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

Submission Title: [Alternative Spreading Code and Channel Code for IEEE802.15.4a]

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Abstract: [Newly designed spreading codes for SOP and channel coding for IEEE802.15.4a are proposed. When perfect balanced is encoded with matched spectral null coding, its spectra have nulls to avoid interference with co-existing systems. Secondly super orthogonal codes is proposed and investigated to apply for low complexity coding and decoding as appropriate channel codes for IEEE802.15.4a. These codes can be applied to evaluate performance of combination of coding and modulation as well as pulse shape for IEEE802.15.4a.]

Purpose: [To forward the discussion within 15.4a group]

Alternative Spreading Code and Channel Code for IEEE802.15.4a

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Agenda

- Appropriate Channel Codes for Coherent and Non-coherent Detection in IEEE802.15.4a
- Appropriate Spreading Codes Coherent and Non-coherent Detection in IEEE802.15.4a
- Joint Optimization of Spreading and Channel Codes, Pulse Shape, and Modulation Schemes
- Summary

1. Channel Codes for Coherent and Non-coherent detection in IEEE802.15.4a

Motivation

- If we select modulation scheme under limited case of channel code, spreading code and pulse shape, then total performance of DS-UWB based WPAN can not be optimized.
- Ideally we should design optimum combination of channel coding, modulation, demodulation, and pulse shape under given conditions.
- Alternative good channel code such as Super-Orthogonal convolutional code is introduced.

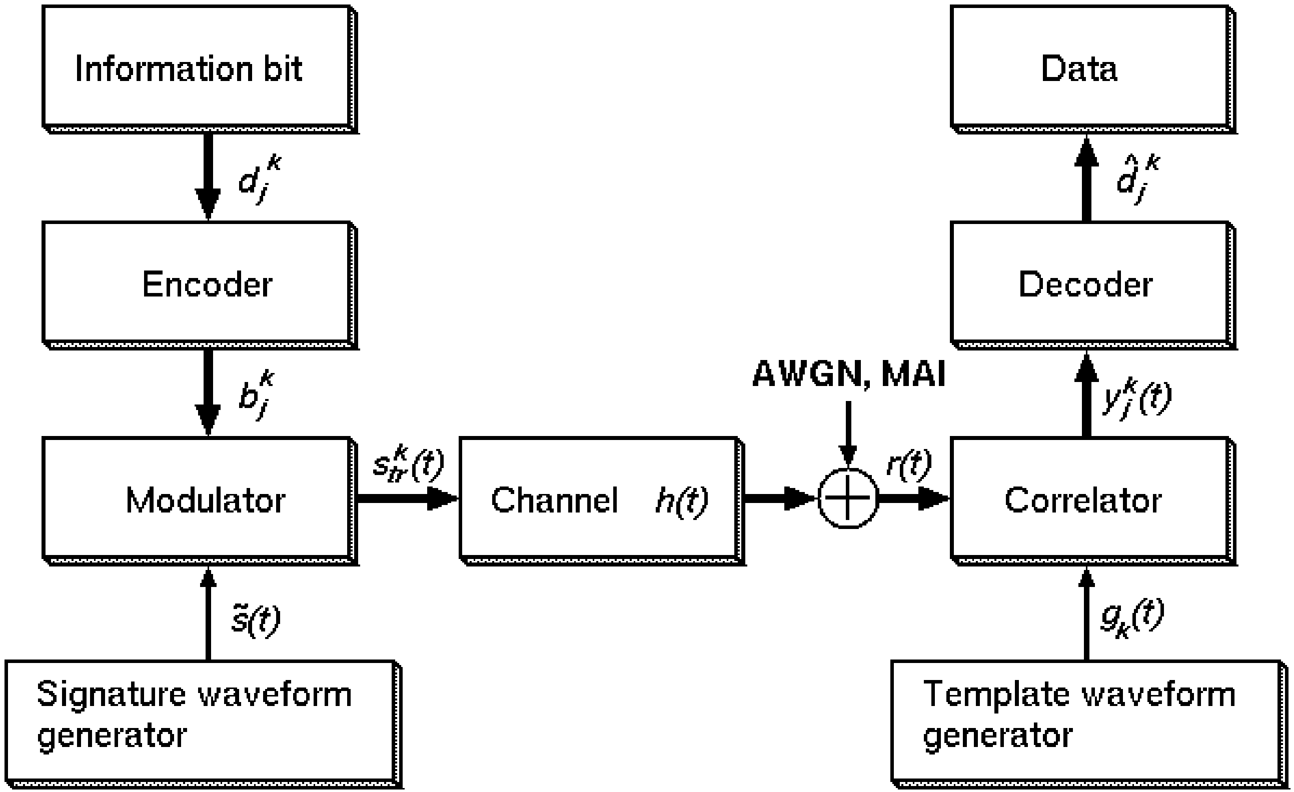
Proposed Selection Criteria
(in decreasing priority order)
in doc.: IEEE 15-05-0424-00-004a

1. PER (packet error rate) performance @1Mb/s with 15.4a channel models, rate ½ convolutional code (constraint length up to 5; more needs justification):
   1.a) **Coherent receiver**
   1.b) **Diff. coherent receiver**
   1.c) **Non-coherent receiver**
2. SOP isolation (at least 2 SOP/band; up to 6 SOP)
3. CMOS-compatible peak-to-peak voltage – We defined this as 1Vpp
4. Spectrum: SPAR (spectral peak-to-average ratio)
5. Receiver flexibility: Support for coherent, diff. coherent and non-coherent RX
6. Scalability: Trade-off performance vs. complexity
7. Resilience to NBI (narrow-band interference)

•Rate ½ convolutional code (constraint length up to 5) is not employed as an optimum channel code but for performance comparison of modulation schemes with three detection schemes as an typical example in 1Mb/s.

•However, other appropriate channel codes should be also employed for the comparison because there is an optimum combination between channel coding and modulation scheme for three detection schemes.

System Model in Tx/Rx



Processing Gain by Spreading Code

- Process Gain(PG)

$$PG = \frac{W[Hz]}{R[bit/sec]} = \frac{T_s}{T_c} = \frac{N_s T_f}{T_c} = N_s N_h$$

- Signal-to-Interference Ratio(SIR)

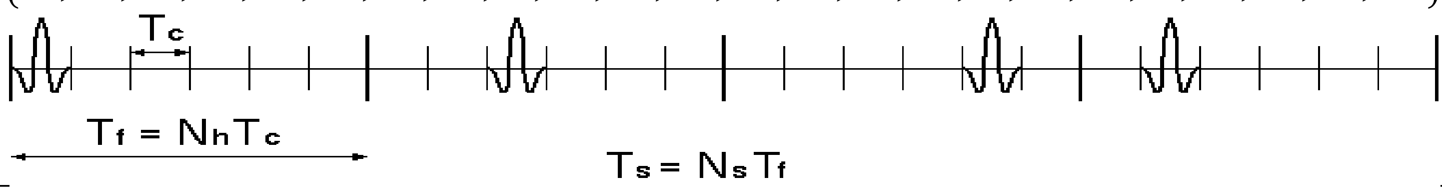
$$SIR = \frac{(A_1 N_s)^2}{\sigma_n^2 + \sum_{k=2}^{N_u} \frac{N_s}{N_h} A_k^2} = \frac{A_1^2}{\sigma_n^2 + \boxed{\frac{\sum_{k=2}^{N_u} A_k^2}{PG}}}$$

Tc	Chip time duration
Tf	Frame length
Ts	Symbol length
Ns	No. of pulses per 1 symbol
Nh	No. of chips in a frame

MUI (Muit-user-Interference) is in propotion with PG

$$c = \{0, 2, 4, 1\}$$

$$\tilde{c} = \{1, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 0, 0, 1, 0, 0, 1, 0, 0, 0, 0\}$$



Channel Code for UWB Transmission

- The lower code rate, the better error-correcting capability and the wider bandwidth a transmitted signal has in general.

$$\text{Code rate} : \quad r = \frac{k \, (\text{Informatio bits})}{n \, (\text{Code length})}$$

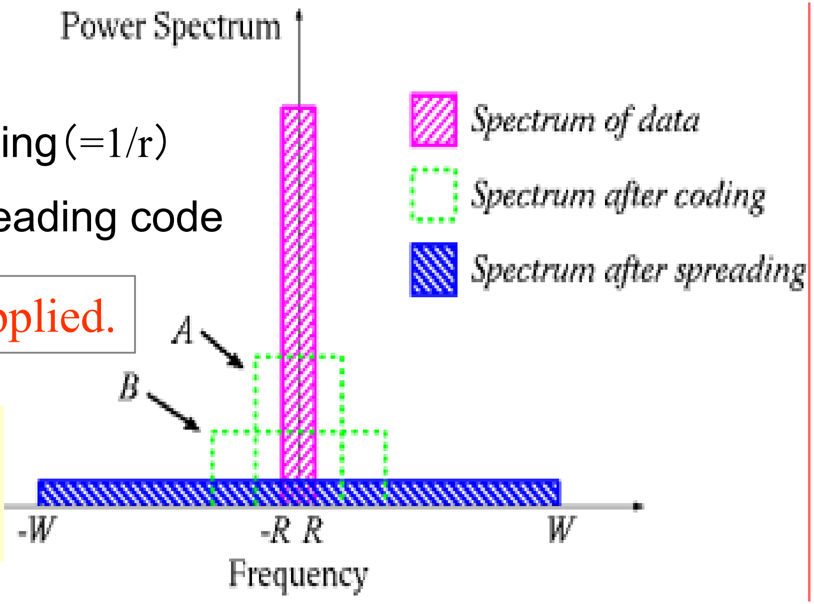
- Spreading Factor $N = F_C F_S$

F_C : Bandwidth spreading ratio due to Coding (=1/r)

F_S : Bandwidth spreading ratio due to Spreading code

A channel code with code rate 1/N can be applied.

Since UWB has larger Spreading Factor N, we can apply a channel code with low code rate or larger error-correcting capability.



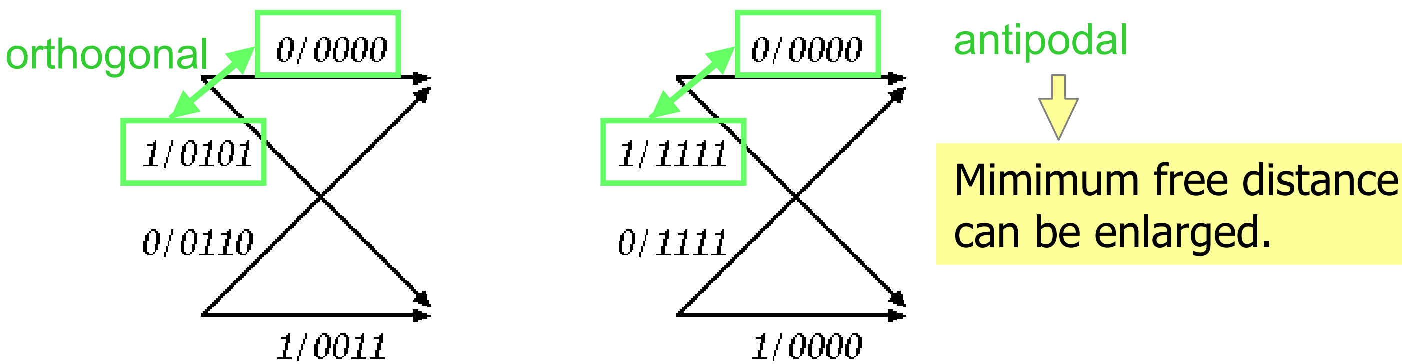
Low-Rate Convolutional Codes

< Low-Rate Orthogonal Convolutional Codes >

- All codewords are Walsh-Hadamard sequences
- Code rate is $r = 2^{-K}$ (K:integer)
- The lower code rate($K \to \infty$), the higher error-correcting capability
- Low-Complexity

