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

Submission Title: *M*-ary Code Shift Keying/Binary PPM (MCSK/BPPM) Based Impulse Radio
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Abstract: [Proposed modulation format increases the ranging and location capability of time hopping impulse radios]

Purpose: [Proposal for the IEEE802.15.4a standard]

Proposal for
IEEE 802.15.4 Alternate PHY

M-ary Code Shift Keying/Binary PPM (MCSK/BPPM) Based Impulse Radio

SFU, Canada & UWB-ITRC, Inha University
Republic of Korea

Motivation

- MCSK/BPPM increases the location/ranging capability of existing Time Hopping (TH) Impulse Radios (IRs)
- H/W complexity is not increased
- Same signal space with respect to TH-BPPM
- "MCSK" can be applied to other TH-IRs; eg. MCSK/BPSK

Contents

- TG4a Requirements
- MCSK/BPPM
- PHY TX Structure
- TH Code Assignment
- Transceiver Architecture
- Information Rate
- Location Accuracy
- Conclusion

TG4a Requirements

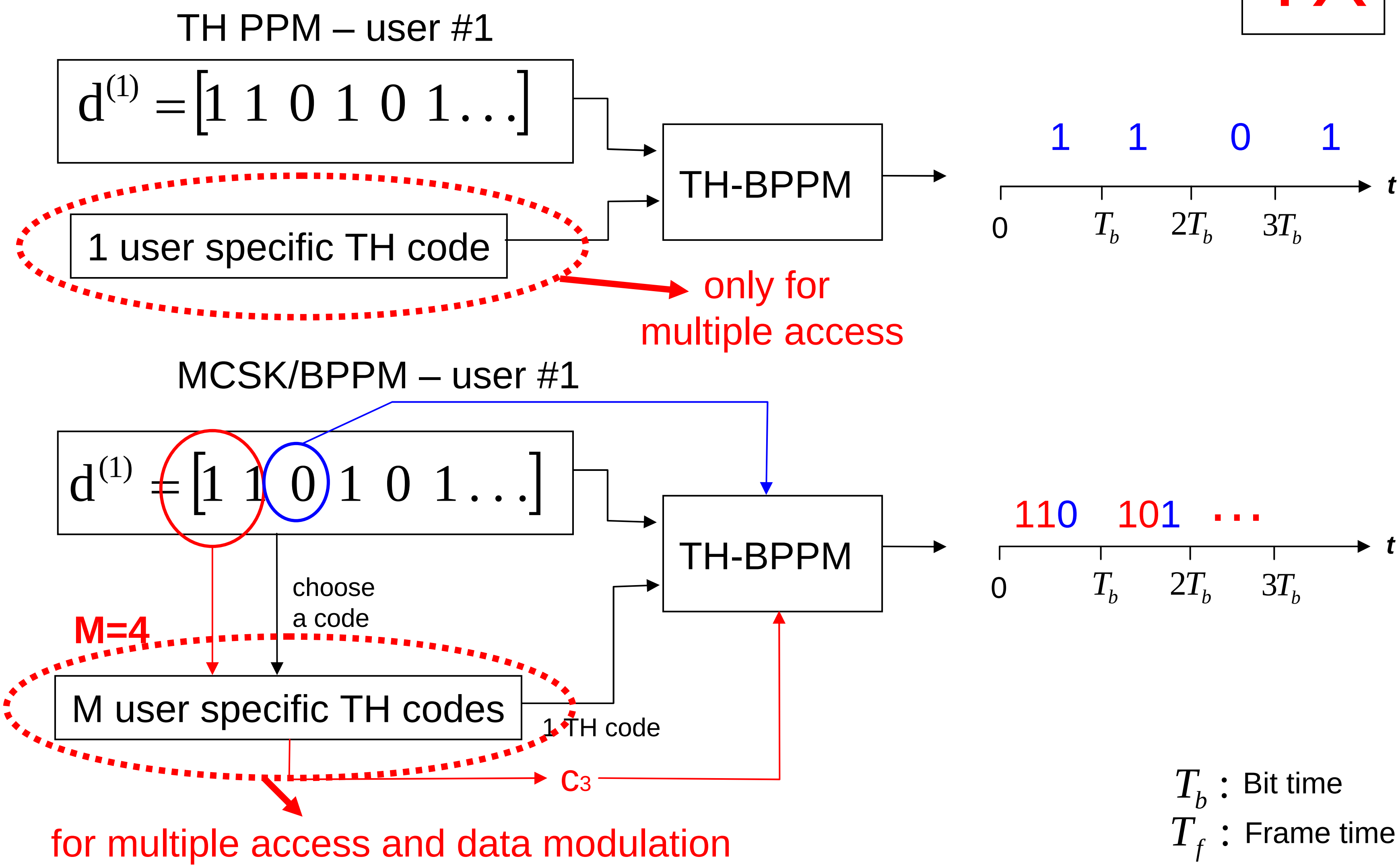
802.15.4a PHY	**MCSK/BPPM compared to TH-BPPM**
scalable information rates	**Better BER performance** at the same/higher information rates and lower transmit power
high precision ranging/ location	**Improved ranging/location precision** capability
low power consumption	**Lower transmit power** at the same/higher information rates and better BER performance
low complexity and cost	**No new circuit** is needed / **simple transceiver** structure

*MCSK/BPPM: *M*-ary Code Shift Keying/Binary Pulse Position Modulation
**TH-BPPM: Time Hopping Binary Pulse Position Modulation

MCSK/BPPM

MCSK: *M*-ary Code Shift Keying
BPPM: Binary Pulse Position Modulation

TX



PHY TX Structure (1/2)

