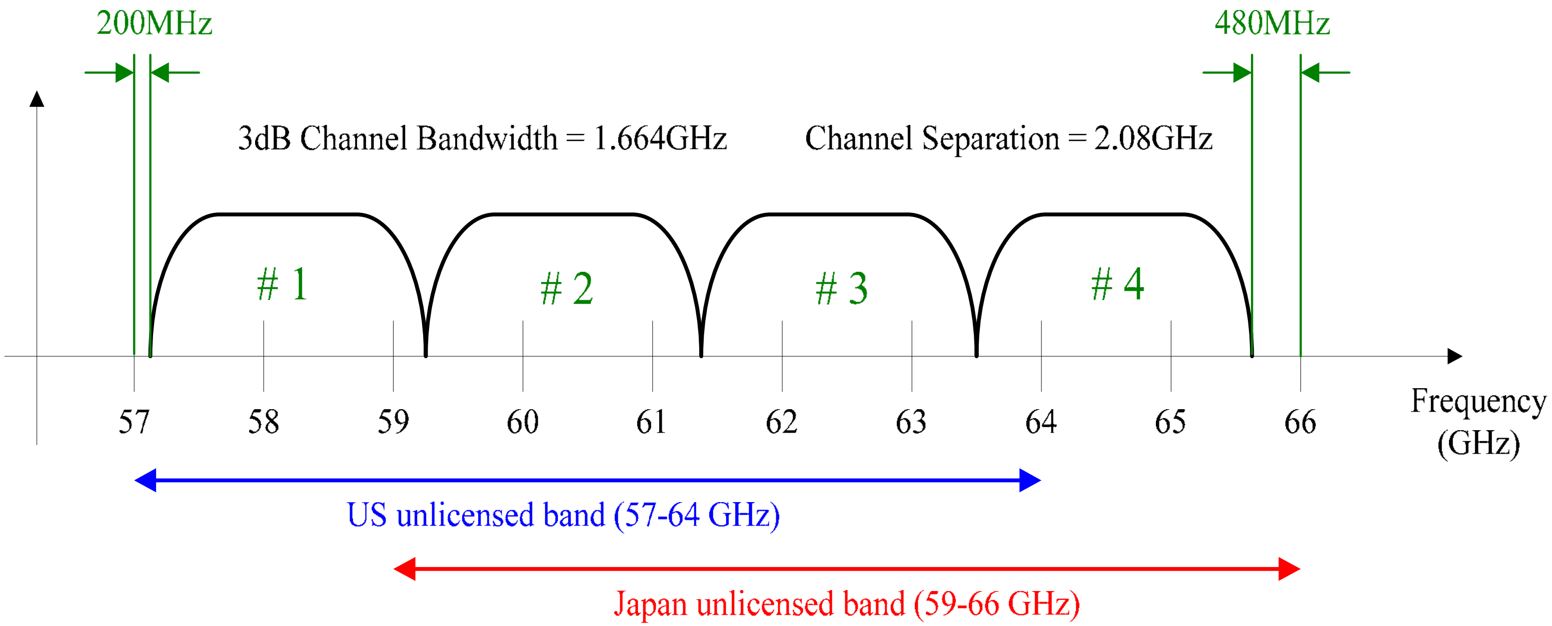


Key Features

- On-Off-Keying (OOK) enables simplest radio architecture to realize lowest cost and fastest time to market
- OOK with RS FEC provides sufficient performances for UM5
- BPSK / QPSK can be an upper compatible system for OOK to support high end applications. It has no significant hardware impacts for BPSK / QPSK transceiver to adopt OOK mode.
- Possibility of Adaptive modulated beaconing (coexistence among different modulation systems)

PHY Layer Design

Channelization



- Support 4 channels over 9GHz bandwidth
- 3-dB bandwidth is 1.664GHz, Channel separation is 2.08 GHz based on 26 MHz Xtal.
- Each channel can further support multiple communication links if TDMA or spatial reuse is adopted.

Channelization

Symbol rate	1.664 Gsps
Pulse shaping	Raised cosine function
Roll off factor	0.25
Effective channel bandwidth	2.08GHz

Channel Number	**Low Freq. (GHz)**	**Center Freq. (GHz)**	**High Freq. (GHz)**	**3 dB BW (GHz)**
1	57.20	58.24	59.28	1.664
2	59.28	60.32	61.36	1.664
3	61.36	62.40	63.44	1.664
4	63.44	64.48	65.52	1.664

Basic Parameters

Modulation Scheme	**OOK**	**BPSK**	**QPSK**
Bits per symbol	1	1	2
Detection	Non-coherent/Coherent	Coherent	Coherent
Outer FEC encoder	Reed Solomon(255, 239)	Reed Solomon(255, 239)	Reed Solomon(255, 239)
Inner FEC encoder	None	None <Optional> Convolutional Code 3/4, 1/2	None <Optional> Convolutional Code 3/4, 1/2
PHY header	Shorten Reed Solomon (32, 16)	Shorten Reed Solomon (32, 16)	
PHY payload data rate	1.5596Gbps	1.5596Gbps <Optional> 1.1697Gbps, 0.7798Gbps	3.1192Gbps <Optional> 2.3394Gbps, 1.5596Gbps

Data Rate Modes

Mode	Modulation	Detection	FEC scheme*	PHY-SAP payload rate [Gbps]**
1.1	OOK	Noncoherent	RS(255,239)	1.5596
1.2	OOK	Coherent	RS(255,239)	1.5596
2	BPSK	Coherent	RS(255, 239)	1.5596
3	QPSK	Coherent	RS(255,239)	3.1192

*) RS(255,239) is the mandatory FEC codes for payload data. Convolutional codes or LDPC can be added as optional inner codes if concatenated FEC encoding is adopted.