Orthogonal Convolutional Codes

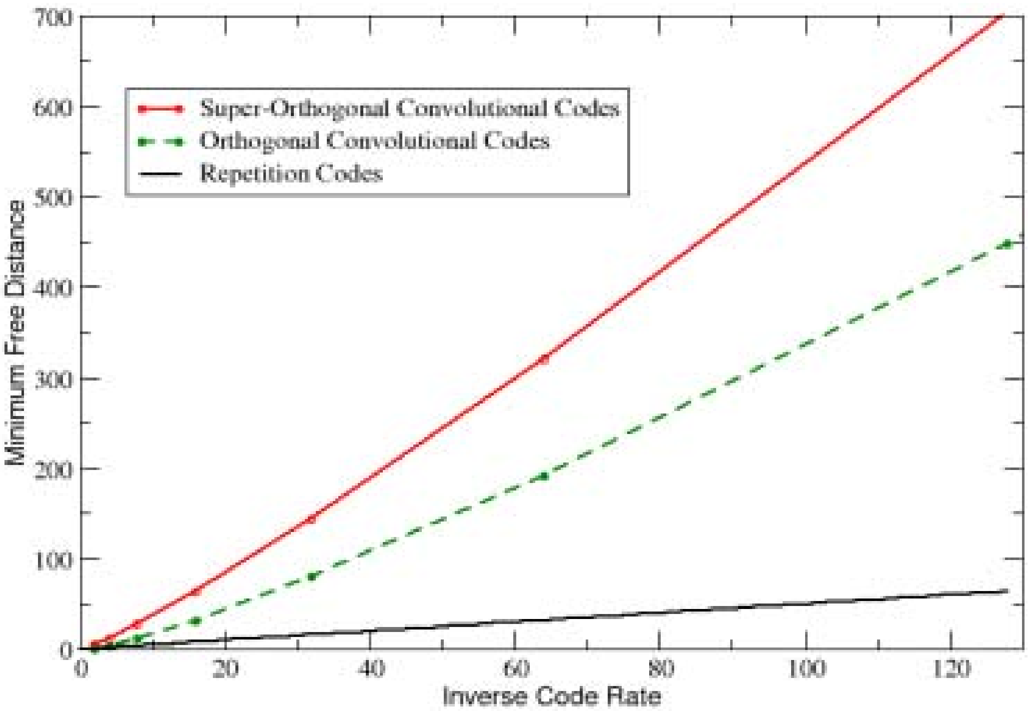
Modified → Super-Orthogonal Convolutional Codes



(a) Orthogonal (b) Super Orthogonal

Low-Rate Convolutional Codes

Comparison of Mimimum Free Distance



Super-Orthogonal(SO) Codes

Orthogonal Codes

Repetition Codes

Performance Evaluation

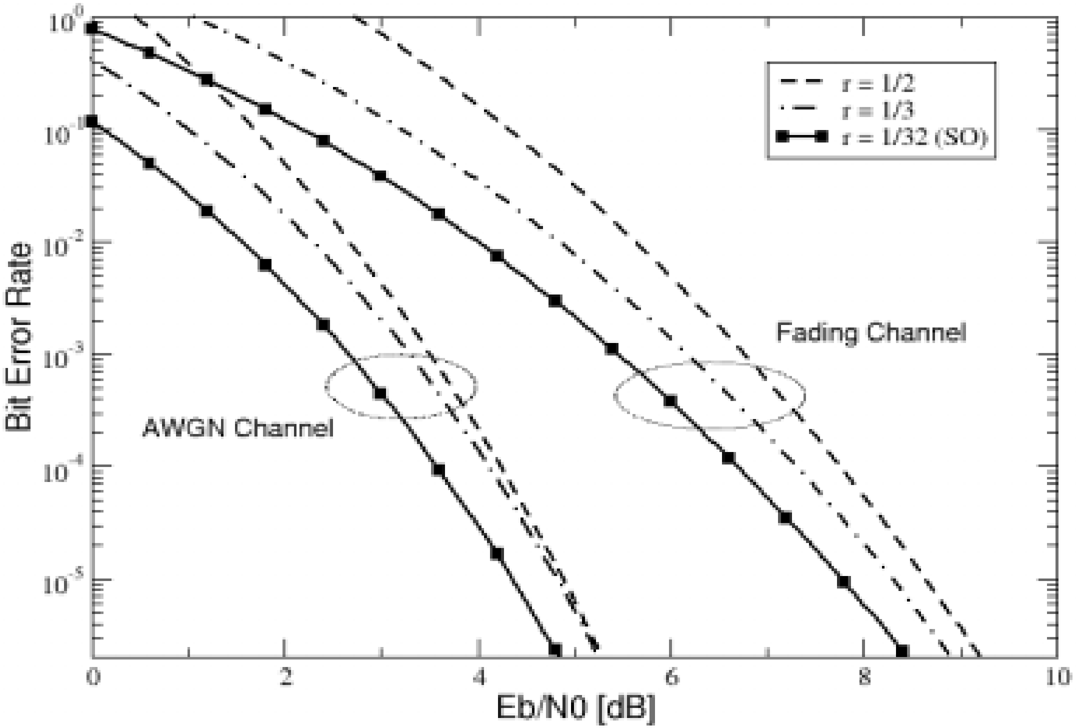
- Channel codes
  - r = 1/2 (133,171)
  - r = 1/3 (133,145,175)
  - r = 1/32 (SO)
- Receiver:
  MF Receiver + MRC-RAKE
  (fading channel)

Simulation Specification

Pulse width	Tp		1	
Chip duration	Tc		1	
Number of chips per frame	Nh		8	
Frame duration	Tf		8	
Code rate	R	1/2	1/3	1/32
Number of pulse repetition	Ns	16	11	1

BER Performance

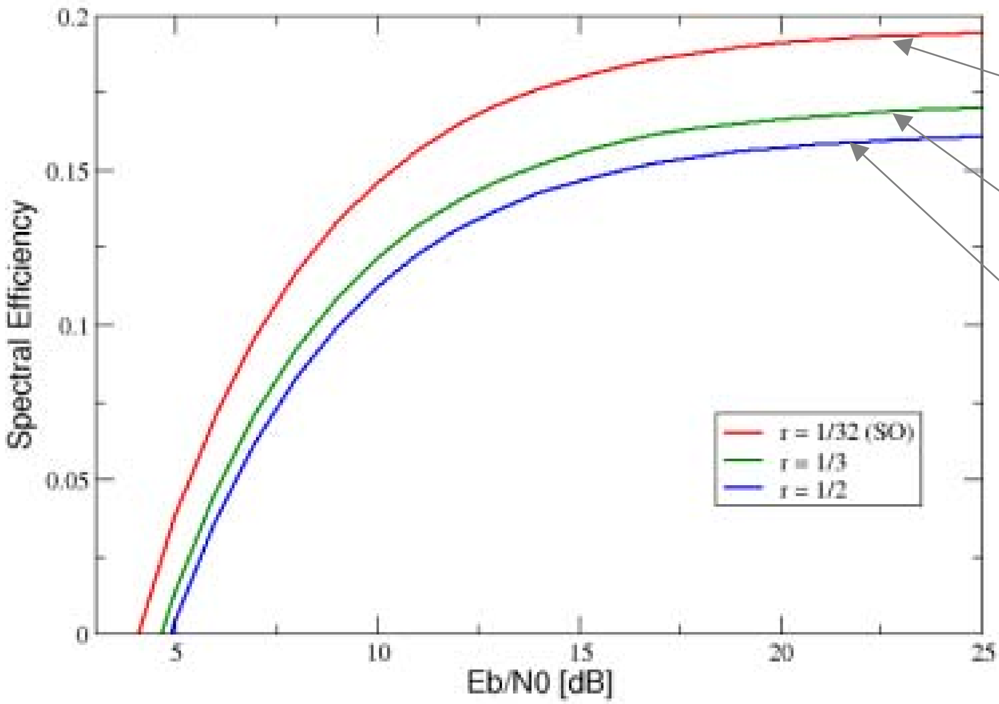
Evaluation based on Union bound



Fading channel model
: CM1
RAKE fingers : J = 8
Number of users : 1

Frequency Spectral Efficiency

Spectral Efficiency $\eta = \frac{N_u R_b}{W} = \frac{N_u}{PG}$ [bits/Hz] , R_b : Transmission rate Satisfying $BER = 10^{-5}$



Super-Orthogonal Code (r = 1/32)

r = 1/3

r = 1/2

The lower code rate, the Higher spectral efficiency SO can obtain.

Super Orthogonal Convolutional Code (SOCC)

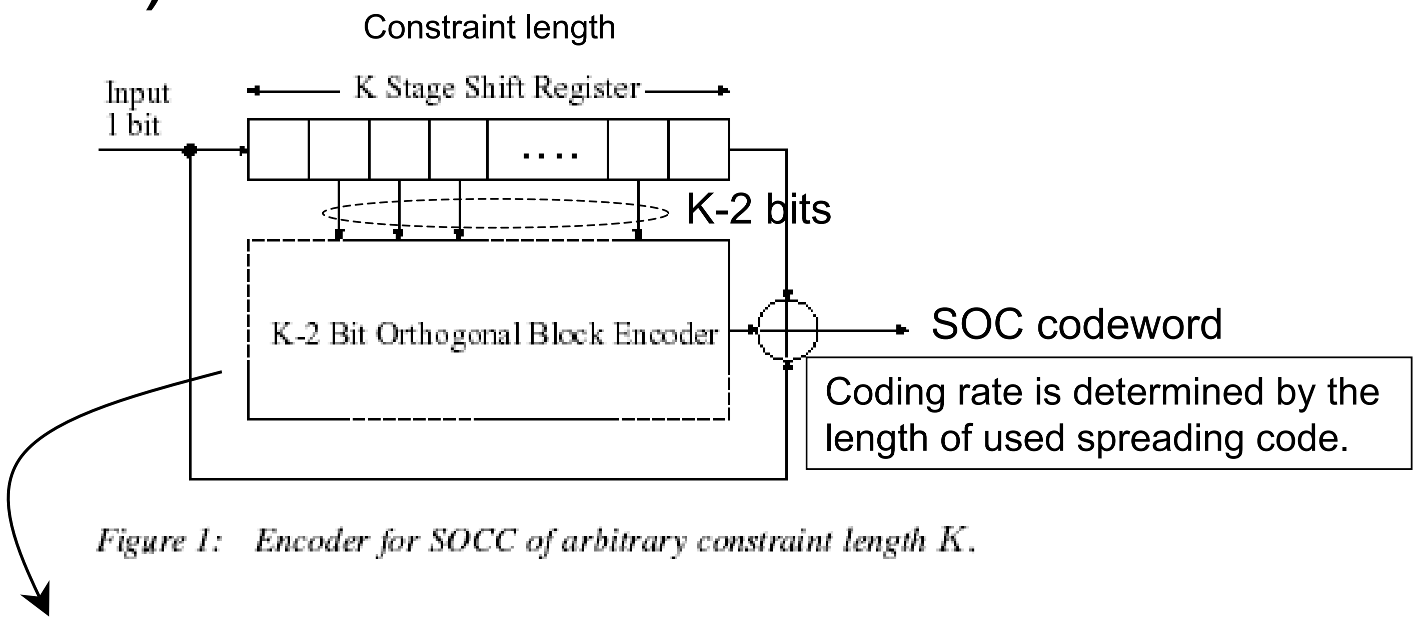


Figure 1: Encoder for SOCC of arbitrary constraint length K.

one orthogonal spreading code is chosen from 2^{K-2} codes

[1] T. Matsumoto, H. Ochiai, and R. Kohno, "A Study on Super-Orthogonal Convolutional Coding using Orthogonal Waveforms for Ultra Wideband Communications," Joint UWBST & IWUWBS2004, Kyoto, Japan, June 2004