TX

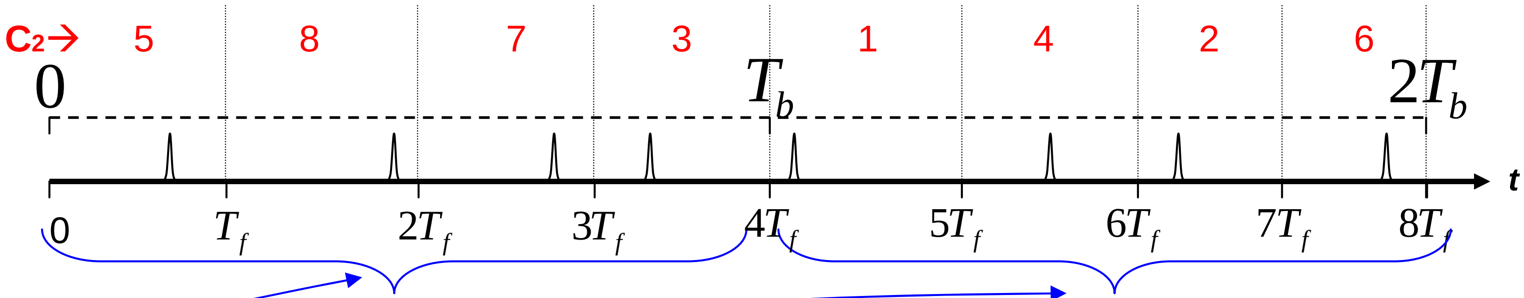
M user specific TH codes

- TH codes are **periodic with N_p**
- each **pulse should be repeated N_s times**
- **$N_p/N_s=k$** is an integer

Example: $M=4, N_p=8, N_s=4$

$$d=[1\,0\,1\,1\ldots] \qquad TH=\begin{bmatrix} c_0 \\ c_1 \\ c_2 \\ c_3 \end{bmatrix}=\begin{bmatrix} 7 & 8 & 2 & 3 & 6 & 4 & 1 & 5 \\ 3 & 6 & 5 & 2 & 8 & 7 & 4 & 1 \\ 5 & 8 & 7 & 3 & 1 & 4 & 2 & 6 \\ 2 & 4 & 8 & 6 & 3 & 7 & 5 & 1 \end{bmatrix}$$

MCSK



$$d=[1\,0\,1\,1\ldots]$$

BPPM

T_b : Bit time

T_f : Frame time

PHY TX Structure (2/2)

TX

M user specific TH codes

- TH codes are **periodic with N_p**
- each **pulse should be repeated N_s times**
- **$N_p/N_s=k$** is an integer

Information rate vs. BER performance for fixed Ns and varying N_p and M

Scenario	Time domain illustration	Info. rate	BER performance
$N_p / Ns = 1$, $M = 4$	2 bits (MCSK); 1 bit (BPPM); 0 – T_b	↑	↓
$N_p / Ns = 1$, $M = 8$	3 bits (MCSK); 1 bit (BPPM); 0 – T_b	↑	↓
$N_p / Ns = 2$, $M = 8$	3 bits (MCSK); 1 bit (BPPM), 1 bit (BPPM); 0 – T_b – $2T_b$	↓	↑

Rows 1–2: *Np/Ns* same, *M* increasing

Rows 2–3: *M* same, *Np/Ns* increasing

T_b : Bit time T_f : Frame time

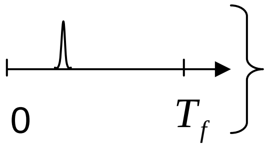
TH Code Assignment (1/2)

TX

Each user has M user specific TH codes → $N_u N_p M$ sample-long sequence ?

NO!

Generation of TH codes – "Case 1: random assignment"



For T_f = 100ns, T_c = 1ns:
100 slots for multiple access → $2^l \equiv N_h;\ l = 6,\ N_h = 64$

m-sequence: $[1\,0\,1\,1\,1\,0\ 0\,1\,0\,1\,0\,0\ 1\,1\,0\,1\,1\,1\ 0\,1\,0\,0\,0\,1\,0\,1\,0\,1\,0\,0 \ldots]$

46 **20** **55**

$N_p = 4$, $M = 4$

$[46\ 20\ 55\ 17\ 20\ 13\ 12\ 31\ 61\ 14\ 56\ 5\ 7\ 24\ 26\ 53\ 45\ 35\ 2 \ldots]$

user #1: c0, c1, c2, c3

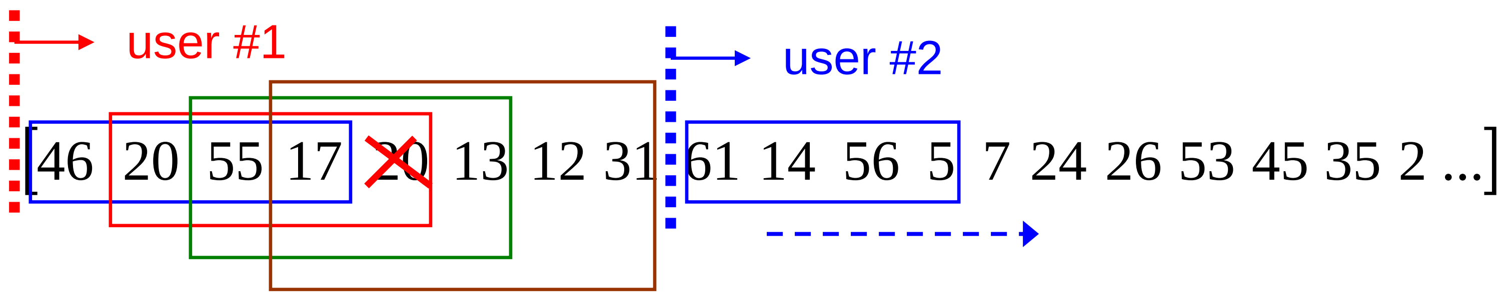
user #2: c0, c1, c2, c3

$$N_u N_p \Rightarrow N_u \left(N_p + M - 1\right)$$

TH Code Assignment (2/2)