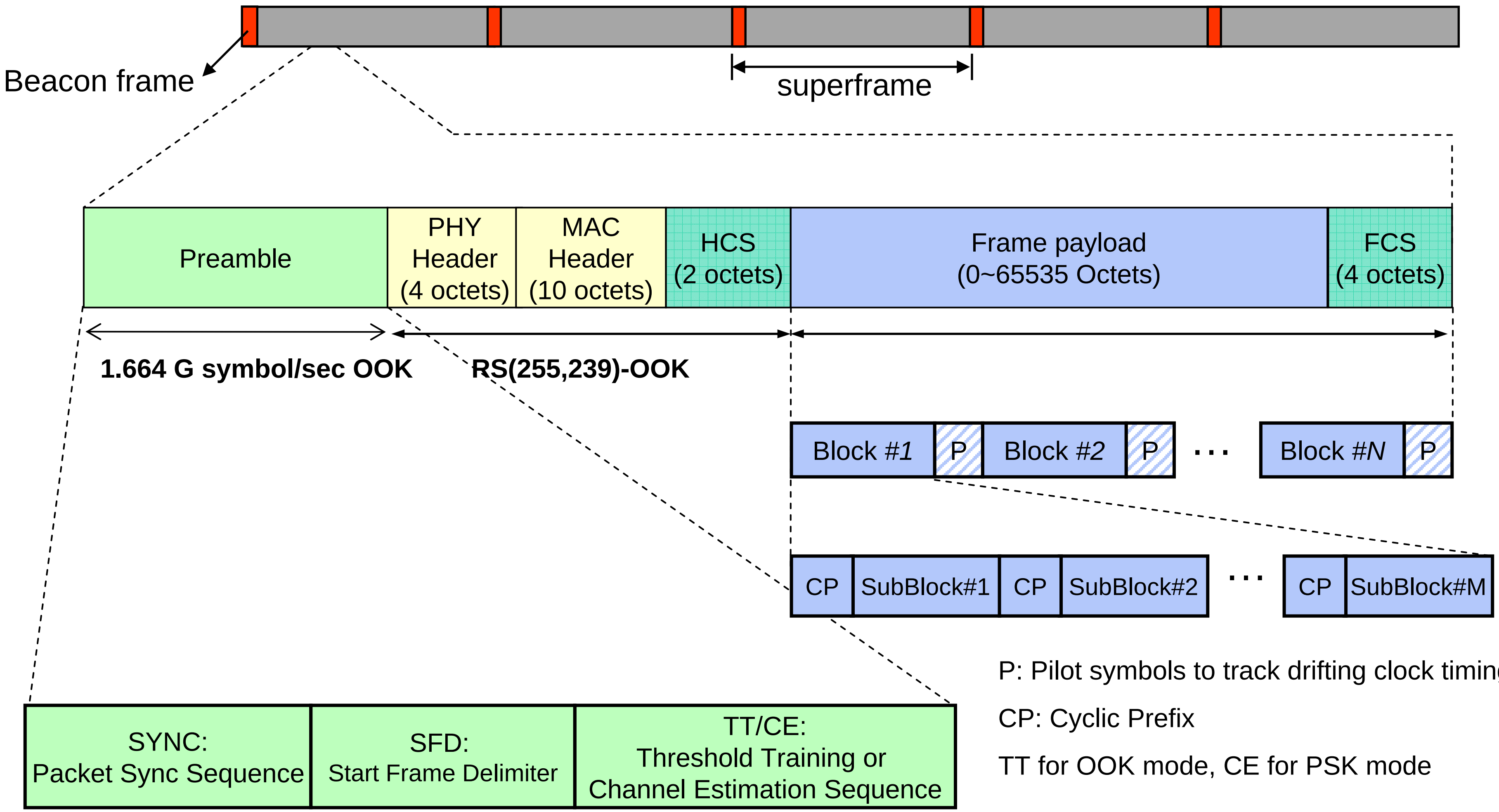
**) Cylix prefix (CP) for FDE can be added as option. In the table, it is assumed there is no FDE applied, so CP = 0.

Why adopt OOK modulation?

- OOK modulation
  - Very simple above 1Gbps of 15.3c PAR
  - Very low power consumption of non-coherent architecture
  - Sufficient performance on AWGN/CM9.1/CM1.3 channels
  - No phase noise effects of local oscillator

- Very suitable for Kiosk file-downloading and portable P2P applications
  - In many cases, Point-to-Point
  - Occurs in short distance
  - Does not need super high rate
  - Power consumption has higher priority