System model

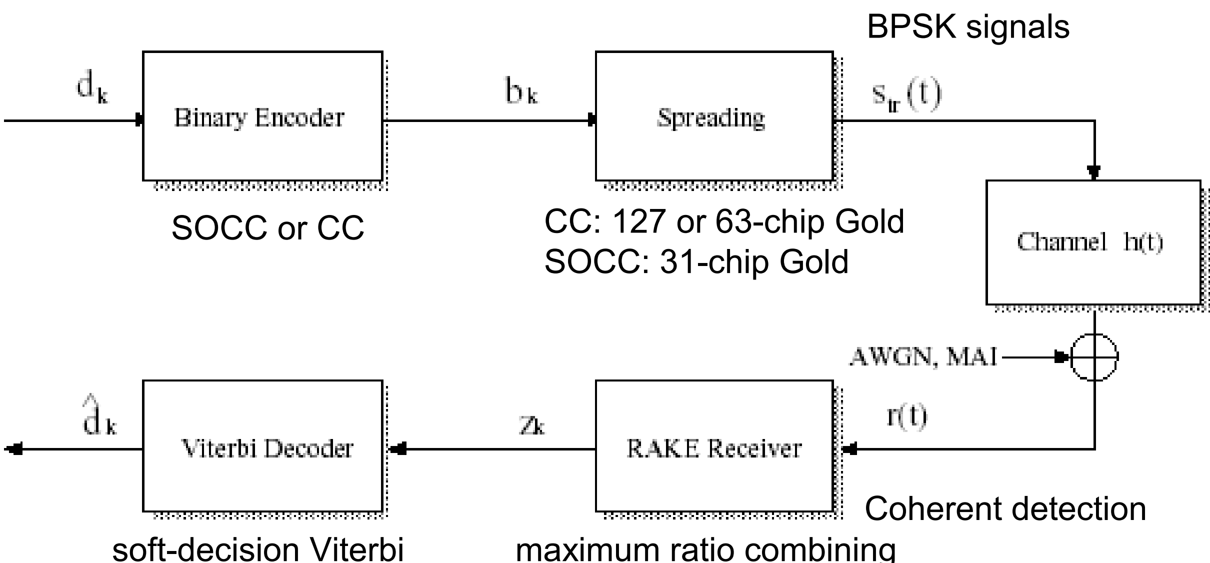


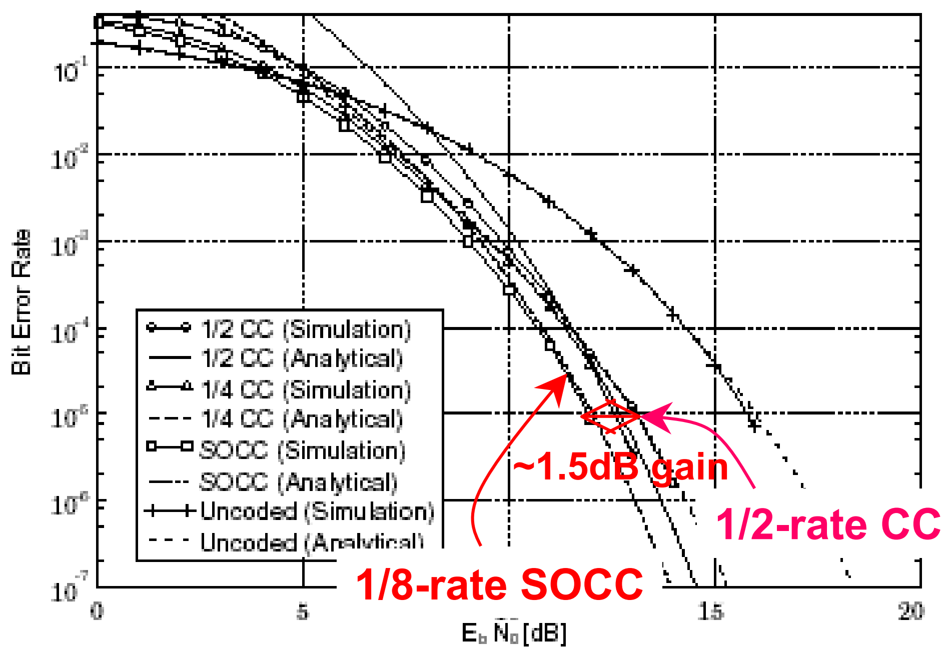
Figure 2: Transmitter model

Waveform: Gaussian
Channel estimation: perfect

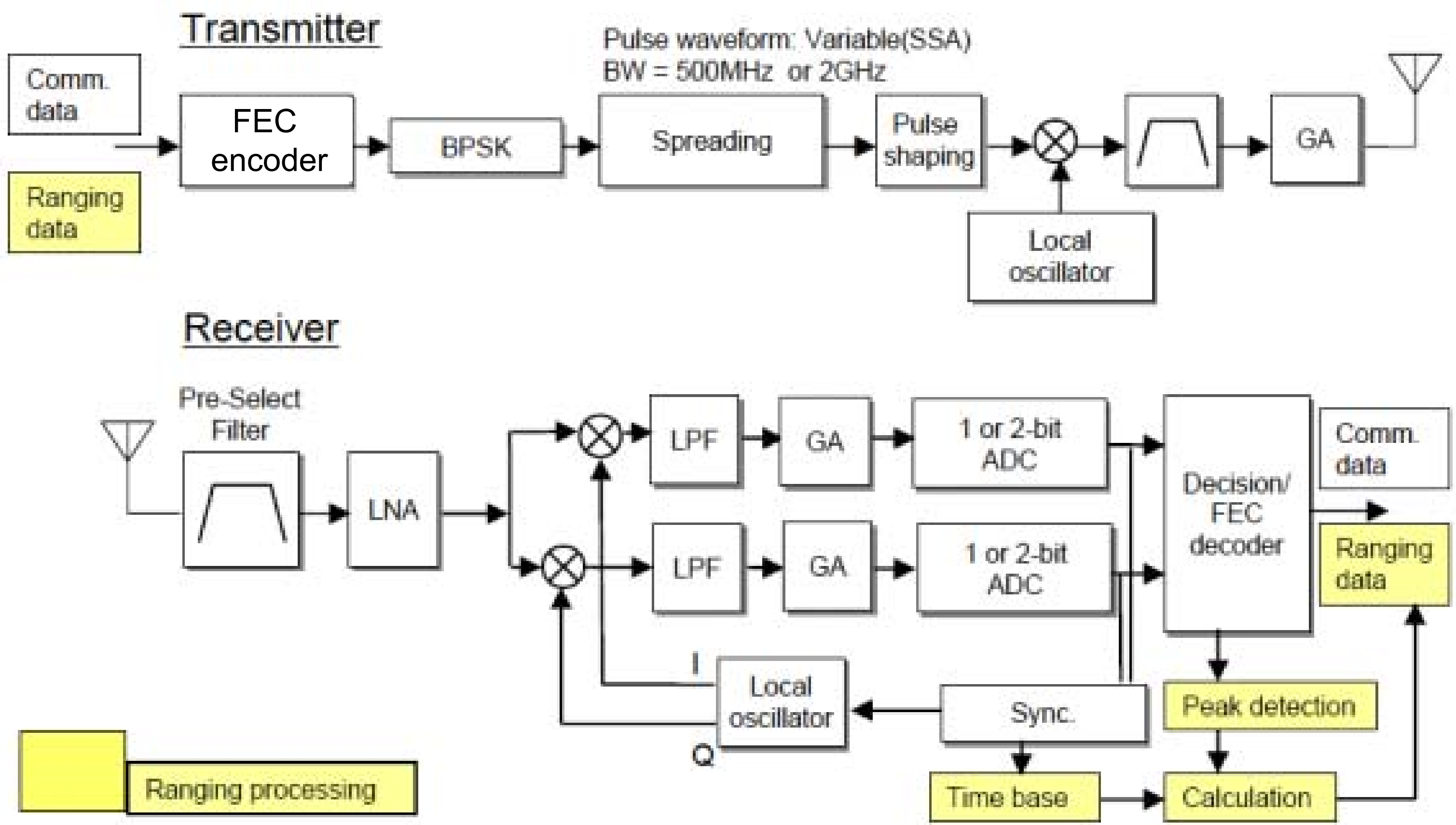
Simulation results

scheme	CC 1	CC 2	SOCC
constraint length K	5		
code rate r	1/2	1/4	1/8
generators	$(23, 35)_8$	$(25, 27, 33, 37)_8$	-
free distance d_f	7	16	64
sequence length N_c	127	63	31
processing gain $F(= N_c/r)$	254	252	248

- 8-finger MRC Rake
- Coherent detection
- CM3 (TG3a)



Simulation Model



Detection Schemes

- Detection Type: Channel Information is known.

  - Coherent detection

- Detection Type: Channel Information is unknown.

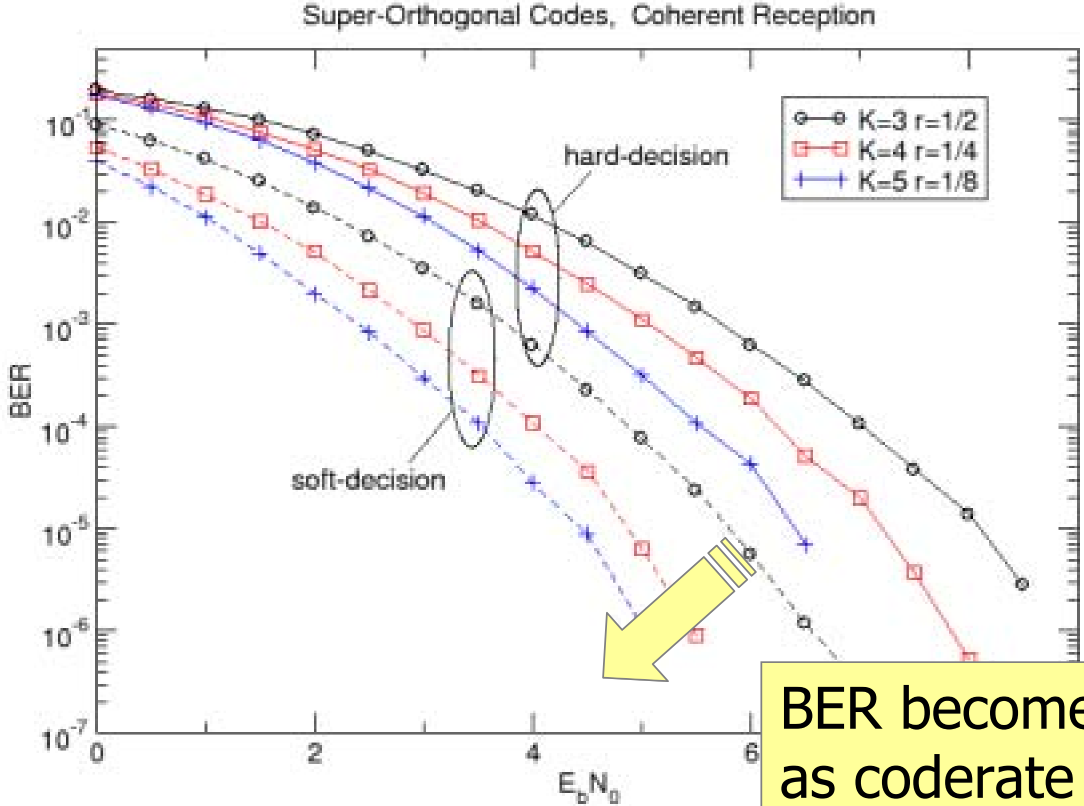
  - Differential Detection

  - Differentially Coherent Detection

Coherent Reception

AWGN channel

(PG = 128 ~ 2048 for R_b=1kbps~4.1Mbps)