TX

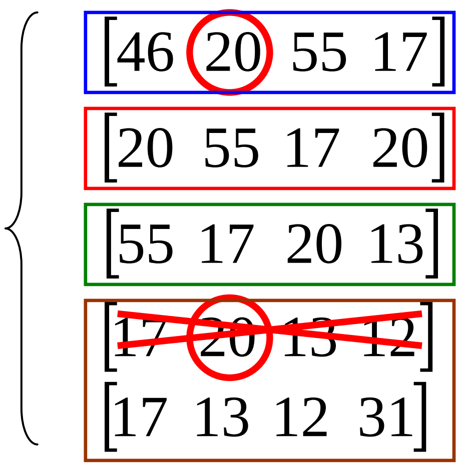
Generation of TH codes – "Case 2: no overlapping"



user #1 user #2 . . . user #k

$N_p = 4$

$M = 4$



no collisions allowed within user codes

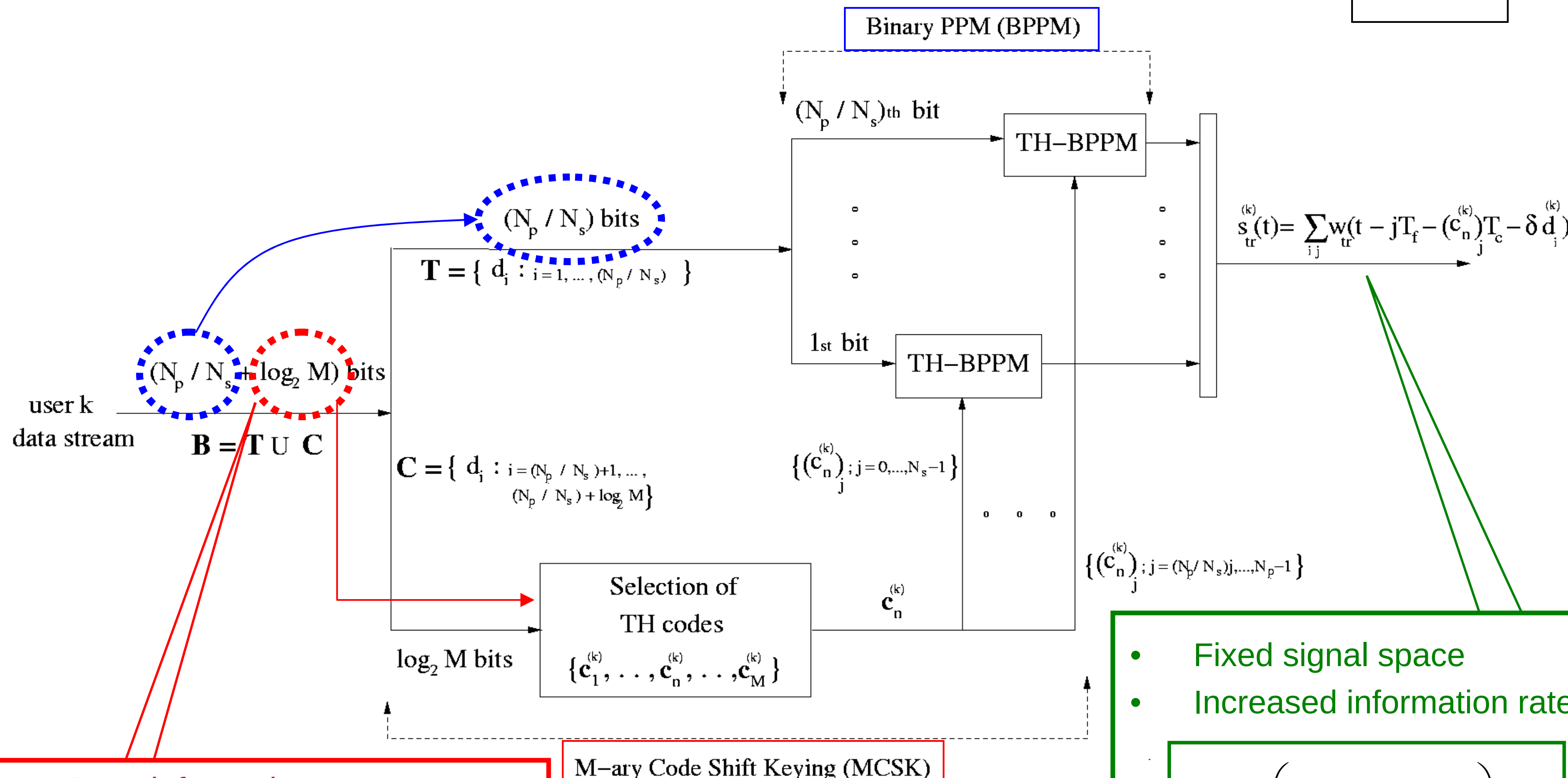
[61 14 56 5]