Frame Format

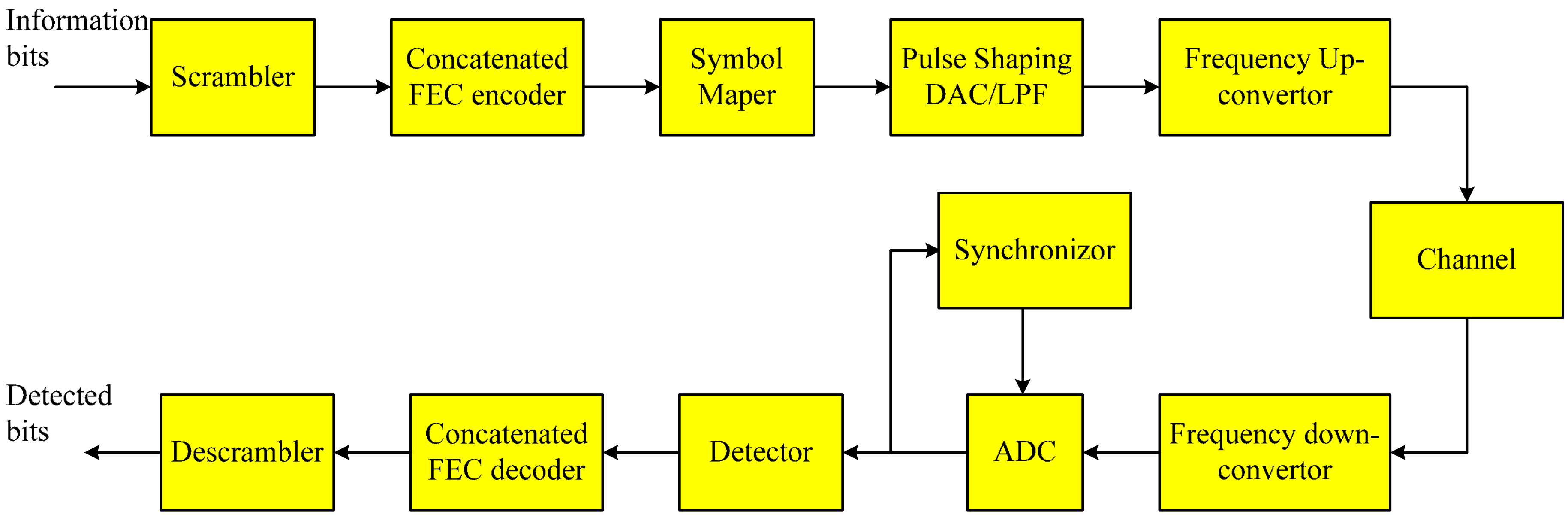


P: Pilot symbols to track drifting clock timing

CP: Cyclic Prefix

TT for OOK mode, CE for PSK mode

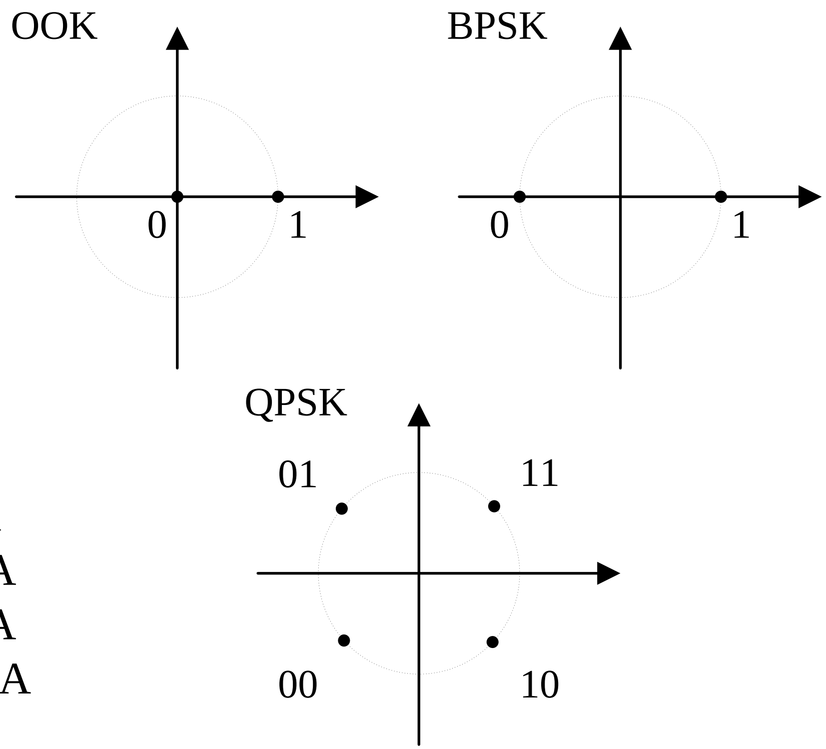
Simplified System Block diagram



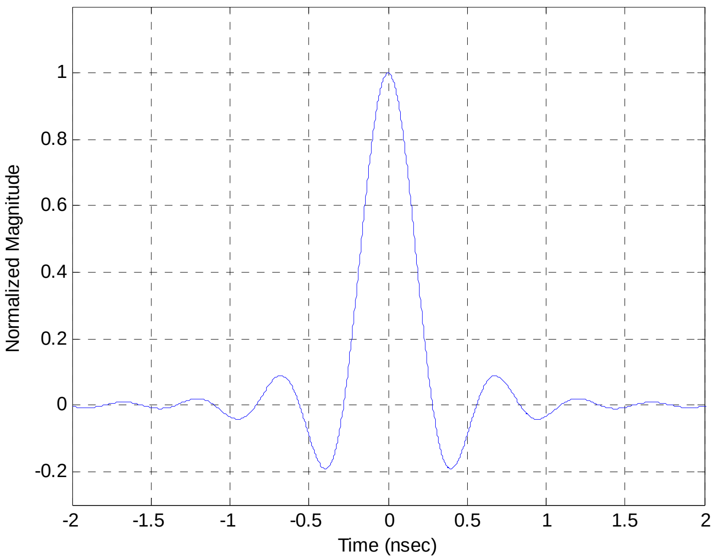
Gray-coded Constellation Mapping

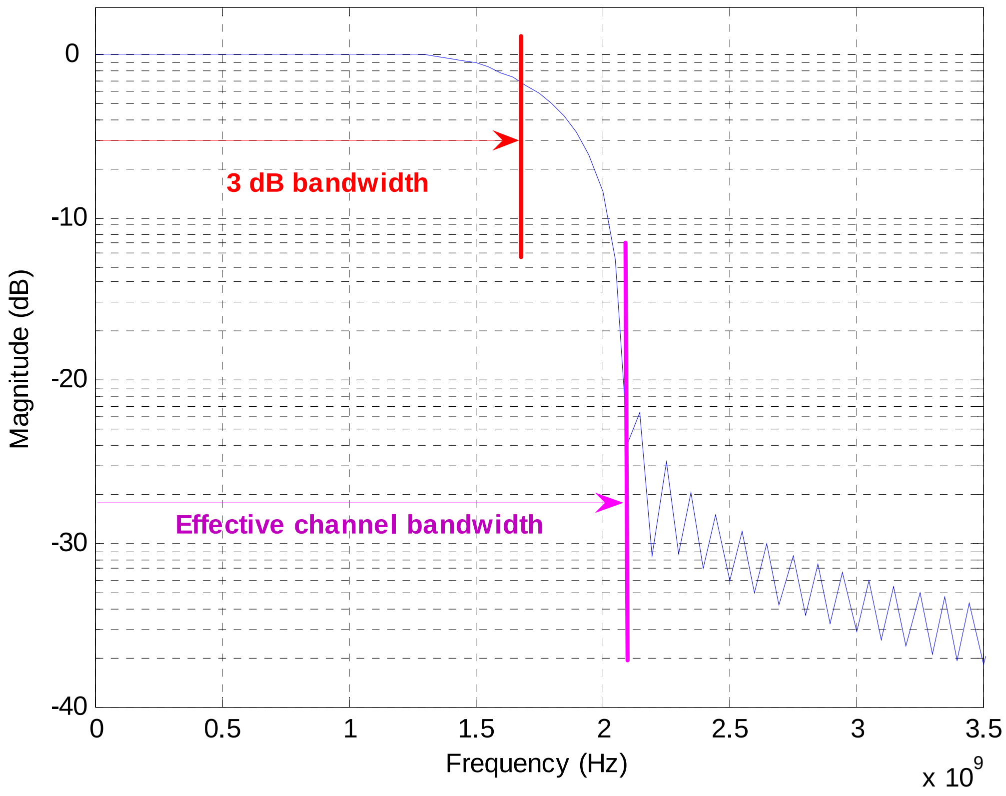
- OOK:
  - Input bit = 1: I-phase = 1, Q-phase = 0
  - Input bit = 0: I-phase = 0, Q-phase = 0
- BPSK:
  - Input bit = 1: I-phase = 1, Q-phase = 0
  - Input bit = 0: I-phase = -1, Q-phase = 0
- QPSK:
  - Input bits = 11: I-phase = A, Q-phase = A
  - Input bits = 10: I-phase = A, Q-phase = -A
  - Input bits = 01: I-phase = -A, Q-phase = A
  - Input bits = 00: I-phase = -A, Q-phase = -A