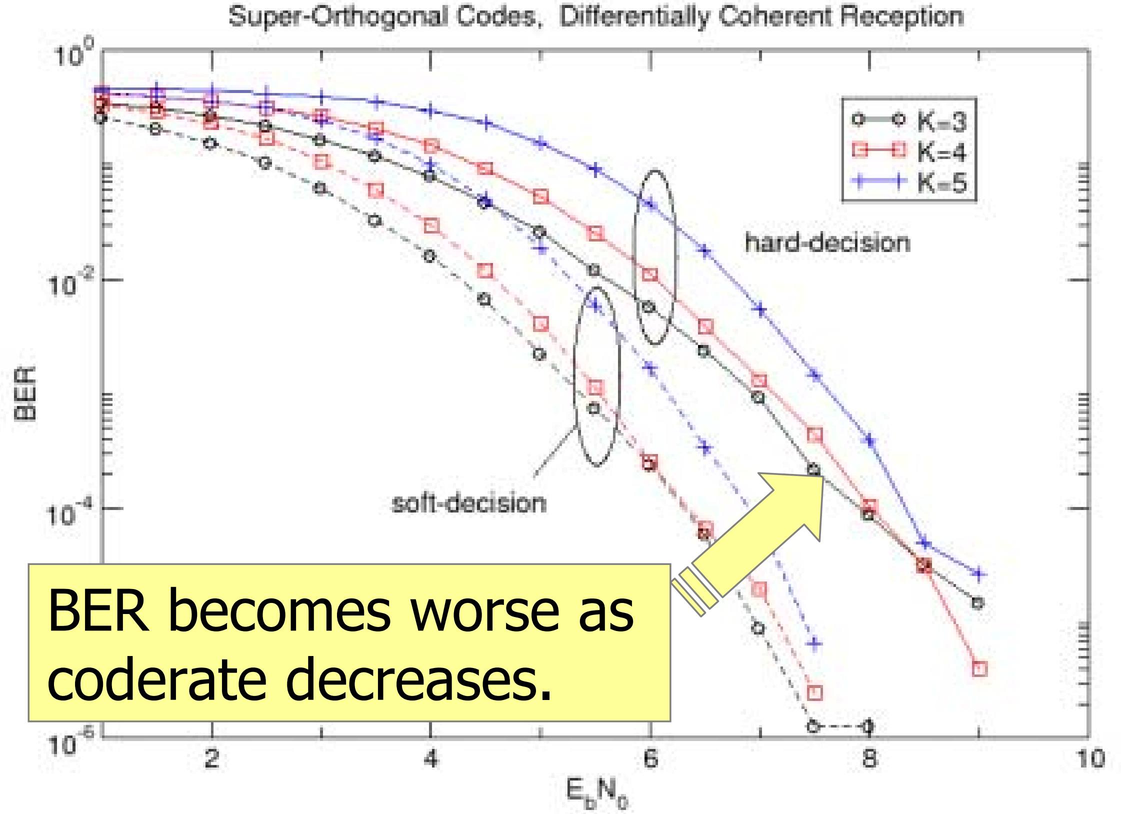


BER becomes better as coderate dereases.

Differentially Coherent Reception

AWGN channel

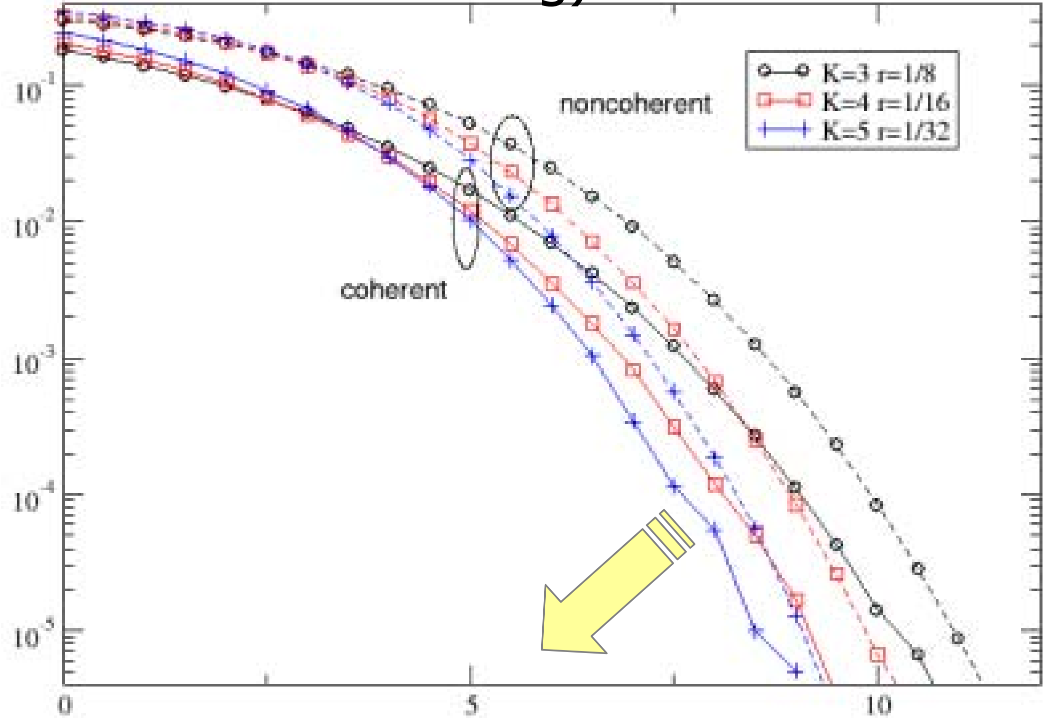
(PG = 128 ~ 2048 for R_b=1kbps~4.1Mbps)



Orthogonal Convolutional Codes

(hard-decision decoding)

AWGN channel

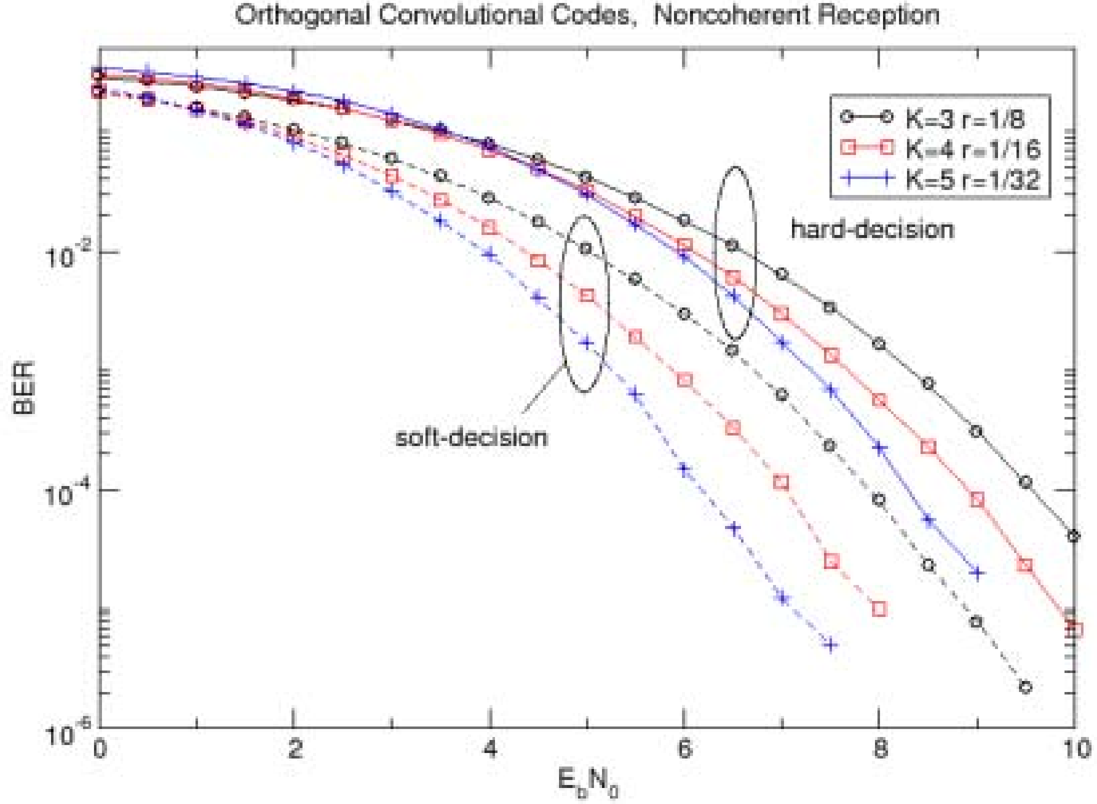


Both coherent, and noncoherent dectectors can perform better as coderate decreases.

Orthogonal Convolutional Codes

AWGN channel

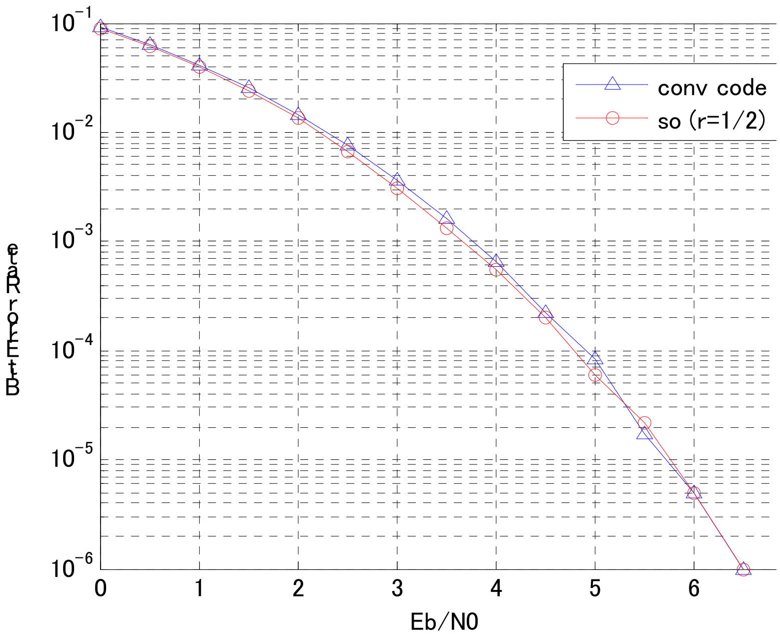
- non coherent detection



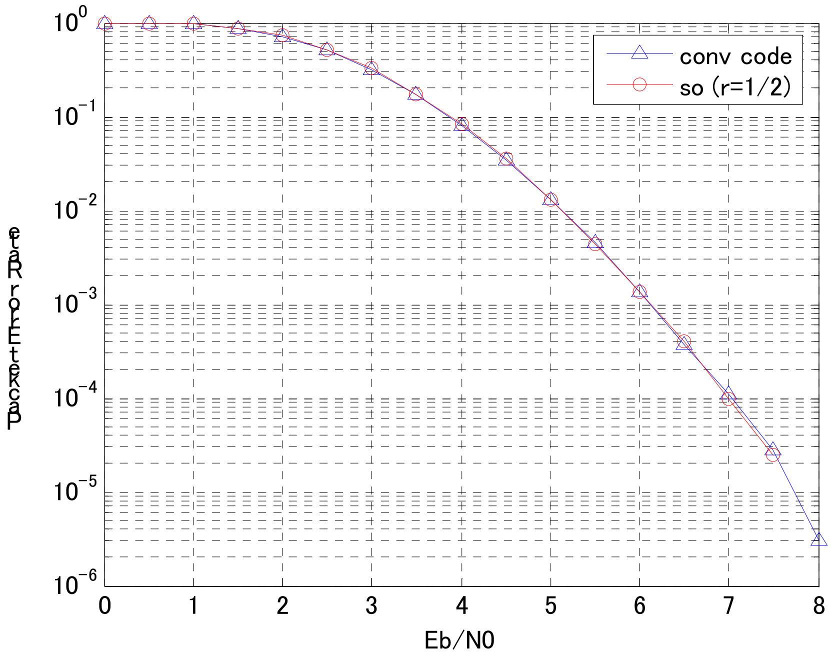
(Constraint length) K=3

- Channel model: **AWGN channel**
- **coherent detection**
- conv code : rate ½ convolutional code
- so : rate **½** super-orthogonal convolutional code

