UWB Spread Spectrum for Multiple Access

Rene Ranftl

Advanced Signal Processing Seminar

June 23, 2009

Outline

Motivation and Introduction
- Standards
- Challenges

Spread Spectrum
- Impulse Radio - Basics
- Time Hopping
- Direct Sequence Spread Spectrum
- Processing gain
- Spreading codes

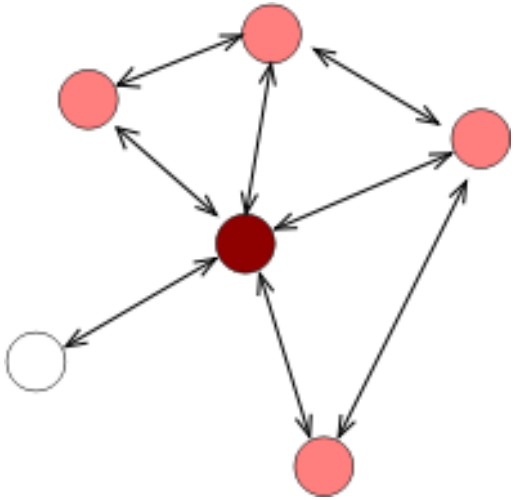
Performance Evaluation

Motivation

UWB devices need to communicate with **multiple** other devices at the same time!

Many UWB applications need multiple access capabilities:

- WPAN
- Wireless USB
- Wireless sensor networks
- ...