  where A = sqrt(2)/2



Pulse Shaping



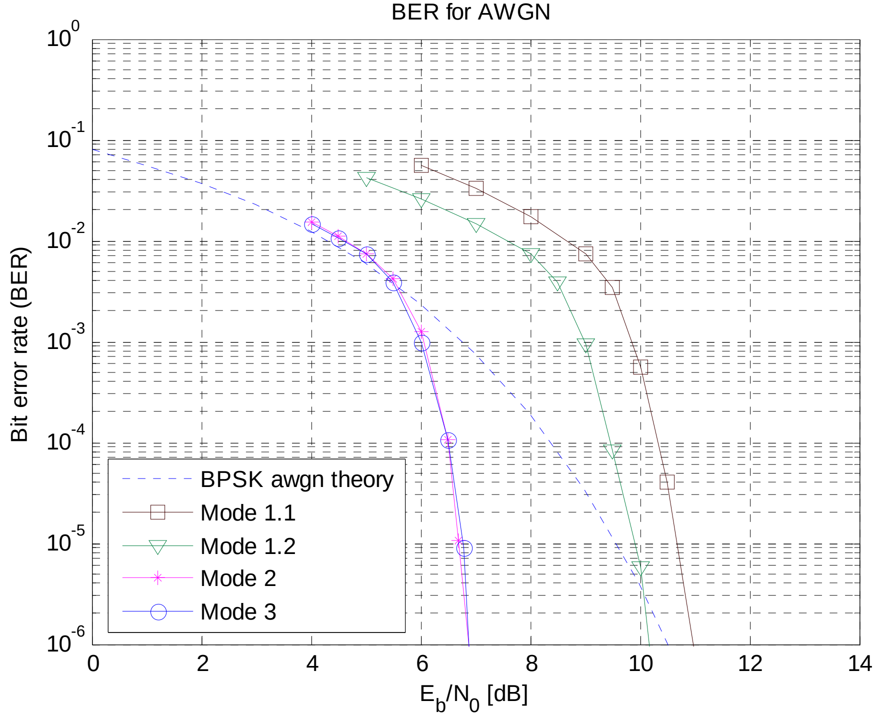


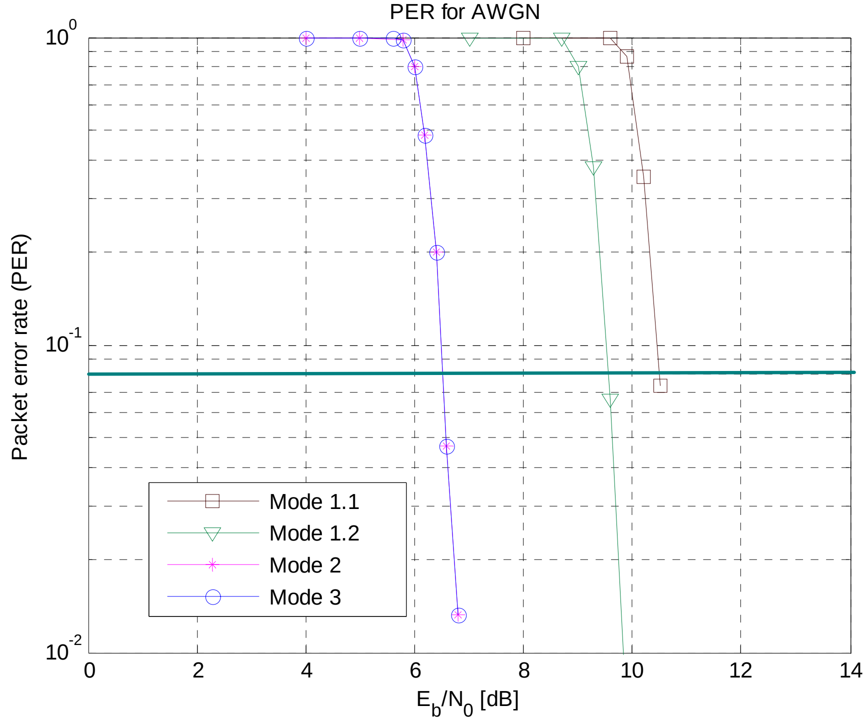
- Ideal shaping

Simulation and Performance Evaluation

- AWGN, CM9.1, CM9.2 and CM1.3 for UM5 Kiosk filing downloading
- Tx and Rx antenna beam width are 30 degrees
- Assume perfect aiming between Tx and Rx directional antennas
- Assume perfect synchronization
- Transmission range is typically at 1 meter
- Payload length = 2K bytes
- Mean 90% PER and BER link success probability versus E_b/N_0 is examined at performance evaluation.
- BER @ 10e-06 and PER @ 8% are adopted as criteria for required E_b/N_0

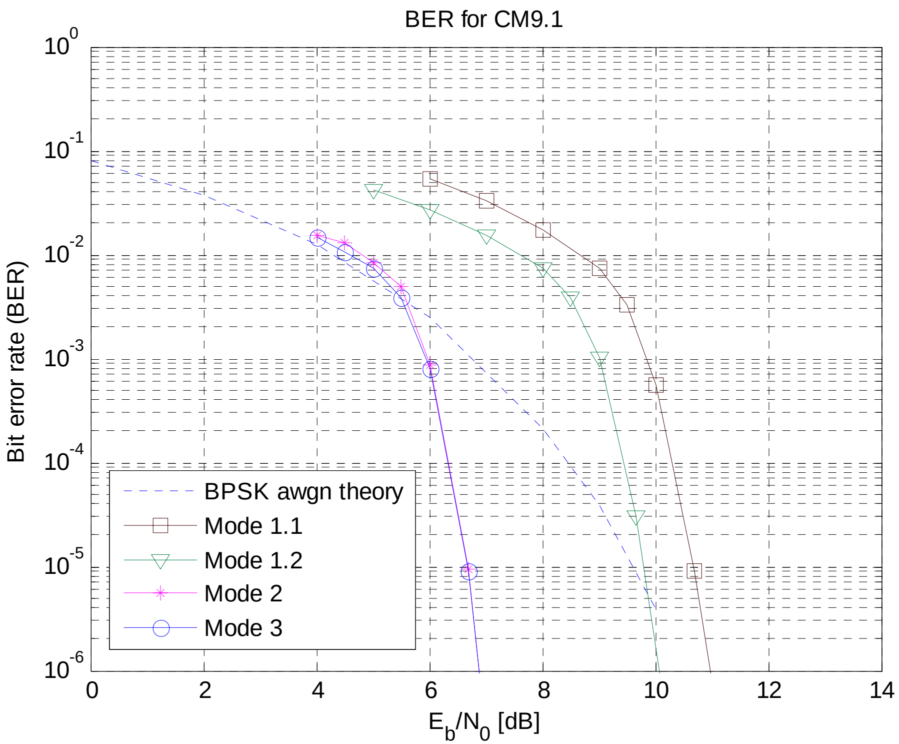
Performance in AWGN

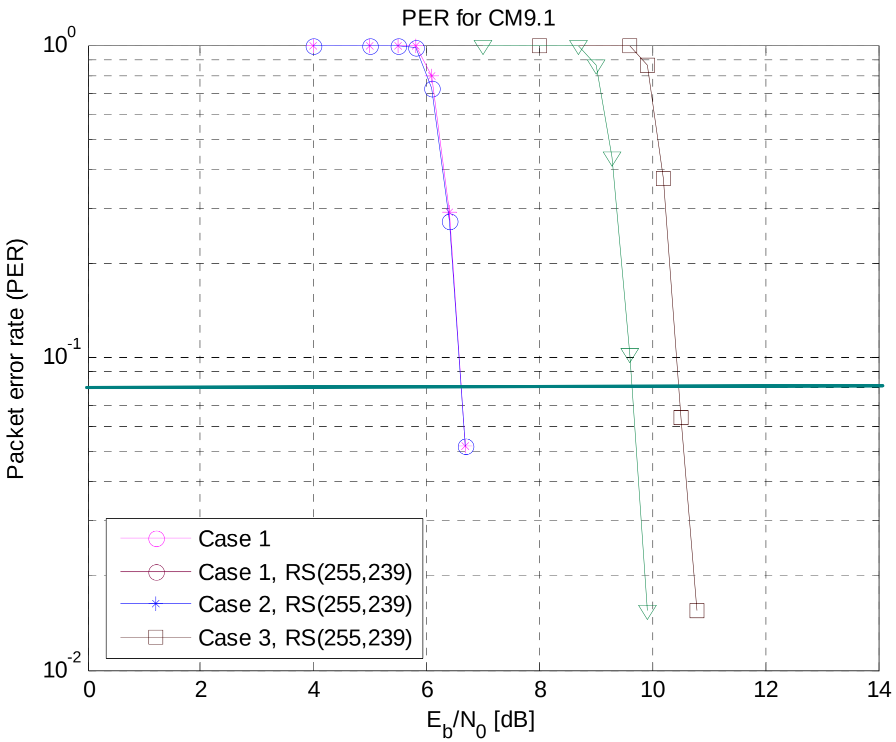




	Required Eb/N0 at BER @ 10e-6 (dB)	Required Eb/N0 at PER @ 8% (dB)
Mode 1.1	11.1	10.5
Mode 1.2	10.2	9.5
Mode 2	6.9	6.5
Mode 3	6.9	6.5