BER



PER

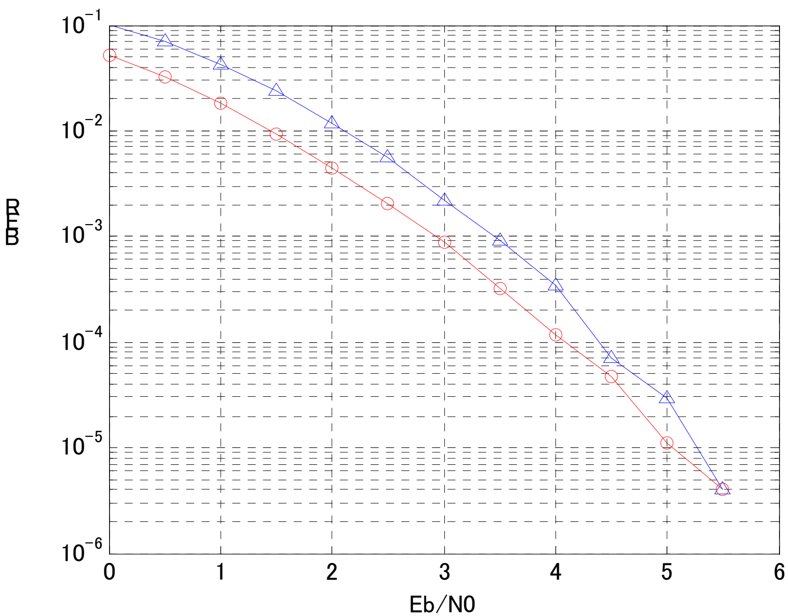


(1packet = 256bit)

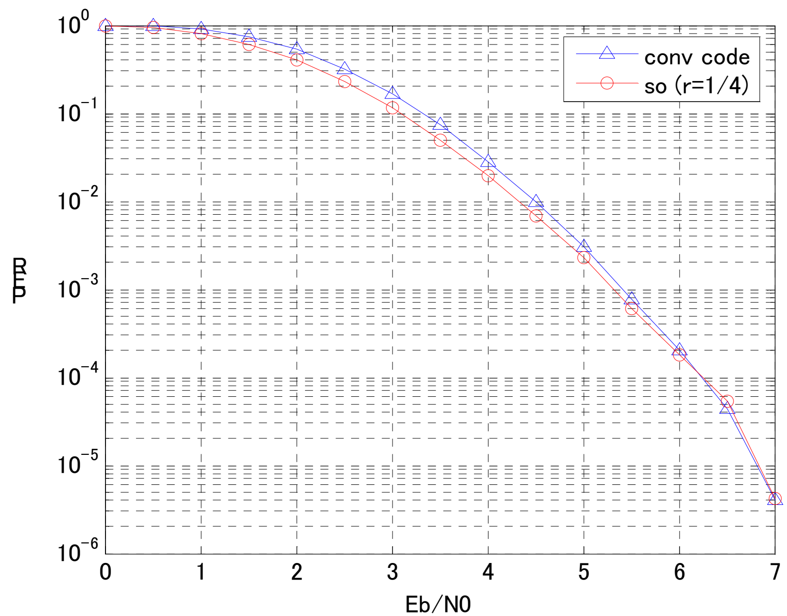
K=4

- Channel model: **AWGN channel**
- **coherent detection**
- conv code : rate ½ convolutional code
- so : rate **1/4** super-orthogonal convolutional code

BER



PER

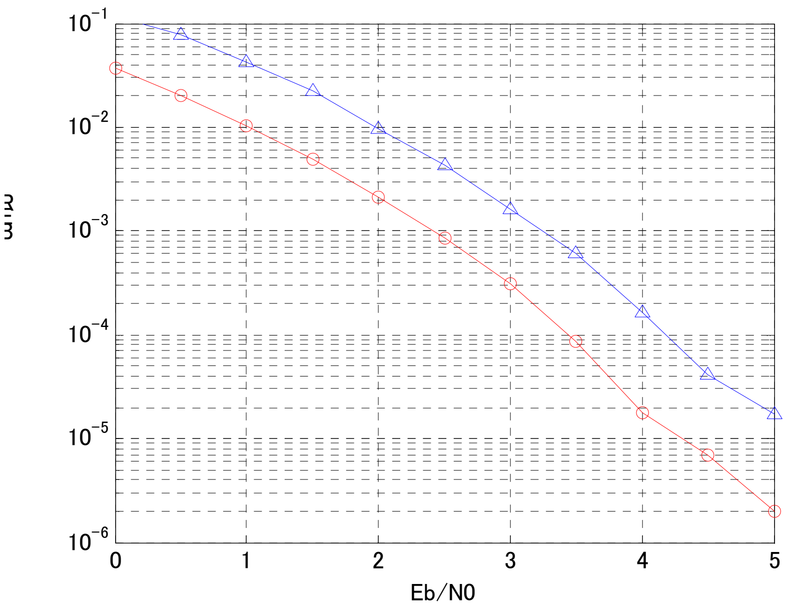


(1packet = 256bit)

K=5

- Channel model: **AWGN channel**
- **coherent detection**
- conv code : rate ½ convolutional code
- so : rate **1/8** super-orthogonal convolutional code

BER



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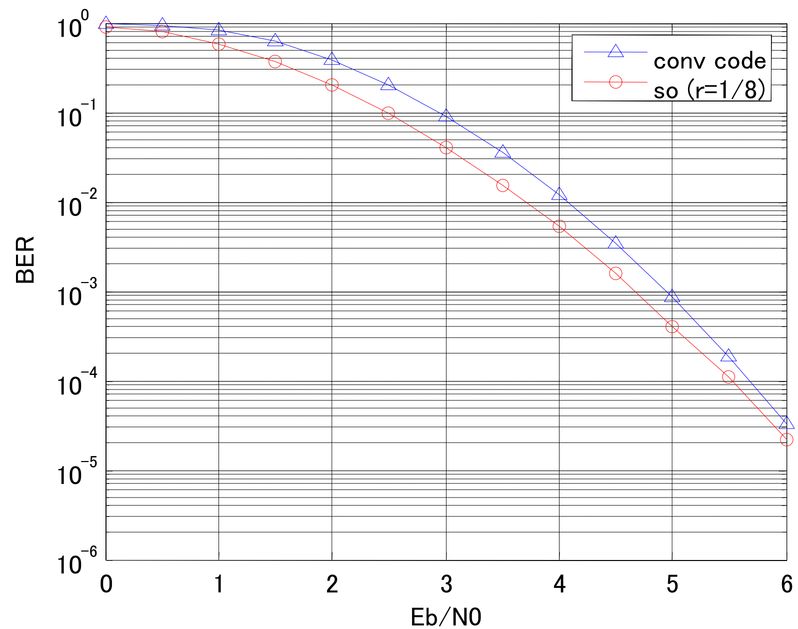
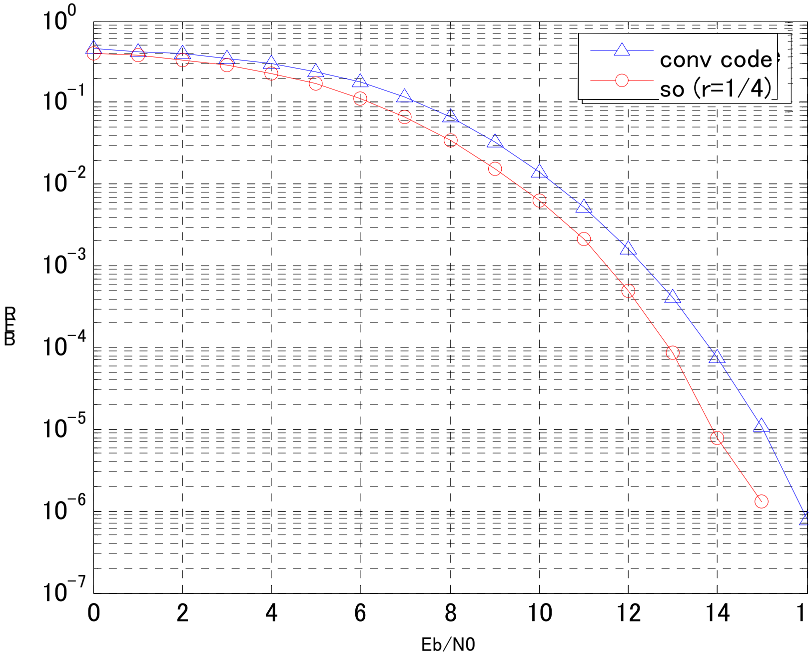


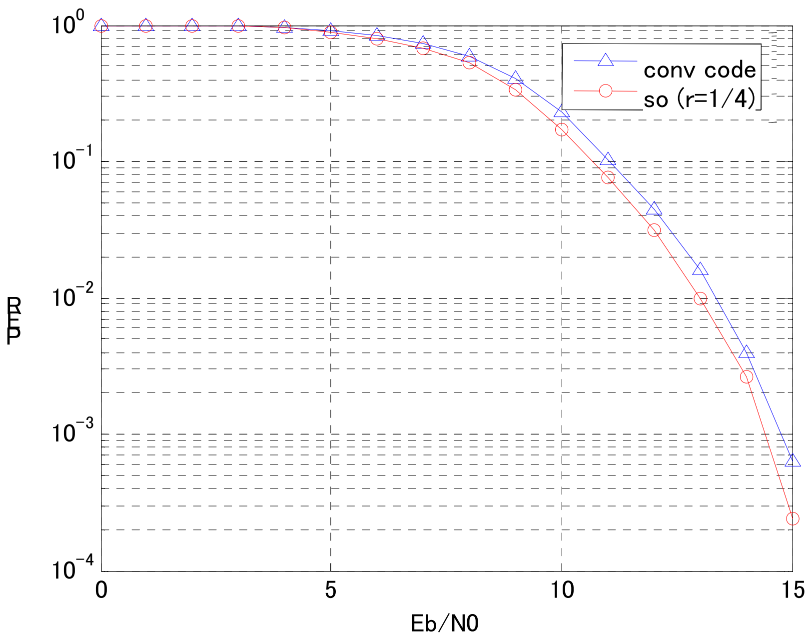
(1packet = 256bit)

- Channel model: **CM1**
- **coherent detection**
- constraint length **K=4**
- conv code : rate ½ convolutional code
- so : rate **1/4** super-orthogonal convolutional code