$$N_u N_p \Rightarrow N_u\left(N_p + M - 1\right) + n$$

n: number of overlaps

General Modulation Format

TX



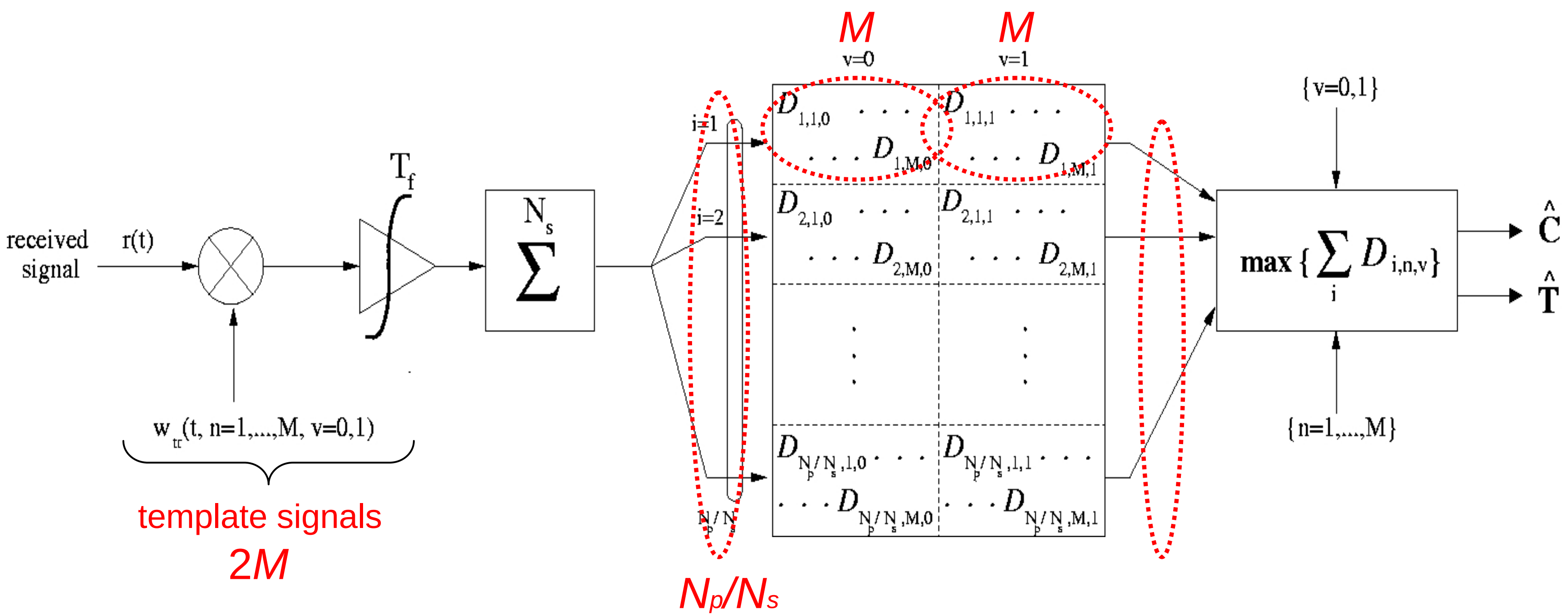
- Extra information
- Random selection of TH codes→**Improved spectrum**

- Fixed signal space
- Increased information rate

$$R_s = \left(1 + \frac{\log_2 M}{N_p / N_s} \right) \cdot R$$

Receiver Structure - MLSE

RX



hardware structure

1 correlator

computation complexity

$2^{(N_p/N_s)}M$

Information Rate (1/3)

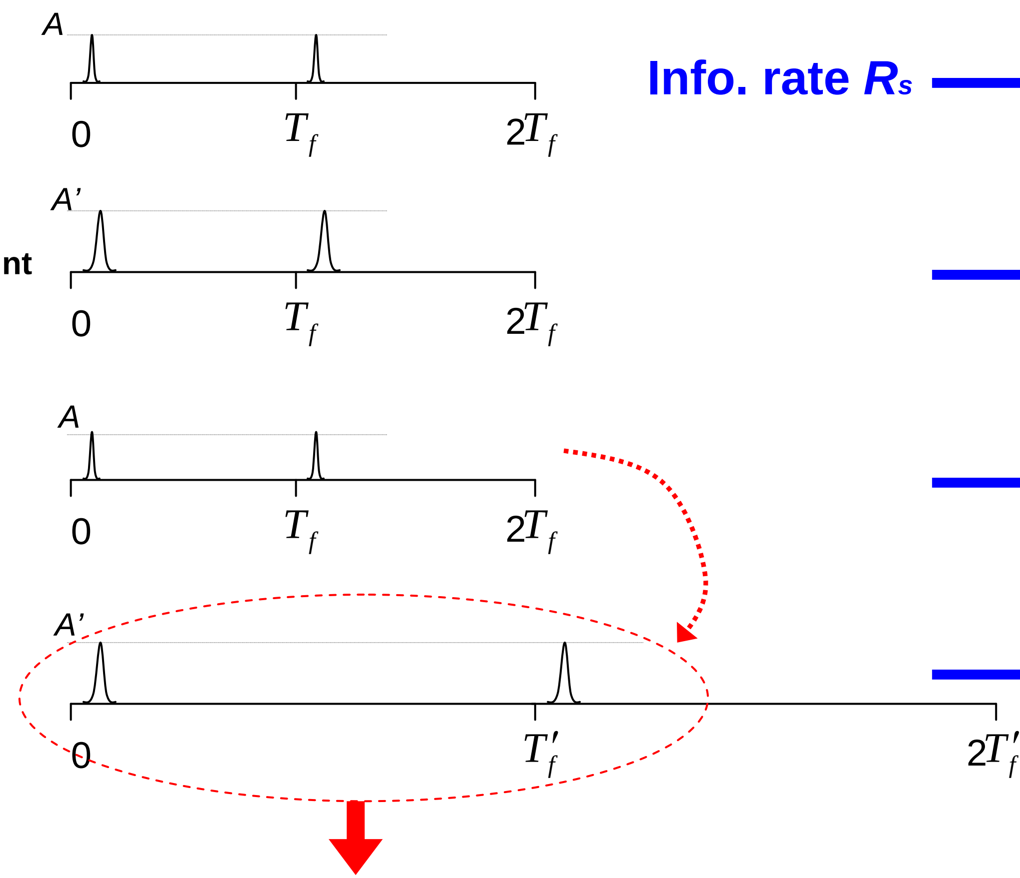
$$R_s = \left(1 + \frac{\log_2 M}{N_p / N_s}\right) \cdot R$$