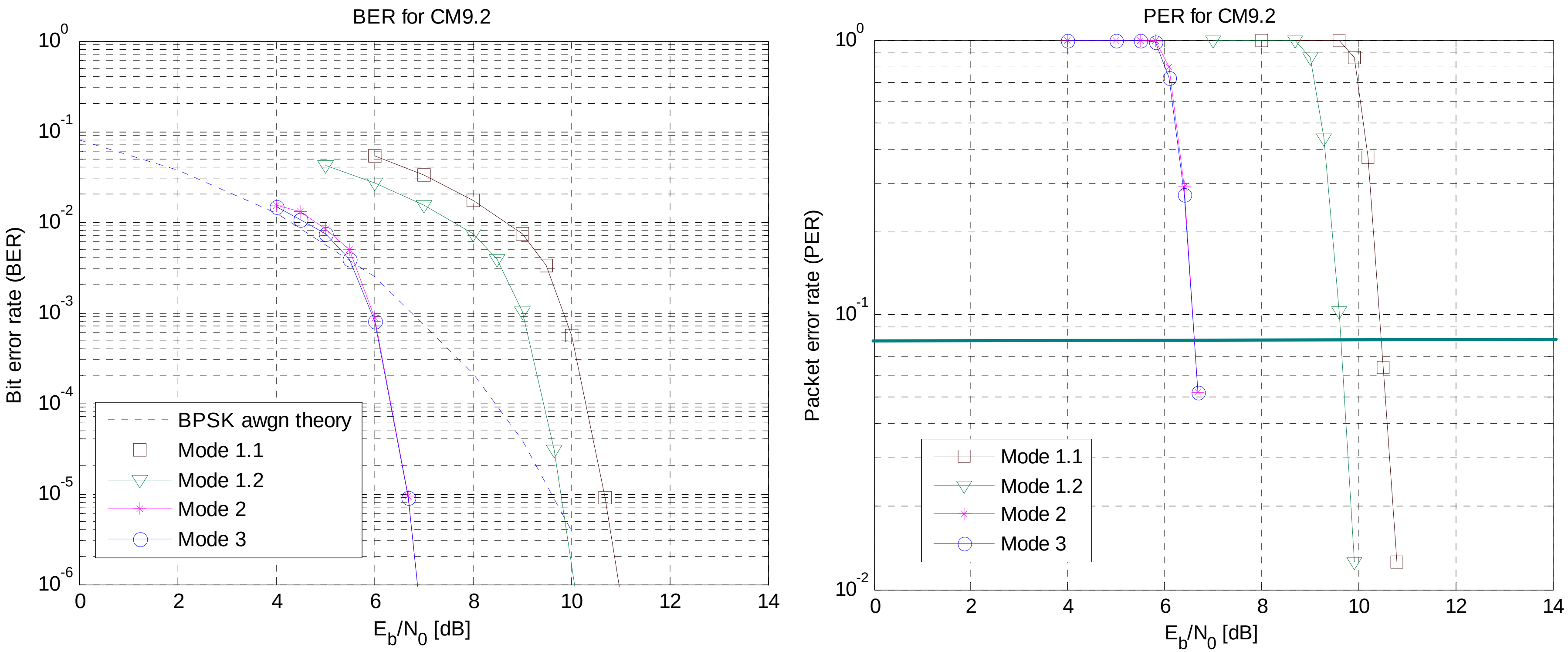
Performance in CM9.1





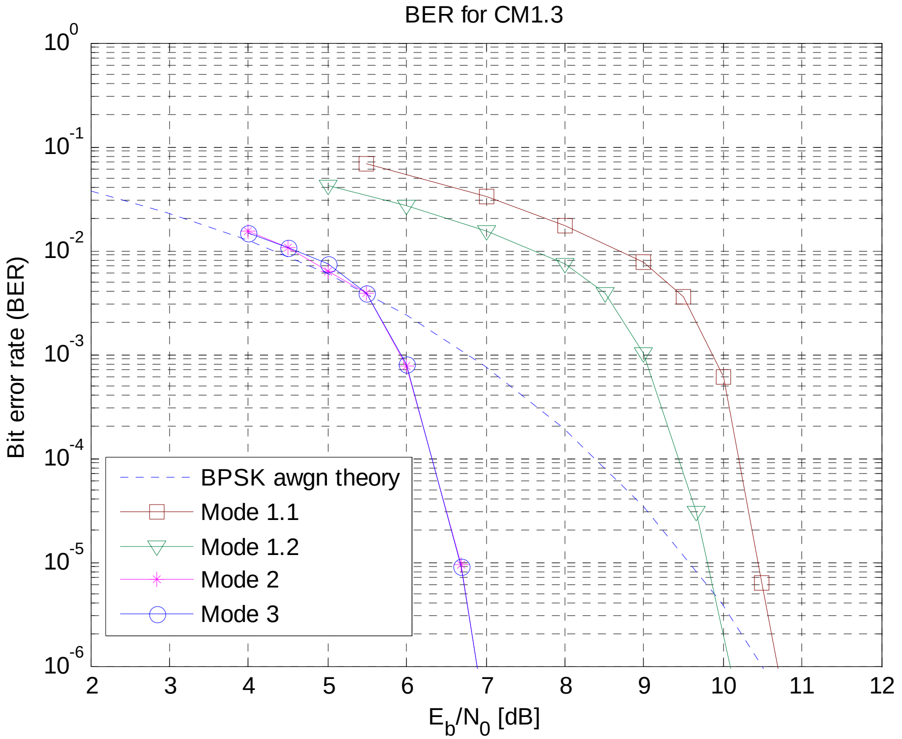
	Required Eb/N0 at BER @ 10e-6 (dB)	Required Eb/N0 at PER @ 8% (dB)
Mode 1.1	11.1	10.6
Mode 1.2	10.2	9.7
Mode 2	6.9	6.7
Mode 3	6.9	6.7

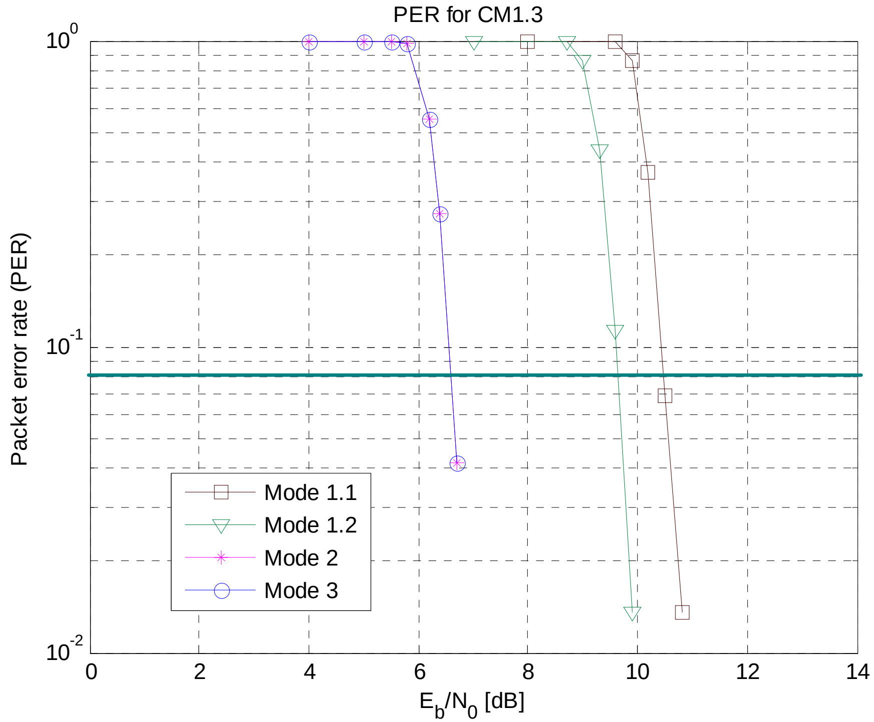
Performance in CM9.2



	Required Eb/N0 at BER @ 10e-6 (dB)	Required Eb/N0 at PER @ 8% (dB)
Mode 1.1	11.1	10.5
Mode 1.2	10.2	9.6
Mode 2	6.9	6.6
Mode 3	6.9	6.6