BER

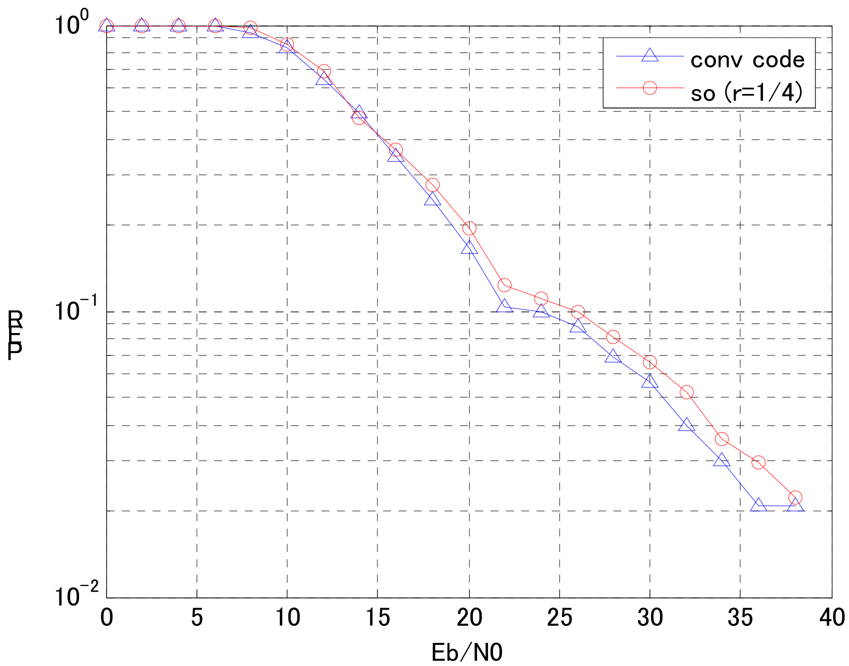


PER



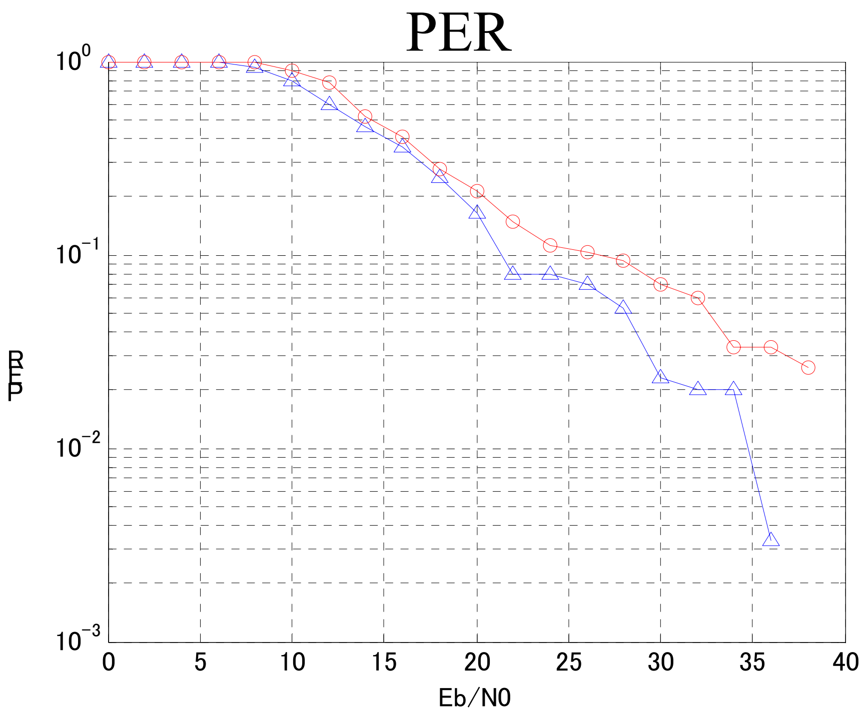
- channel model: **CM1**
- **differentially coherent detection**
- constraint length **K=4**
- conv code : rate ½ convolutional code
- so : rate **1/4** super-orthogonal convolutional code

PER



(1packet = 256bit)

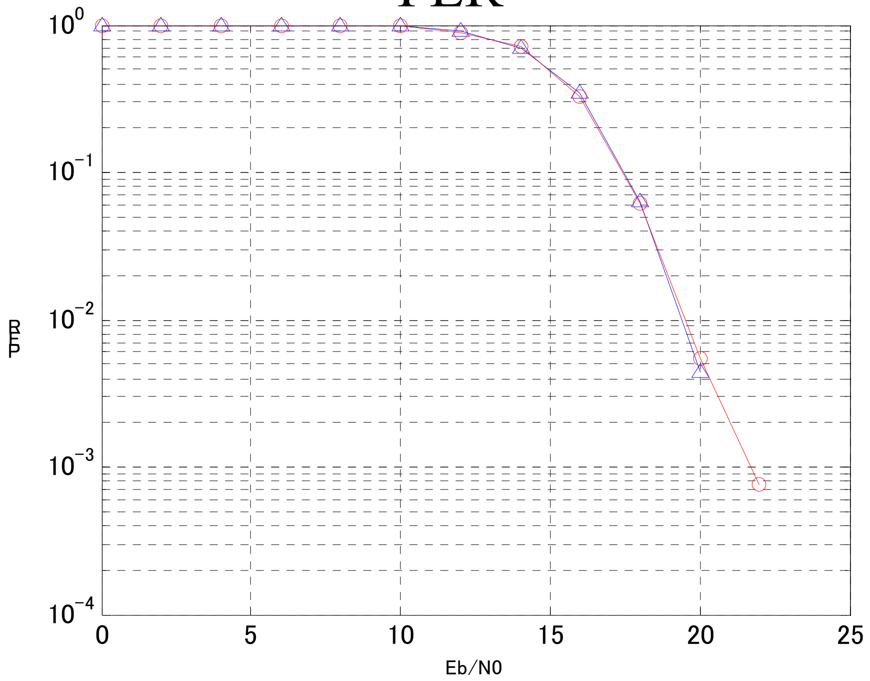
- channel model: **CM1**
- **differentially coherent detection**
- constraint length **K=5**
- conv code : rate ½ convolutional code
- so : rate **1/8** super-orthogonal convolutional code



(1packet = 256bit)

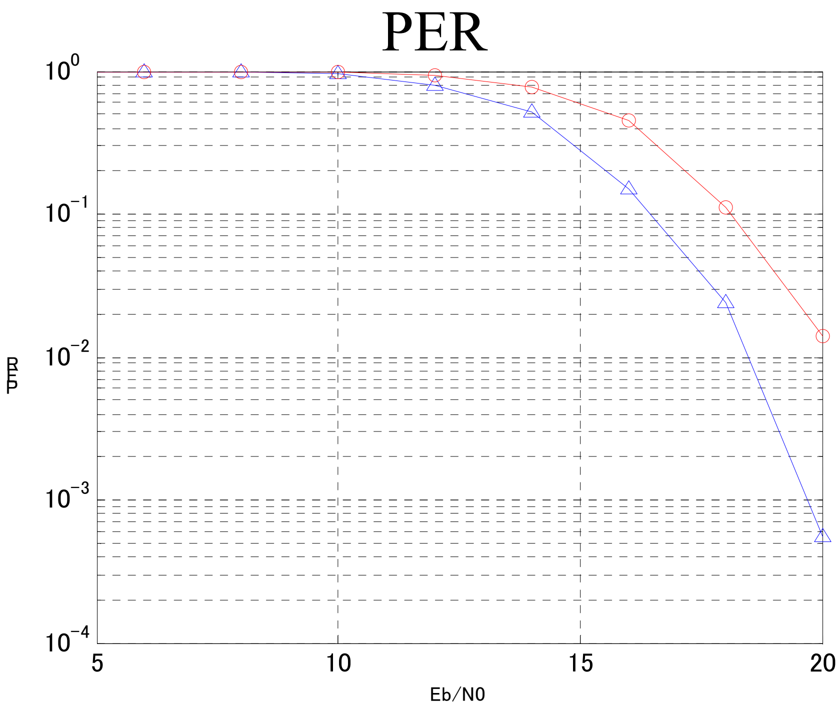
- channel model: **CM1**
- **noncoherent detection**
- constraint length **K=4**
- conv code : rate ½ convolutional code
- so : rate **1/4** super-orthogonal convolutional code

PER



(1packet = 256bit)

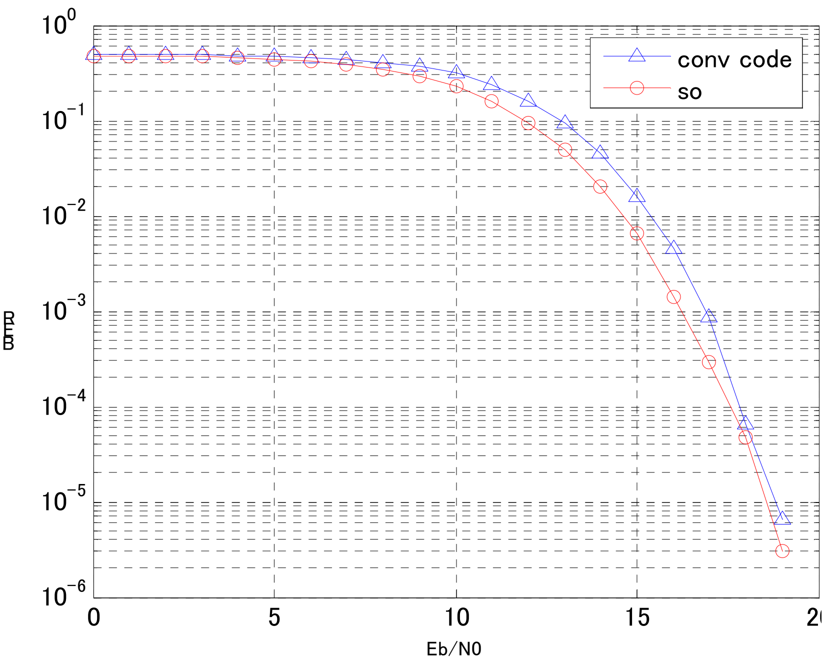
- channel model: **CM1**
- **noncoherent detection**
- constraint length **K=5**
- conv code : rate ½ convolutional code
- so : rate **1/8** super-orthogonal convolutional code



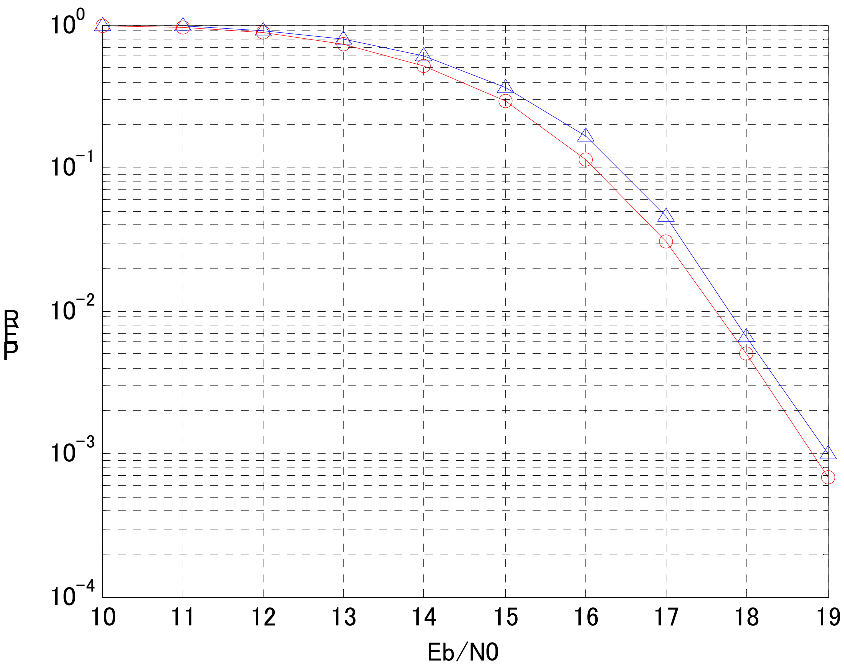
(1packet = 256bit)

- Channel model: **CM8**
- **coherent detection**
- constraint length **K=5**
- conv code : rate ½ convolutional code
- so : rate **1/8** super-orthogonal convolutional code