TH-BPPM
Ns = 2, M=1

MCSK/BPPM
“Constant Energy/Bit” Constraint
Ns = 2, Np=2, M=2

MCSK/BPPM
“Constant Power” Constraint
Ns = 2, Np=2, M=2

MCSK/BPPM (same info. rate)
“Constant Power” Constraint
Ns = 2, Np=2, M=2



Info. rate R_s → R

→ $2R$

→ $2R$

→ R

$$A' = \sqrt{1 + \frac{\log_2 M}{N_p / N_s}}\, A$$

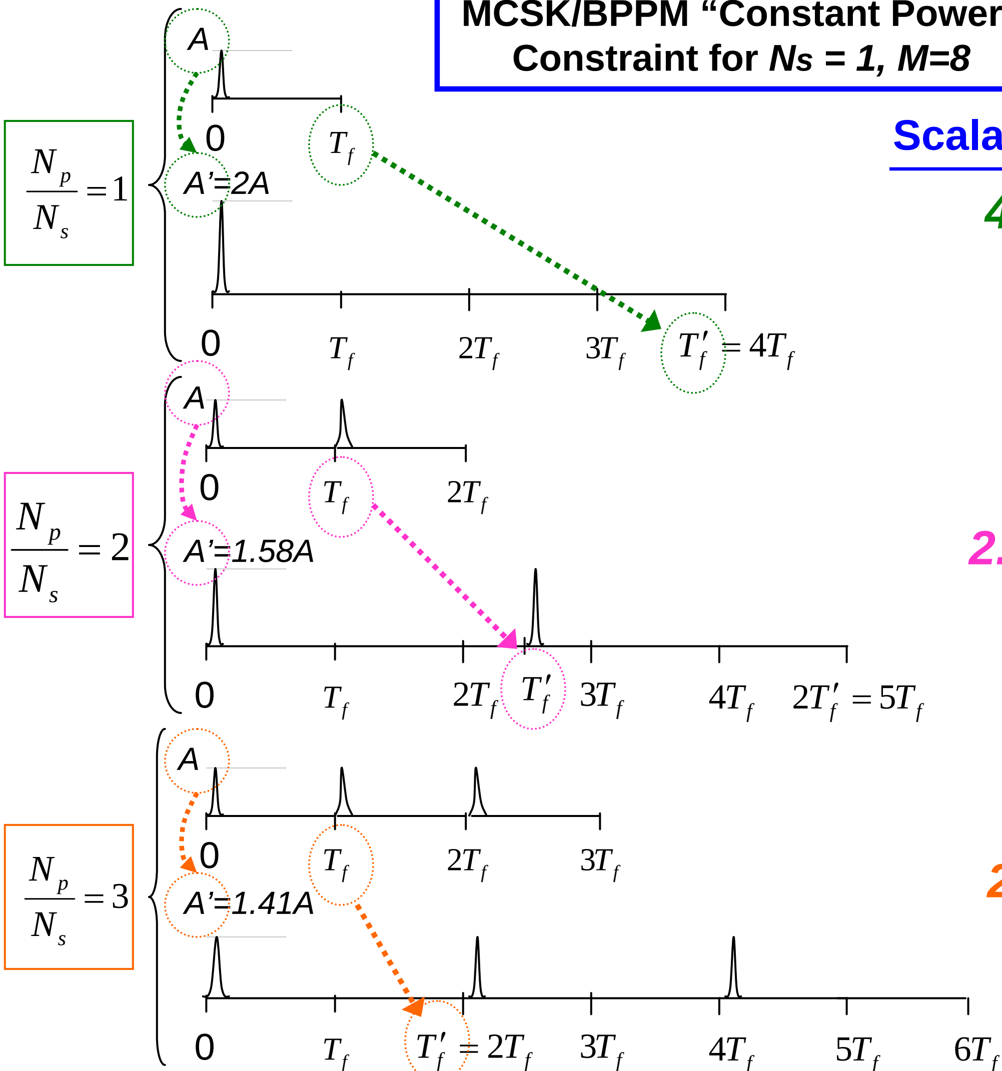
$$T'_f = \left(1 + \frac{\log_2 M}{N_p / N_s}\right) T_f$$

can be adjusted to achieve higher information rate at lower transmit power and still maintain better BER performance at the same time

Information Rate (2/3)

$$R_s = \left(1 + \frac{\log_2 M}{N_p / N_s}\right) \cdot R$$

MCSK/BPPM "Constant Power" Constraint for *Ns = 1, M=8*



Scalable info. rates

4R → R

2.5R → R

2R → R

BER performance
(wrt TH-BPPM)

- increased SNR
- reduced collusions
- no processing gain
- not much improvement

- increased SNR
- reduced collusions
- processing gain
- improved BER
- TX power can be lowered
- info rate can be increased

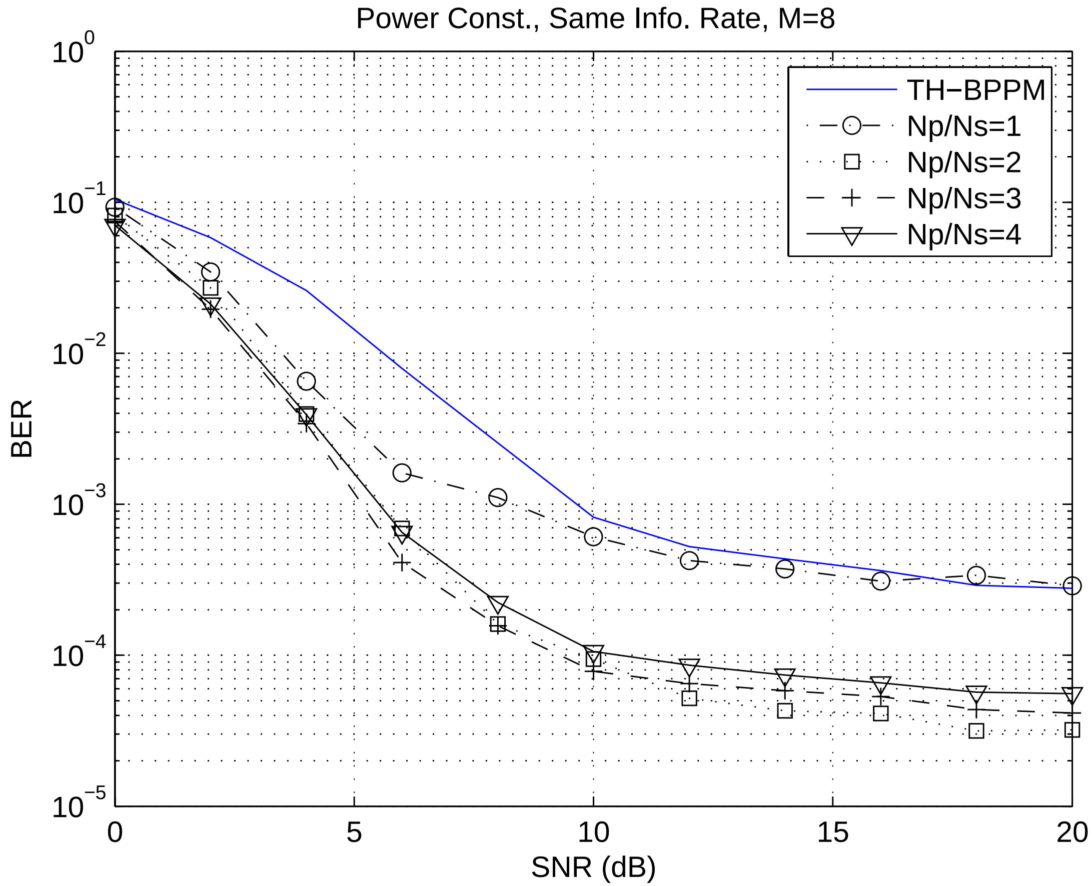
$$A' = \sqrt{1 + \frac{\log_2 M}{N_p / N_s}} A$$