Performance in CM1.3





	Required Eb/N0 at BER @ 10e-6 (dB)	Required Eb/N0 at PER @ 8% (dB)
Mode 1.1	11.1	10.6
Mode 1.2	10.2	9.6
Mode 2	6.9	6.7
Mode 3	6.9	6.7

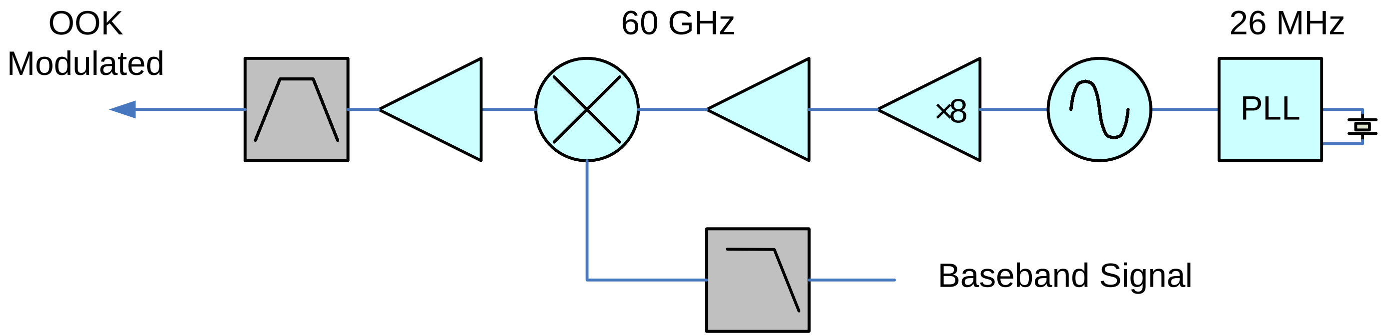
Required E_b/N_0 (dB) Summary Table

Mode	AWGN		CM9.1		CM9.2		CM1.3	
	BER @ 10e-06	PER @ 8%	BER @ 10e-06	PER @ 8%	BER @ 10e-06	PER @ 8%	BER @ 10e-06	PER @ 8%
1.1	11.1	10.5	11.1	10.6	11.1	10.5	11.1	10.6
1.2	10.2	9.5	10.2	9.7	10.2	9.6	10.2	9.6
2	6.9	6.5	6.9	6.7	6.9	6.6	6.9	6.7
3	6.9	6.5	6.9	6.7	6.9	6.6	6.9	6.7

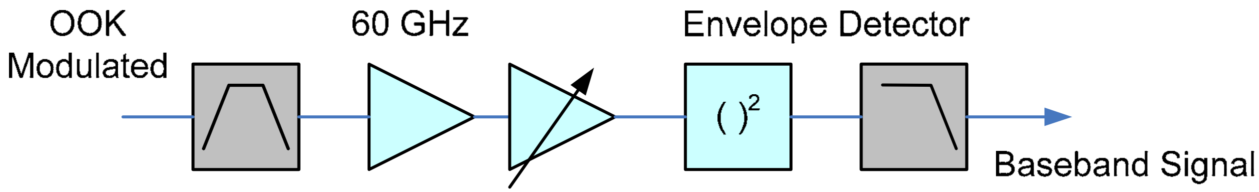
Implementation Feasibility

Block Diagram – OOK Radio Architecture *(non-coherent detection)*

- OOK non-coherent enables **Simplest Radio Architecture**
- Transmitter : Up Converter