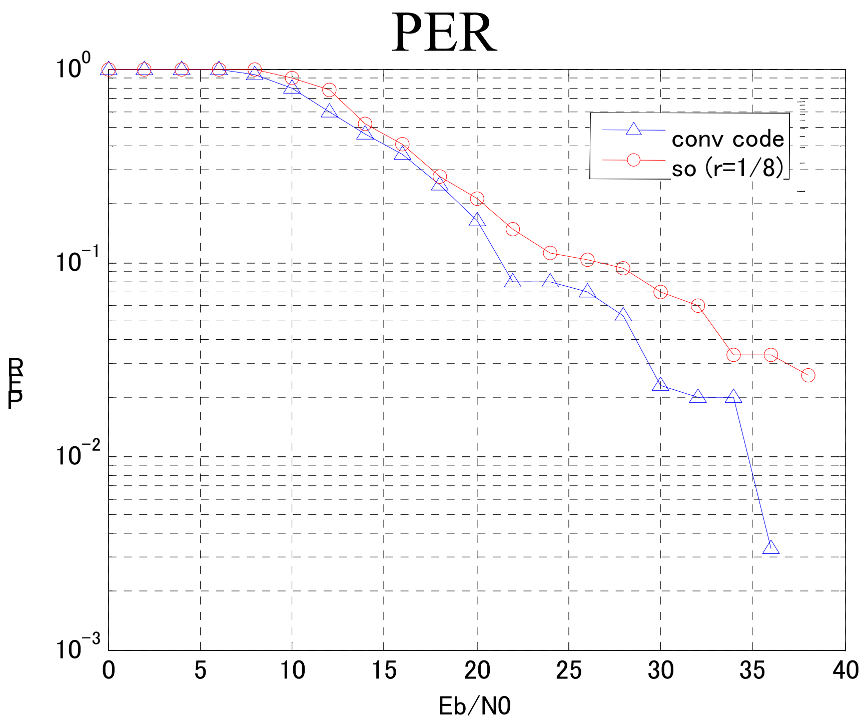
BER



PER

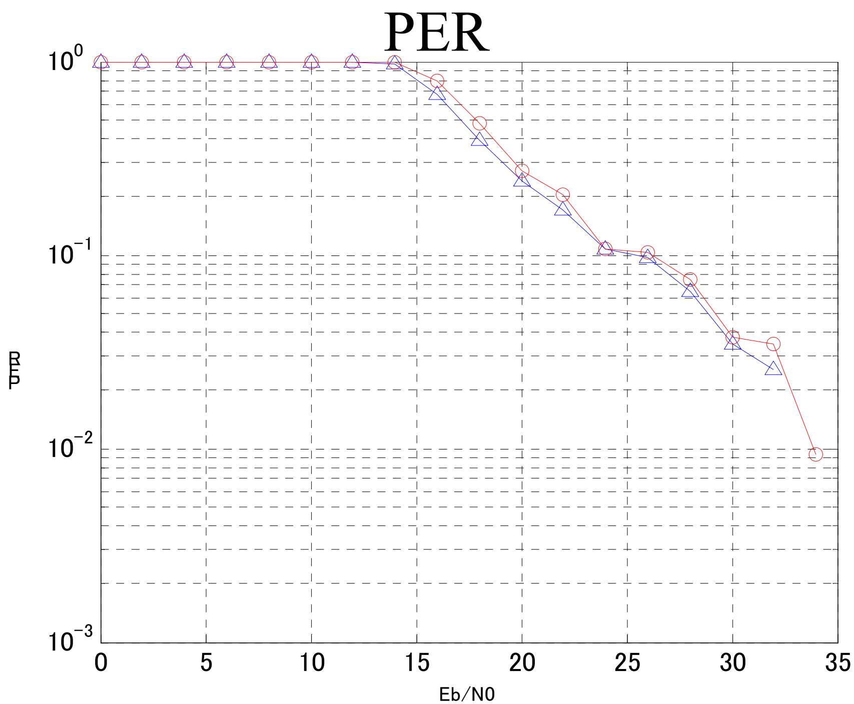


- channel model: **CM8**
- **differentially coherent detection**
- constraint length **K=5**
- conv code : rate ½ convolutional code
- so : rate **1/8** super-orthogonal convolutional code



(1packet = 256bit)

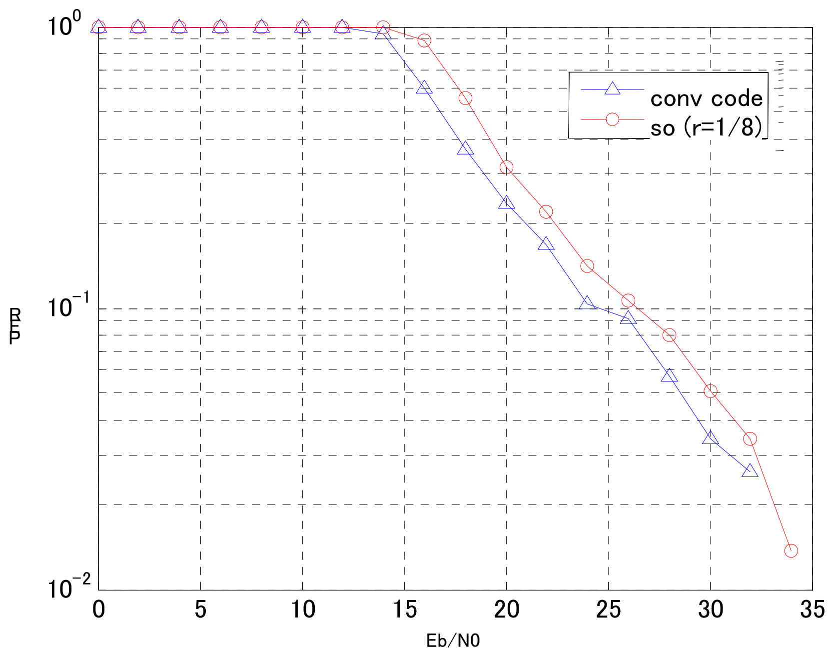
- channel model: **CM8**
- **differentially coherent detection**
- constraint length **K=4**
- conv code : rate ½ convolutional code
- so : rate **1/4** super-orthogonal convolutional code



(1packet = 256bit)

- channel model: **CM8**
- **differentially coherent detection**
- constraint length **K=5**
- conv code : rate ½ convolutional code
- so : rate **1/8** super-orthogonal convolutional code

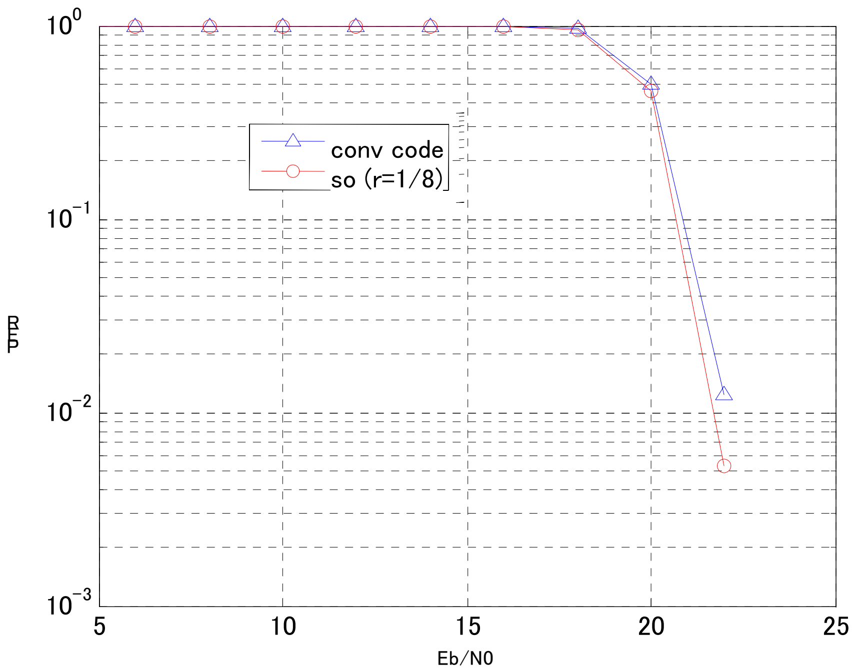
PER



(1packet = 256bit)

- channel model: **CM8**
- **noncoherent detection**
- constraint length **K=5**
- conv code : rate ½ convolutional code
- so : rate **1/8** super-orthogonal convolutional code

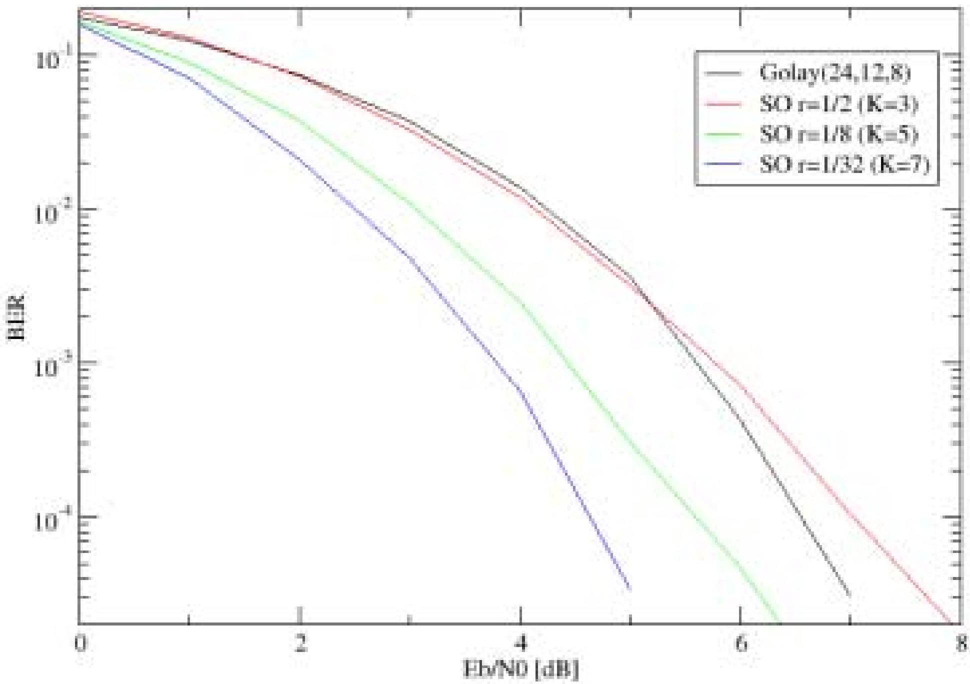
PER



(1packet = 256bit)

Performance Comparison of Golay code and SOC code(1/2)

In AWGN channel



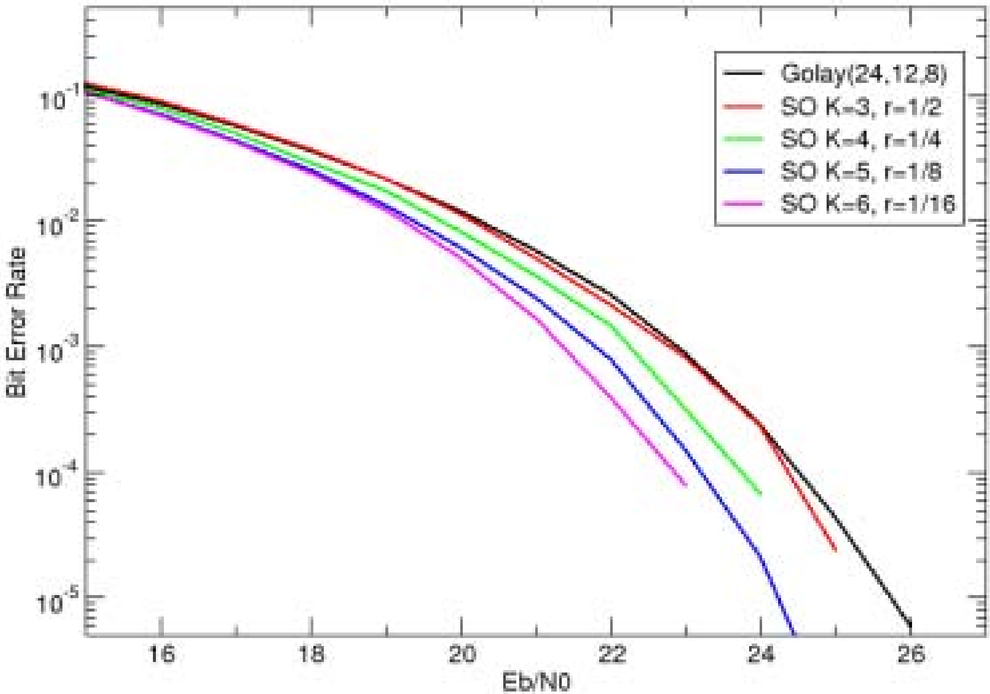
- Transmission rate: 1Mbps
- Coherent detection with 1 bit ADC
- Channel codes :

① Extended Golay (24,12,8) code: extended by adding 1 bit parity with Golay(23,12) code with coderate ½.

② Super-Orthogonal Covolutional(SOC) code: constraint length K=3~7, coderate r=1/2~1/32

Performance Comparison of Golay code and SOC code(2/2)

In CM1 : indoor residential LOS



- Transmission rate: 1Mbps
- Coherent detection with 1 bit ADC
- Channel codes :

① Extended Golay (24,12,8) code: extended by adding 1 bit parity with Golay(23,12) code with coderate ½.