$$T'_f = \left(1 + \frac{\log_2 M}{N_p / N_s}\right) T_f$$

Information Rate (3/3)

“Constant Power” Constraint

→ *Improved performance at the same information rate for M=8*



Location Accuracy

MCSK/BPPM
“Constant Power” Constraint

	Procedure	Result	Comment
Step 0	Initial conditions for TH-BPPM	R_0 (information rate); BER_0 (performance) TX_0 (power)	
Step 1	Increase *M*	$R_1 > R_0$; $BER_1 > BER_0$; $TX_1 = TX_0$	
Step 2	Increase *Np/Ns*	$R_1 > R_2 > R_0$; $BER_1 > BER_2$; $TX_2 = TX_0$	BER_2 may or may not be less than BER_0
Step 3	Increase *T’f*	$R_1 > R_2 > R_3 > R_0$; $BER_2 > BER_3$; $TX_0 > TX_3$	BER_3 may or may not be less than BER_0
Step 4	Increase *A’*	$R_4 = R_3 > R_0$; $BER_3 > BER_4$ & $BER_0 > BER_4$; $TX_0 > TX_4 > TX_3$	**Increased frame time with longer observation period, higher information rate, better BER performance and lower transmit power**

→ ***Accurate Ranging/Location***

Conclusion

- MCSK/BPPM provides:
  → increased information rate
  → lower transmit power
  → better BER performance
  → improved spectral characteristics

Simultaneously!

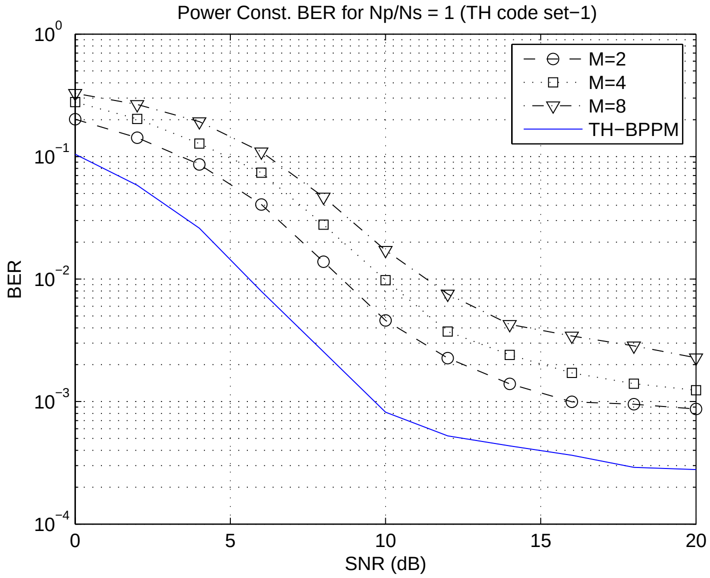
- MCSK/BPPM is capable of:
  → information rate scalability
  → location/ranging accuracy