Standards

IEEE 802.15.3a

- Direct Sequence - CDMA
- OFDM - Frequency Hopping

IEEE 802.15.4a

- Direct Sequence - CDMA
- Timehopping

Standards

IEEE 802.15.3a

- Direct Sequence - CDMA
- OFDM - Frequency Hopping

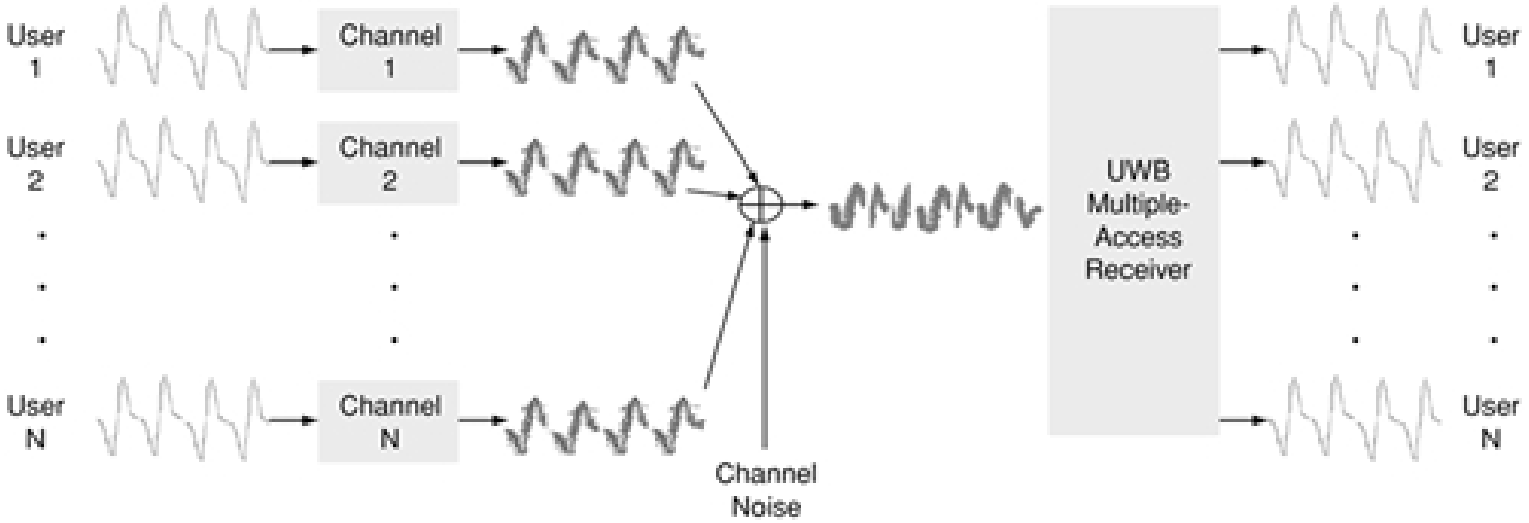
IEEE 802.15.4a

- Direct Sequence - CDMA
- Timehopping

Challenges

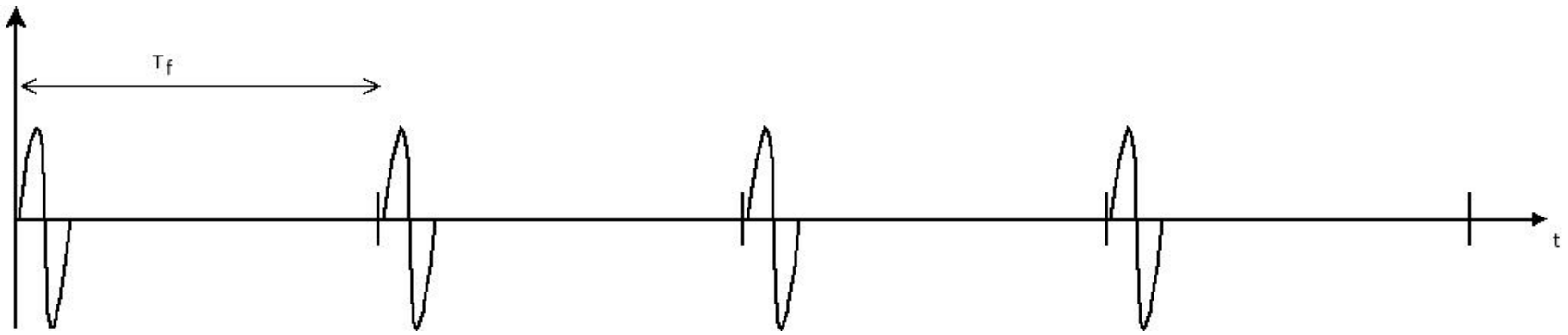
- Narrowband interference
- Multipath interference
- Receiver complexity
- Transmitter complexity
- **Multiuser interference**

Communication model



Impulse Radio - Basics

- Very short pulses
- Carrierless transmission
- Low power transmission
  $\longrightarrow$ Represent each symbol by series of pulses
- Long 'IDLE' state after each pulse (frame)
  $\longrightarrow$ Low duty cycle