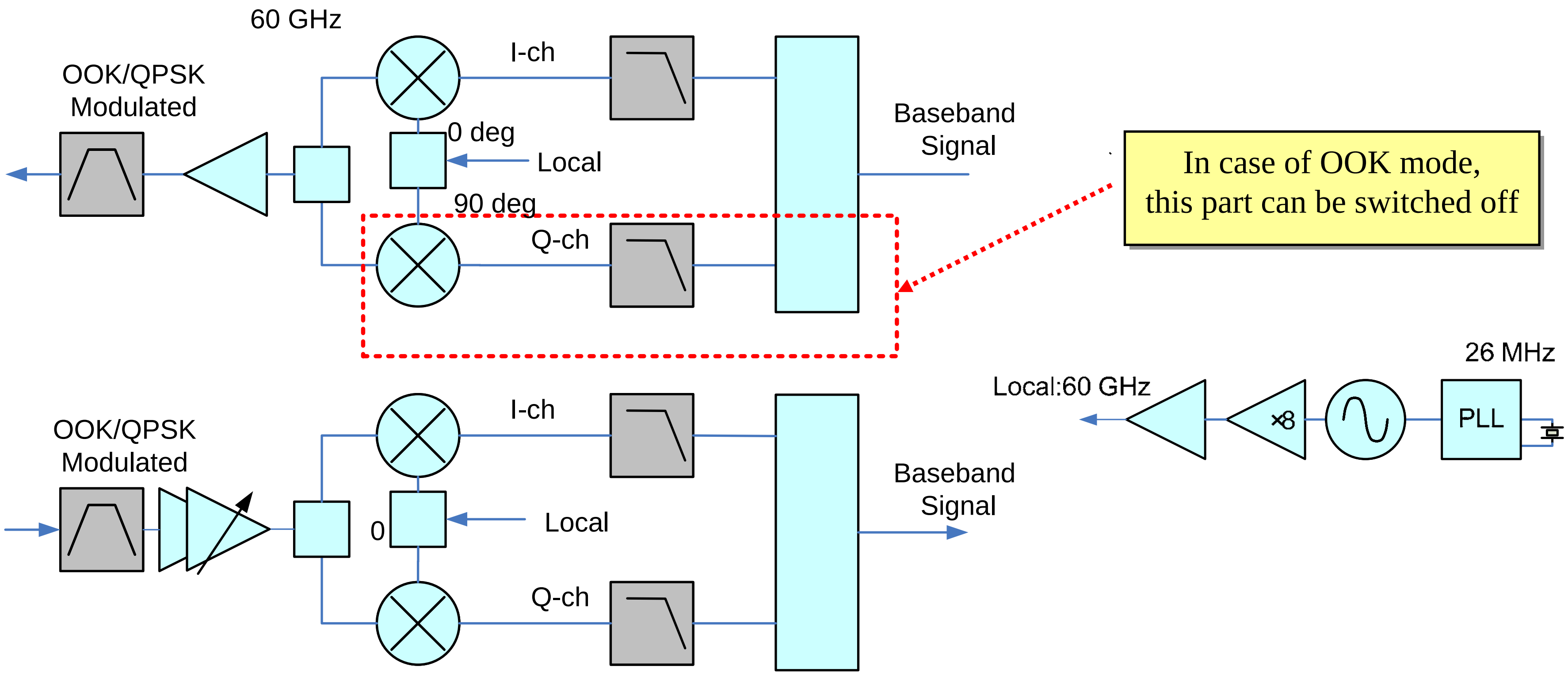


- Receiver : Envelop Detection



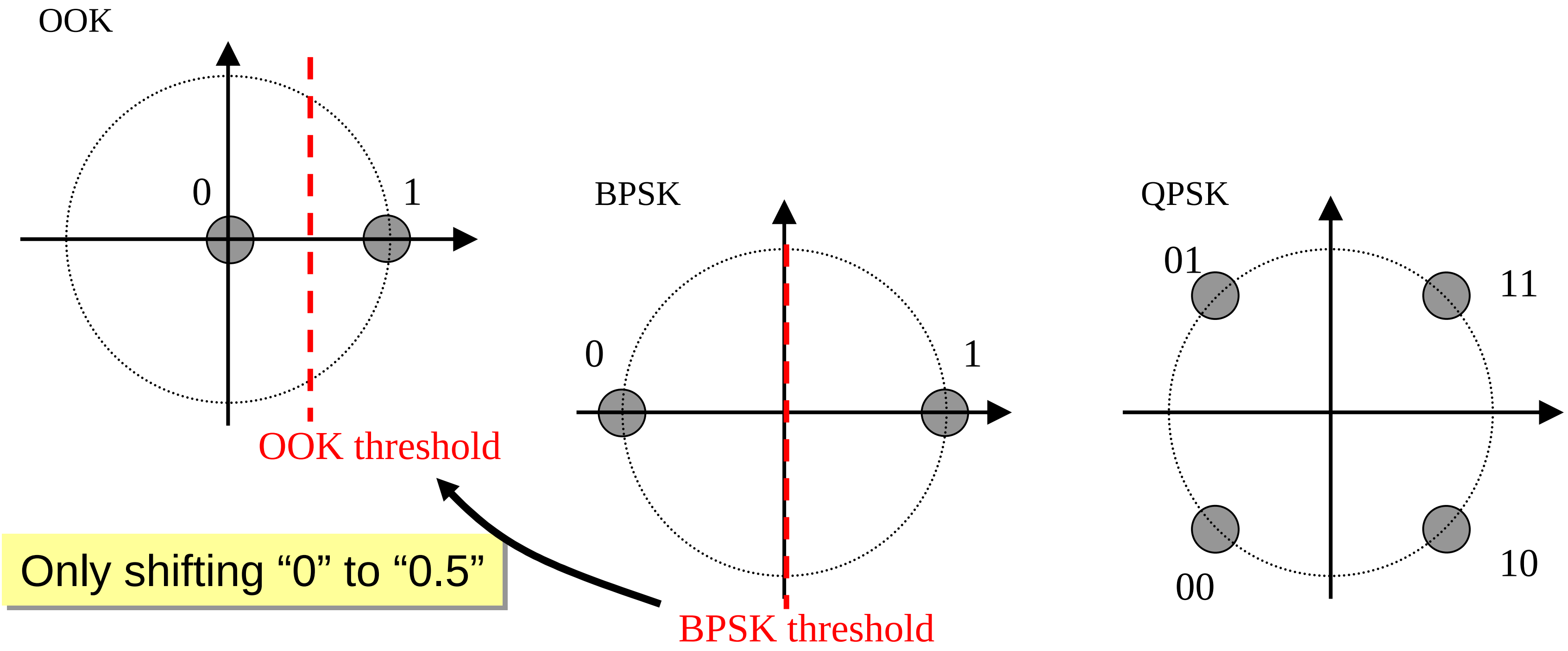
Block Diagram – OOK/PSK Architecture *(coherent detection)*

- Transmitter/Receiver : Quadrature Modulator/Demodulator



Signal Constellation Mapping

- No additional analog circuit is necessary to detect OOK signal for BPSK/QPSK receiver



Manufacturability

- UM5 device can be integrated in 90nm-CMOS-SoC
  - RF
    - 0 dBm output power is enough for short range of UM5
    - 90 nm CMOS is easy to generate 1mW output power
    - No need low phase noise
  - Baseband
    - Envelope detector can be employed in case of non-coherent
    - No need wide bit-width GHz sample ADC

Power Consumption Estimations in RF *(non-coherent)*

Block	Circuit	Power Consumption (mW)	Notes
TX	PA	20	0 dBm output
	MIX	10	
	VCO	20	7.5 GHz OSC + 8 multiplier
	PLL	50	
	Sub total	100	During RX, PA and MIX can be turned off
RX	LNA	10	10 dB
	VGA	20	20 dB (max)
	Detector	5	Diode detector with bias
	Baseband Amp.	5	Broadband amp.
	Sub total	40	During TX, all circuits can be turned off

Assumption by 90nm-CMOS, some results are calculated by using 0.15um GaAs based P-HEMT
Ref: B.Heydari et.al., “Low-Power mm-wave Components up to 104 GHz in 90nm CMOS”, ISSCC2007

Link Budget Margin (AWGN)

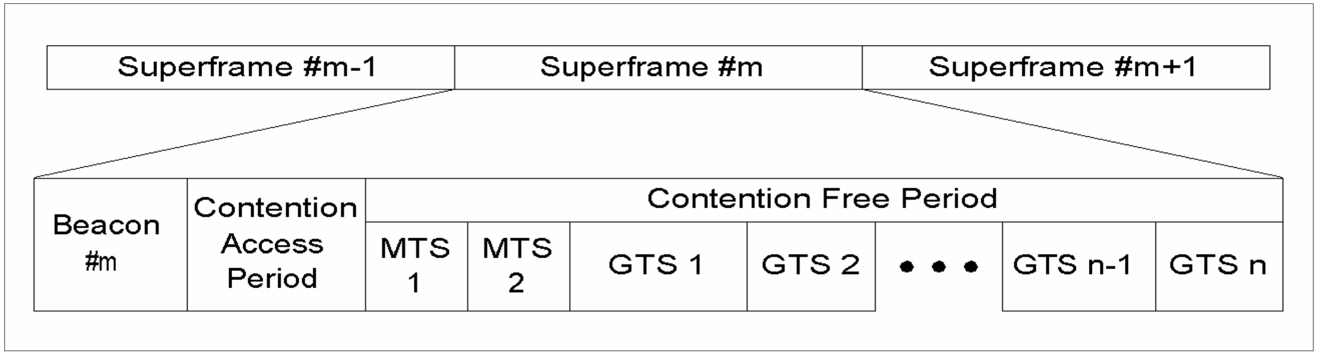
	Low Power Mode		Unit
Modulation scheme	OOK		
Detection	Noncoherent		
Range	1	0.5	m
Symbol Rate	1.664		GSps
FEC	RS(255,239)		
Avg Tx power	0		dBm
Tx Antenna Gain	10		dBi
EIRP	10		dBm
Center Frequency Assumption	60		GHz
Attenuation in free space	-68	-62	dB
Rx Antenna Gain	10		dBi
Received Carrier Power	-48	-42	dBm
Noise Power (2.08GHz BW)	-80.65		dBm
Rx Noise Figure	10		dB
Noise Power (with Noise Figure)	-70.65		dBm
Implementation Loss	5		dB
CNR (with Implementation Loss)	17.65	23.65	dB
Required Eb/No @ BER=10e-06	11.1		dB
Required CNR @ BER = 10e-06	9.85		dB
Oxygen Loss	0.015	0.0075	dB
Link Margin	7.78	13.79	dB

Larger than Required Eb/N0 @ PER = 8% → (Required Eb/No @ BER=10e-06)

MAC Layer

Supporting OOK and PSK coexistence based on 802.15.3 MAC

Superframe structure (802.15.3)



- Arrangement of periods and slots is decided by PNC (PicoNet Controller) and is informed using beacons.
- An unassociated device tries to associate to the piconet after receiving a beacon.
  - An unassociated device sends a association request packet during CAP (Contention Access Period) according to the contention basis.
- An associated device sends packets :-
  - During CAP according to the contention basis if PNC allows to use CAP for data transmission.
  - Or asking PNC to allocate time slots in CFP (Contention Free Period).