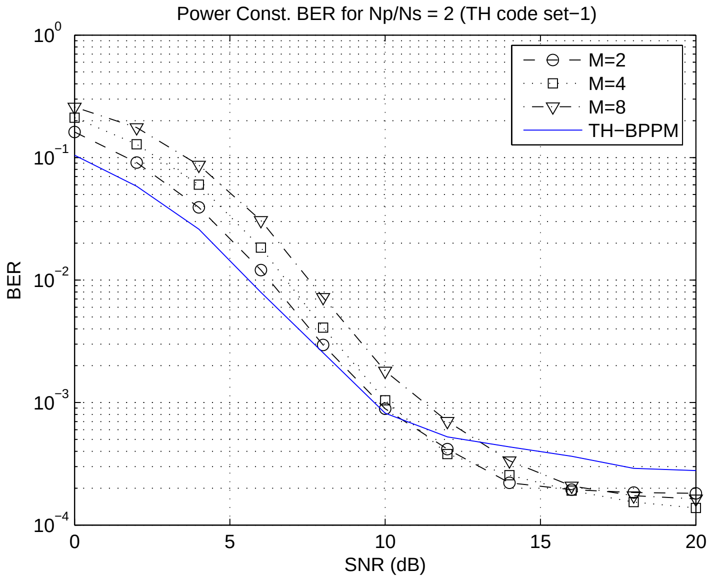
IEEE 802.15.4a PHY

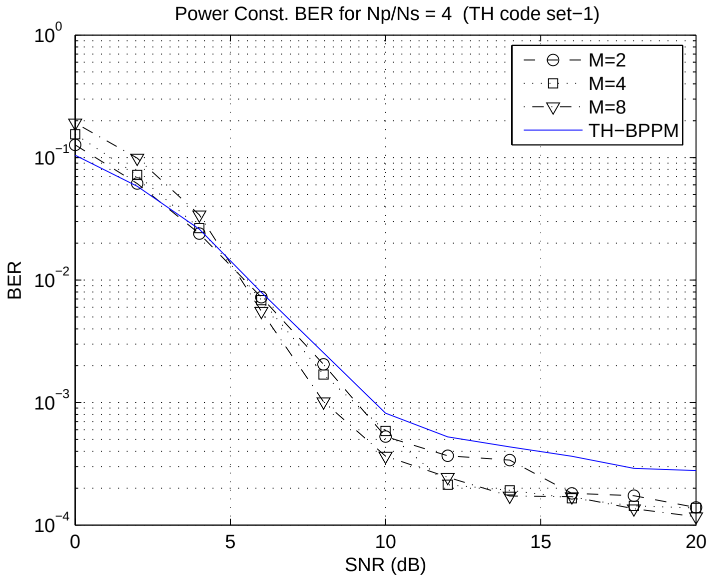
Back-up Slides

MCSK/BPPM

“Constant Power” Constraint

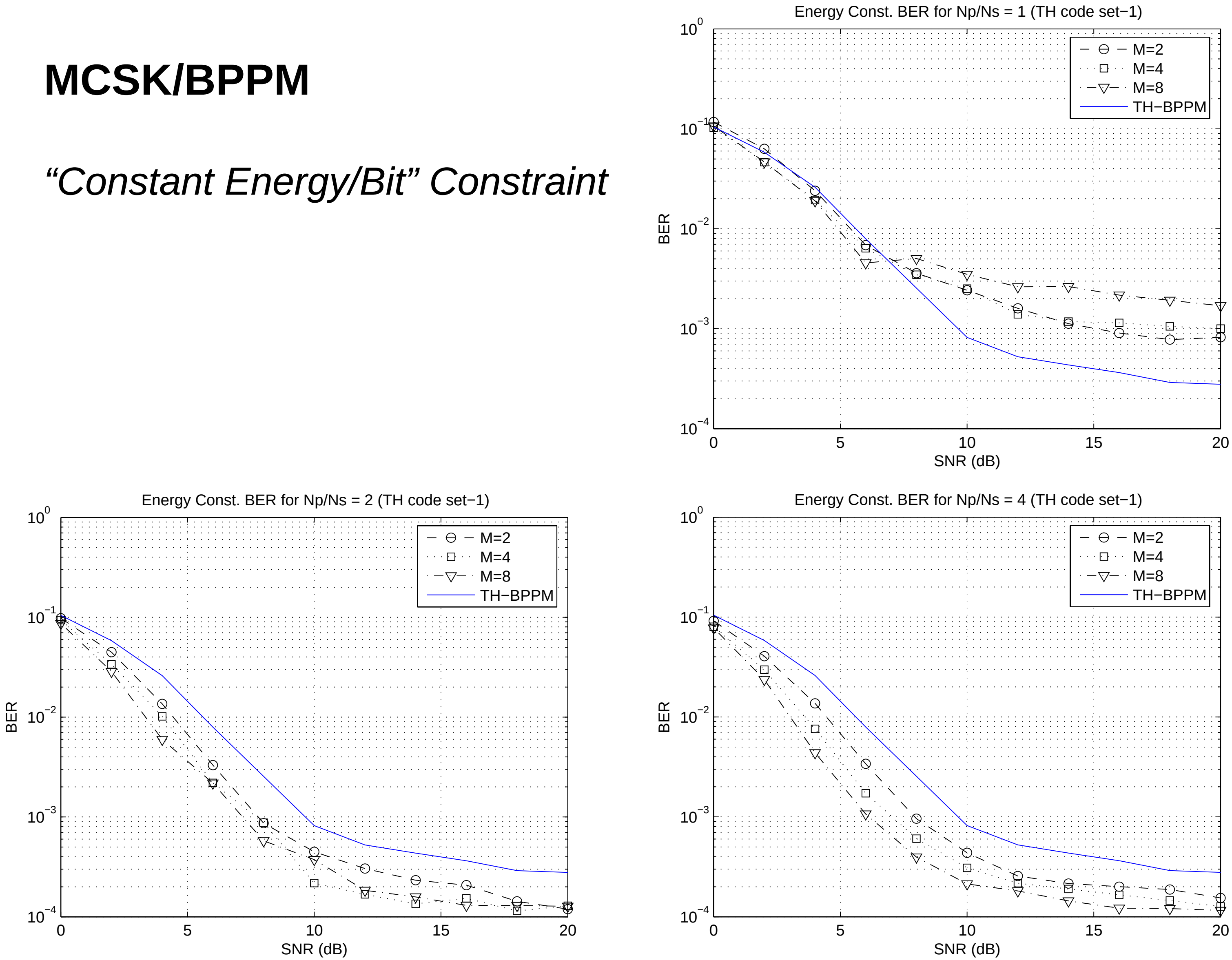






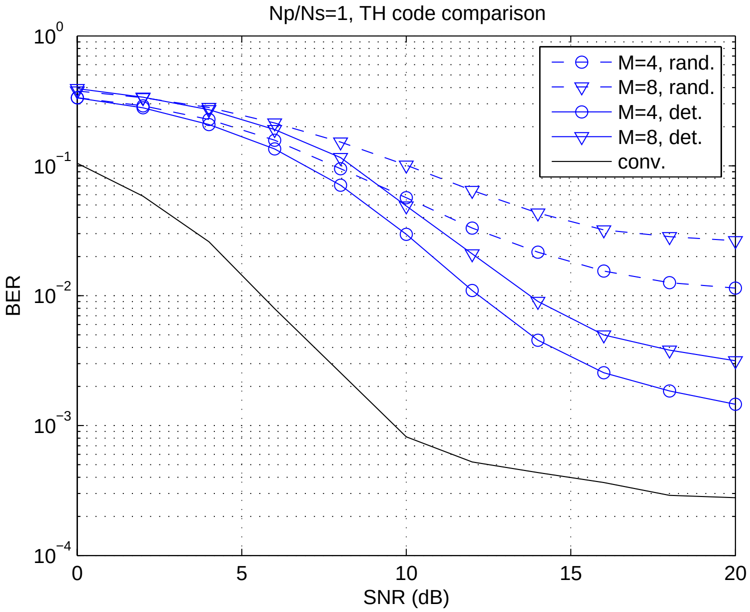
MCSK/BPPM

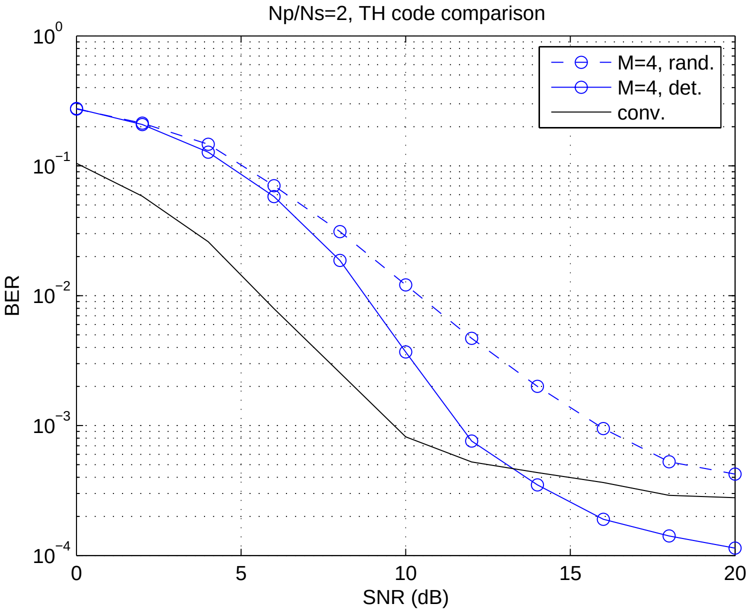
“Constant Energy/Bit” Constraint



Effects of TH Code Design on the Performance