② Super-Orthogonal Covolutional(SOC) code: constraint length K=3~7, coderate r=1/2~1/32

Summary of Channel Codes

1. Super-Orthogonal Convolutional (SOC) Code

(1) SOC code performs better BER and PER than either Golay code or a conventional convolutional code in case of coherent detection while SOC code does worse in case of differential detection as a coderate decreases in AWGN channel.

(2) SOC code overperforms a conventional convolutional code in case of coherent detection in fading channel such as CM1 and 8.

(3) SOC code with a lower coderate reduces a spreading gain, so a code and a spreading rates should be jointly optimized under the constraint of $r = 2^{-K+2}$

2. Orthogonal Convolutional (OC) Code

(1) OC code performs better BER and PER than a conventional convolutional code in both cases of coherent and differential detection as a coderate decreases in AWGN channel.

* Joint optimization between spreading and channel codes is important.

UWB-PHY modulation criteria

1. PER (packet error rate) performance @1Mb/s with 15.4a channel models,
rate ½ convolutional code (constraint length up to 5; more needs justification)

Revise !

1. PER (packet error rate) performance @1Mb/s with 15.4a channel models,
appropriate covolutional codes (coderate less than ½, and constraint length up to 5; more needs justification)

Simulation Guidelines

1. PER (packet error rate) performance @1Mb/s vs. Eb/N0
    1. AWGN
        1. Performance Coherent, Diff. Coherent, Non-coherent receive
    2. 4a channel models
        1. Order of importance: CM1, CM8, then others
        2. Show PER performance without receiver enhancements (e.g. a single rake finger for coherent receivers)
        3. Show PER performance with proposal's enhancements

2. SOP isolation
    1. Desired signal set at 6dB above sensitivity (Eb/N0 where 1% PER was achieved in the channel model.)
    2. Vary SINR compute PER. Multiple interferer scenarios should use equal power.
3. Spectrum: SPAR (spectral peak-to-average ratio)
    1. State/show what back-off will be required.

2. Spreading Codes Coherent and Non-coherent detection in IEEE802.15.4a

Motivation

- Spreading code for a preamble is important for acquisition, tracking, and more number of SOPs.
- The same spreading code for a preamble could be used for information spreading for a whole frame.
- Spreading code can be also designed to avoid interference to coexisting systems with appropriate spectral notches.
- Matched spectral code that is a kind of spectral null code is applied so that PBTS(perfect balanced ternary sequence) can be modified to make appropriate nulls in its spectra.

Matched spectral null coding

•Matched spectral code can make an appropriate spectral null by encoding a sequence such as PBTS as follows.

x1 x2 ... → x1 x2 ... ¥bar{x1} ¥bar{x2} ...

Case 0: 2 consecutive bits are encoded into 1 symbol like.

Example. [1 0 1 1 0 1] → [1 0 0 1 1 1 0 0 0 1 1 0]

•By the same manner, we can make various spectral nulls.

In the next page,

Case 1: 4 consecutive bits are encoded into 1 symbol.

Case 2: 6 consecutive bits are encoded into 1 symbol.

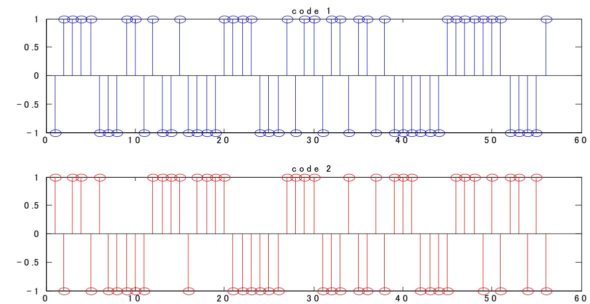
Matched spectral null coding

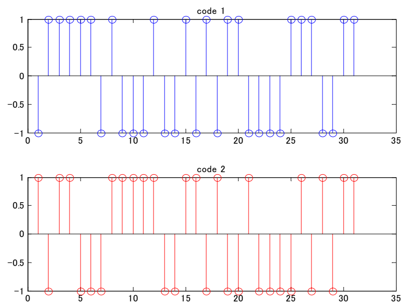
Case 0: [1 0 1 1 0 1] → [1 0 0 1 1 1 0 0 0 1 1 0]

Case 1: 4 successive bits are encoded into 1 symbol.

Case 2: 6 successive bits are encoded into 1 symbol.

Case 1

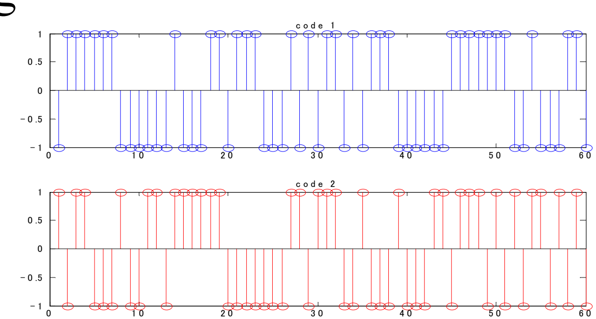




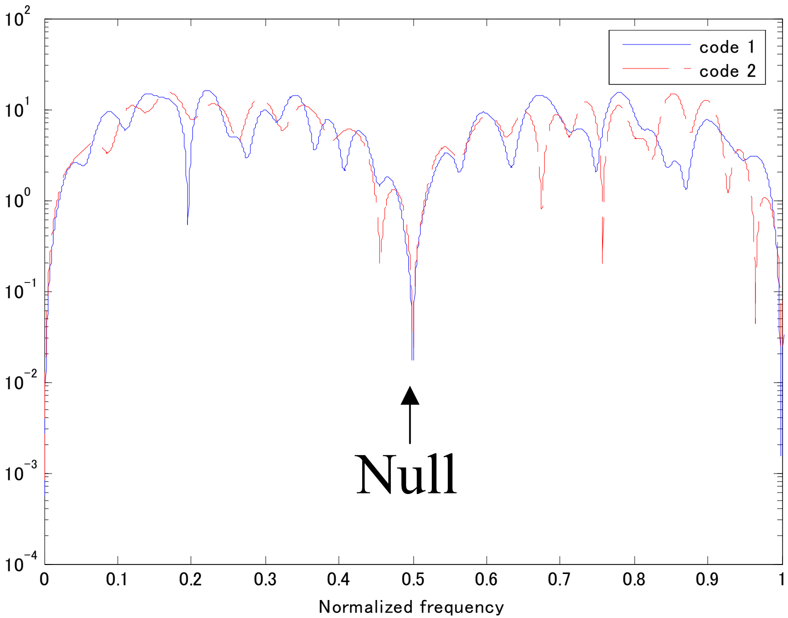
Matched spectral null coding

PBTSs
(energy detection)

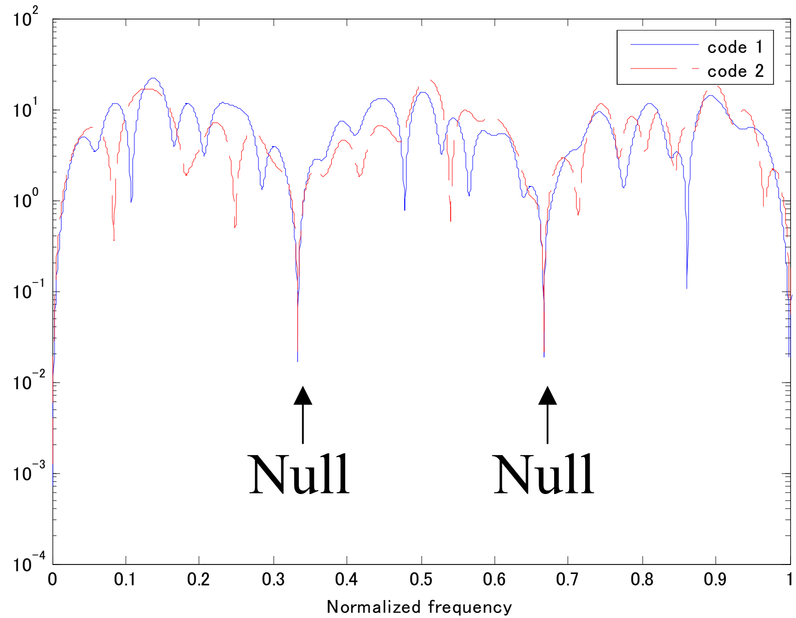
Case 2



Spectra of Matched spectral null coded PBTS

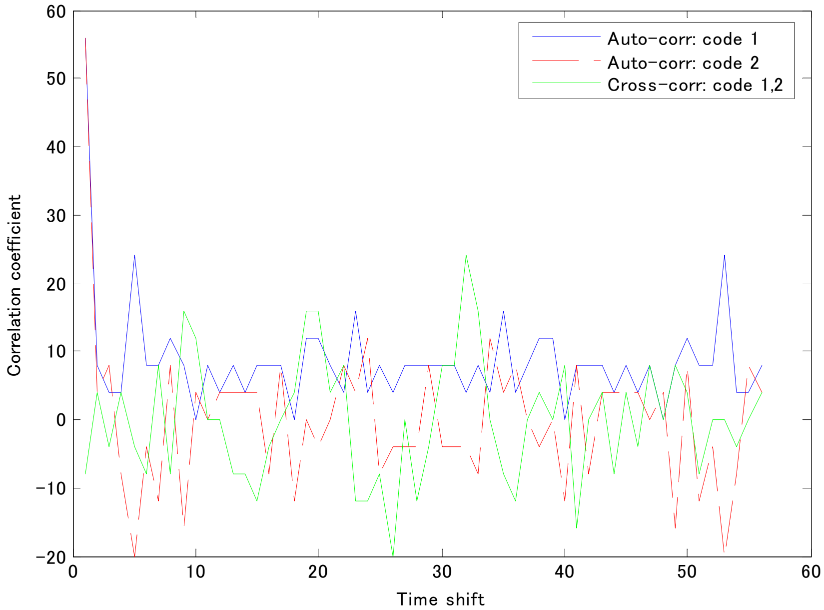


Case 1

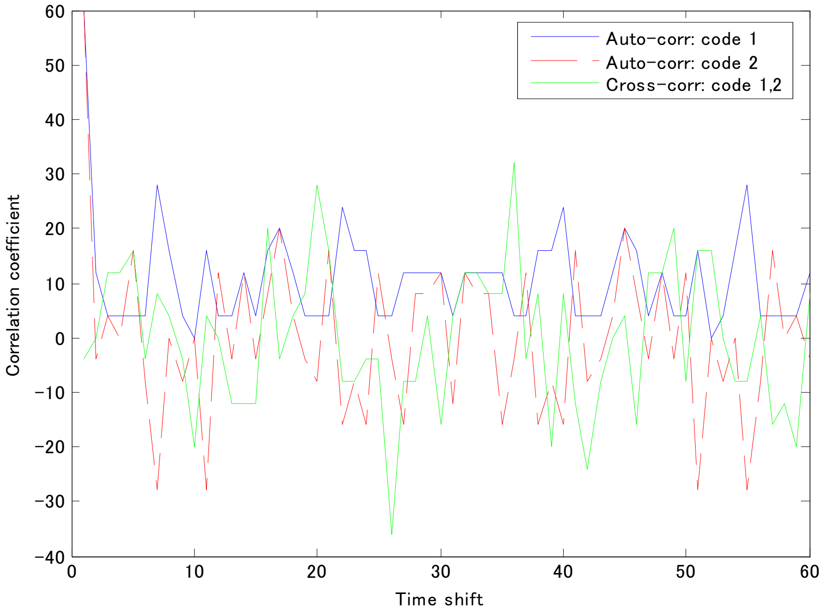


Case 2

Correlation characteristics of matched spectral null coded PBTS



Case 1



Case 2

Concluding Remarks

- Major specifications for signaling such as modulation, channel code, spreading code, and pulse shape should be jointly optimized.
- However, according to priority of selection criteria, all specifications can be selected under some conditions, so that received signals can be demodulated with either coherent and noncoherent detection.
- At least some channel codes such as SOC and OC codes and some typical spreading codes such as PBTS and its modified version should be applied in simulation for performance comparison.