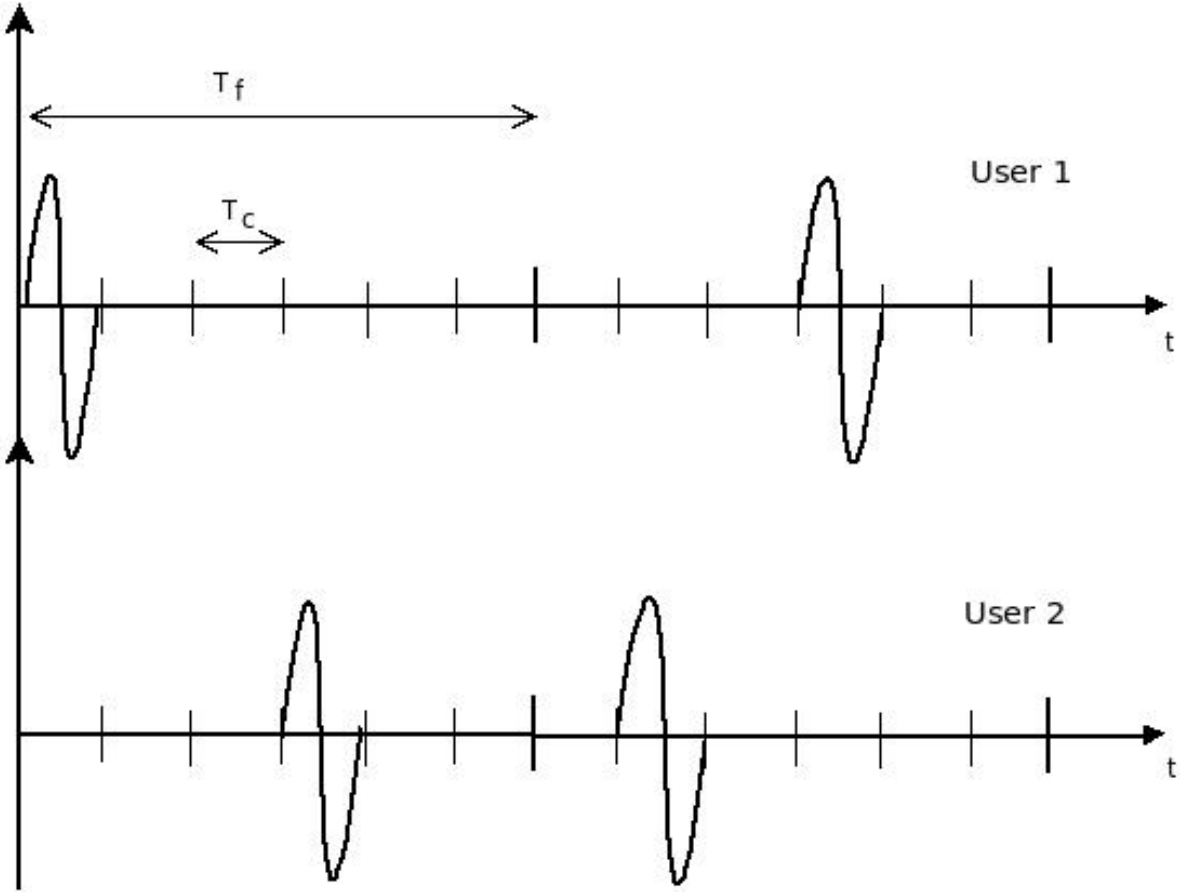
Timehopping

The algorithm

- Subdivide frame
- Assign pseudo-random sequence per user (chip sequence)
- Timeshift each pulse according to chip sequence

- Identify users using chip sequence
- Similar to RCDMA systems

Timehopping - Example



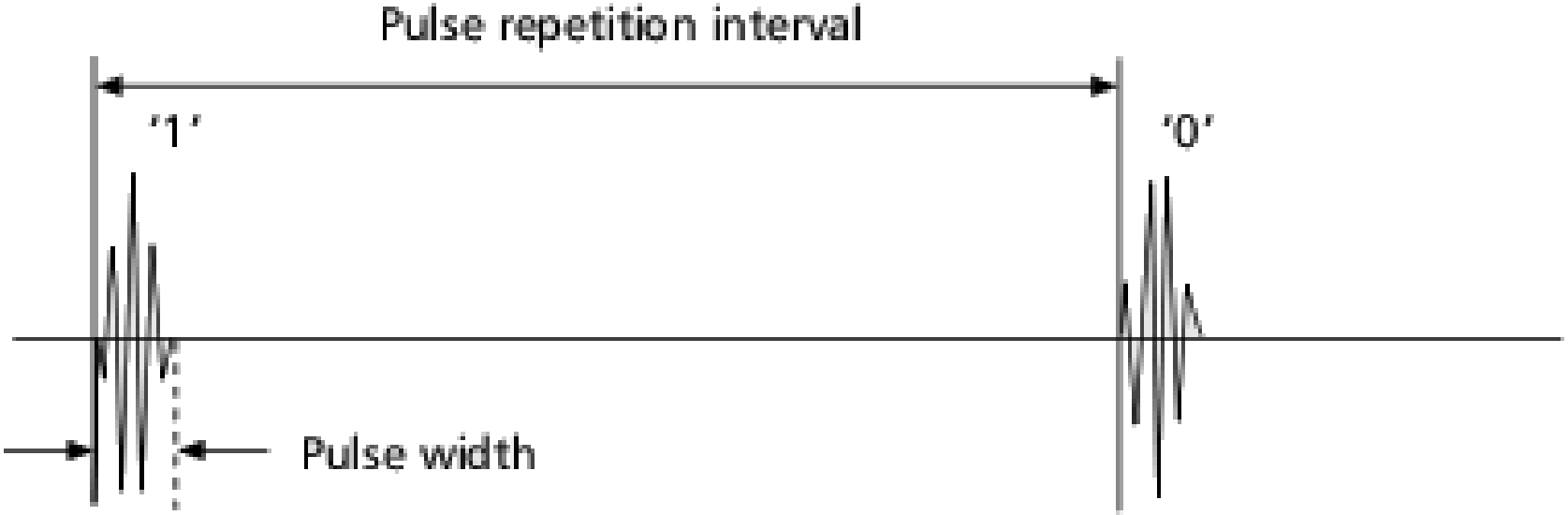
Timehopping - Modulation

Modulating data symbol changes only every N_f frames!