MCSK/BPPM "Constant Power" Constraint





TH Code Spectrum of:

a) TH-BPPM, N_p=10

b) ideal MCSK/BPPM, $N_p \rightarrow \infty$

c) realistic MCSK/BPPM

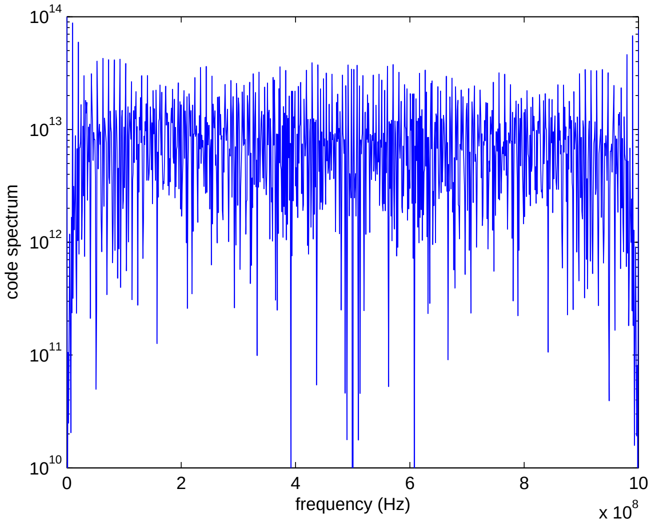


Fig. a. TH-BPPM

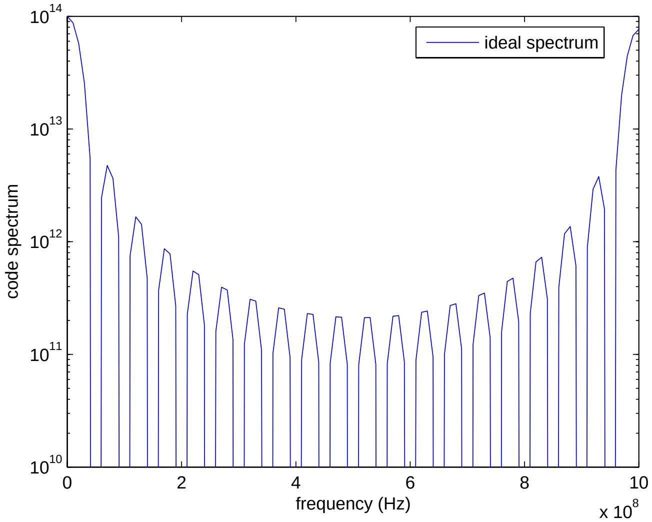


Fig. b. ideal MCSK/BPPM

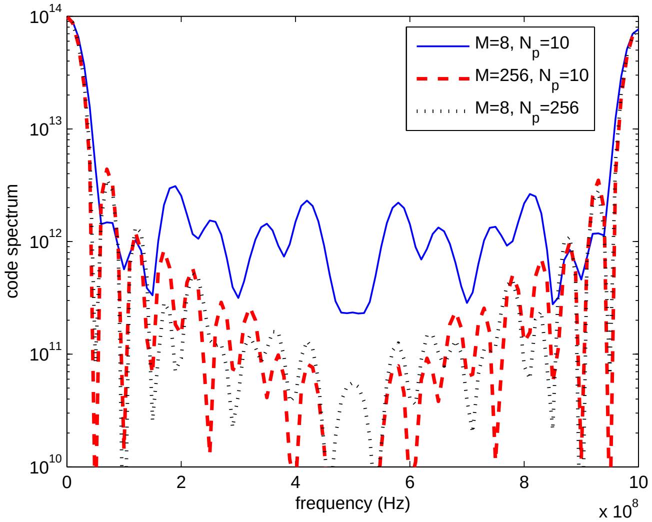


Fig. c. realistic MCSK/BPPM