Observation on IEEE UMD requirement

- There are two mandatory UMs:
  - UM1: Uncompressed video streaming
    - Point to Point, Long Range, High Power, High Data Rate, Full MAC
    - Examples: Set-top Box to TV, PC to Monitor, etc.
  - UM5: Kiosk file downloading
    - Point to Point, Short Range, Low power, Low Data Rate, Minimum MAC
    - Examples: Phone, PDA, iPod, etc
- Two mandatory UMs leads to different requirements on PHY layer
  - High End PHY (HEP):
    - Advanced Digital Modulation with High Power, e.g. OFDM and SC-FDE, to support rate > 2Gbps over severe multipath channels
  - Low End PHY (LEP):
    - Simple Digital/Analog Modulation with Low Power, e.g. ASK, MSK, FSK, to support rate at 1Gbps over almost AWGN channels
- So all devices must be able to coexist at the same piconet to avoid any interference; therefore, coexistence issue must be solved.

Basic requirements for Coexistence

- IEEE802.15.3 MAC is supported
  - Centralized Piconet with one master device (PNC) to coordinate the channel use by sending beacon periodically
    - When HEP and LEP exist at the same piconet, HEP device can be PNC to save power of LEP device and support a long range beacon.
  - Other devices must listen to PNC beacon before access the medium.
  - Other devices must request medium reservation at CAP using contention based medium access.
  - Time-sharing medium reservation at CFP
- HEP and LEP devices are “independent”, but communication between HEP and LEP devices is supported.
- No unnecessary complexity for LEP devices (simple and low-power)
- The beacon coordination should be efficient and fair. No interference among different communications.

Coexistence among Different PHYs

- Issues:
  - Each device should know the arrangement of each elements in the superframe.
    - This means each device has to understand the beacon.
  - Each unassociated device should send packets during CAP.
    - This means contention access mechanism among different PHYs is necessary.

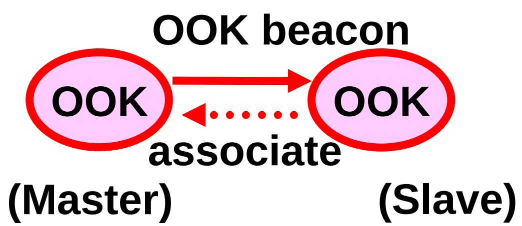
- Possible solutions:
  - Understanding the beacon
    - Single beacon in common signal format
    - Multiple beacons in each signal format
  - Contention access mechanism
    - Using sensed power as sensed carrier
    - Split CAP into multiple CAPs for each signal format

Multiple Beaconing

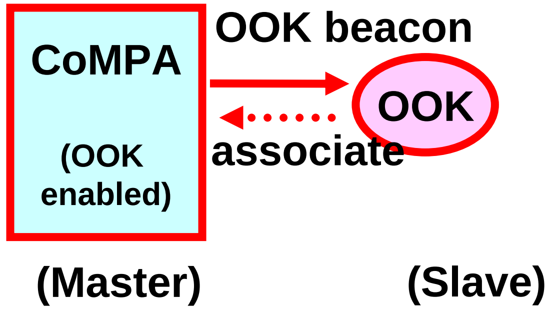
- Multiple beacons are preferable.
  - Single common beacon should be sent in the simplest format (e.g. OOK). But that beacon has drawbacks. (transmission range, resistance to multi-path, etc.)
  - Only PNC-enabled devices should have multiple PHYs capability.
  - In 802.15.3 basis, only PNC sends beacons, so overhead of multiple beacons is not large.
  - If PNC has multiple PHYs capability, it is possible to relay packets among different PHY devices.
- Factors for further considerations:
  - Scheduling multiple beacon transmission
  - Coexistence scenario among HEP and LEP systems

Coexistence Scenario with “CoMPA”

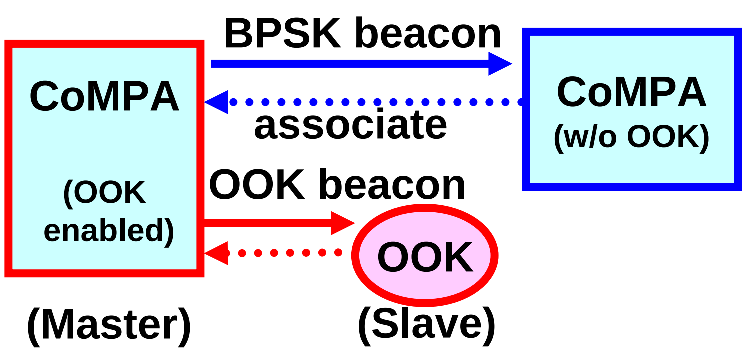
Case 1



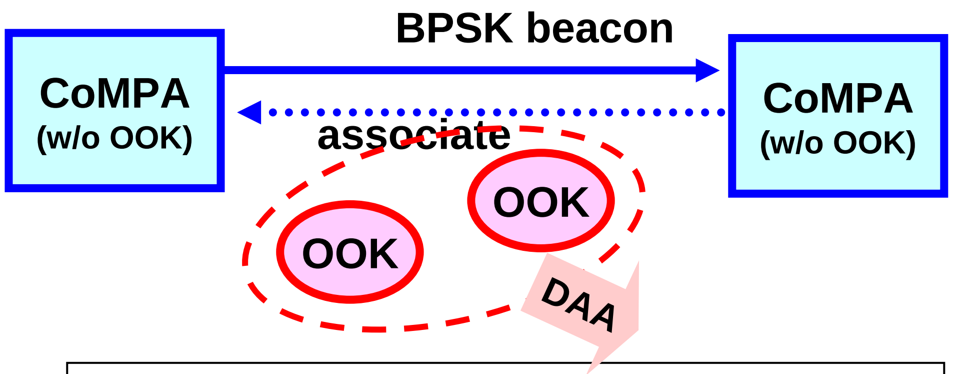
Case 2



Case 3



Case 4



CoMPA device (with OOK) should secure a time slot as a PNC in the CoMPAs' superframe at first and should send a beacon to OOK with that time slot information to assure coexistence.

If there is an CoMPAs' piconet and there is no OOK enabled CoMPA device, OOKs should avoid conflict according to the DAA manner

Signal Format Comparison

		signal format		
		OOK	PSK	OFDM
transmitter	SC-OOK	OK	NG	NG
	SC-PSK	easy*1	OK	NG
	OFDM	easy*1	possible*2	OK
receiver	SC-OOK	OK	NG	NG
	SC-PSK	easy*1	OK	NG
	OFDM	easy*1	possible*2	OK

*1: It is easy for SC-PSK/OFDM transmitter/receiver to transmit/demodulate OOK signals.
*2: It is possible for OFDM transmitter/receiver to transmit/demodulate PSK signals.

1. Single Carrier (OOK or PSK) has advantage to interoperate other schemes.
2. Considering transmission range, PSK is better for common signaling.
3. On the other hand, OOK is still suitable for thin devices, simple applications.

Summary

- OOK modulation as an additional mode for BPSK/QPSK transceiver w/o hardware impact
  - Very simple with sufficient rate for portable
  - Very low power consumption compared with other modulations
  - Works well on AWGN/KIOSK channels
  - Very suitable for portable P2P applications
  - Simple coexistence with BPSK/QPSK and other signal devices

Nest Steps Toward July Meeting

- We will create joint submission with CoMPA's single carrier PSK based proposal.
- We also seek further mergers with other parties to enhance the future market capability.