PAM

Carry information using antipodal signaling

$$s_{tr}^k(t) = \sqrt{\frac{E_k}{N_f}} \sum_{j=-\infty}^{\infty} b_{\lfloor j/N_f \rfloor}^k w_{tr}(t - jT_f - c_j^k T_c)$$

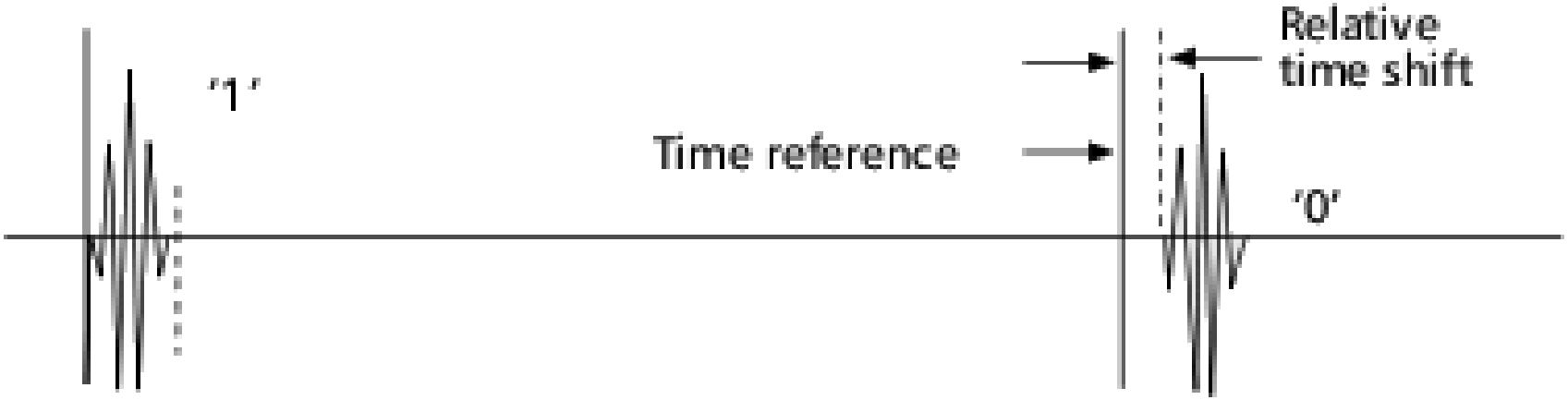


Timehopping - Modulation

PPM

Carry information using additional timeshift τ

$$s_{tr}^k(t) = \sqrt{\frac{E_k}{N_f}} \sum_{j=-\infty}^{\infty} w_{tr}(t - jT_f - c_j^k T_c - \tau b_{\lfloor j/N_f \rfloor}^k)$$



Timehopping - Receiver

Flat fading channel:

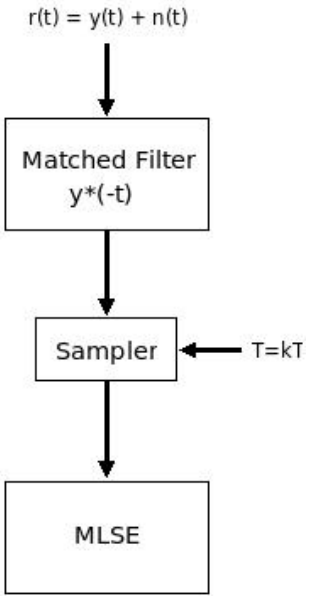
$$r(t) = \sum_{k=1}^{K} \sqrt{\frac{E_k}{N_f}} \sum_{j=-\infty}^{\infty} b^k_{\lfloor j/N_f \rfloor} w_{tx}(t - jT_f - c^k_j T_c) + n(t)$$

Optimum Receiver

Matched filter + MLSE

Suboptimum Receiver

- RAKE design
- Time reversal
- Autocorrelation receiver



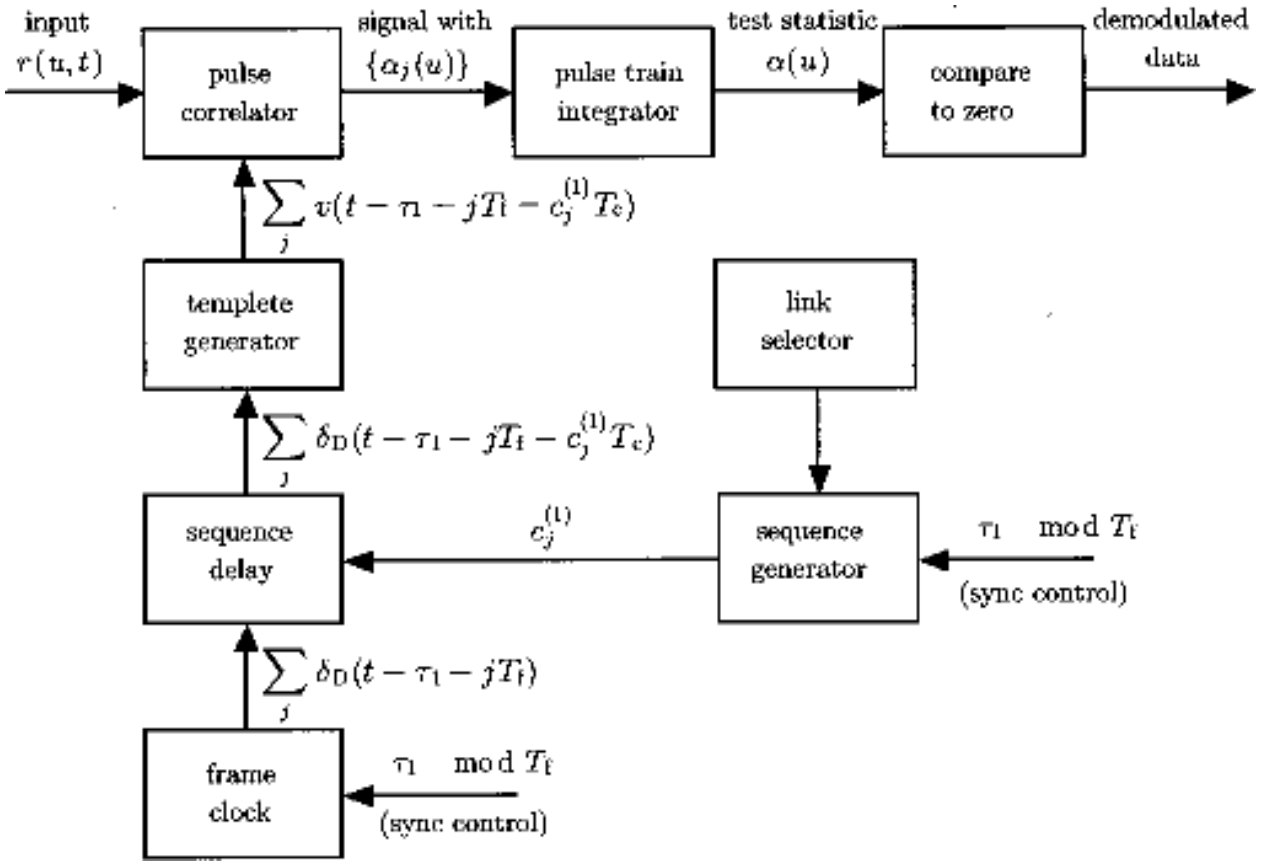
Timehopping - Receiver

Multi User Detectors

- Blinking Receiver
- Correlator
- MMSE Receiver
- ML approach
- Turbo algorithm

Most RCDMA MUDs can be used!

Timehopping - Receiver



Timehopping

Advantages

- CDMA-MUD
- Robust

Disadvantages

- Probability of collisions rises with number of users
- ISI for later pulses in interval

Direct Sequence Spread Spectrum

$$s_{tr}^k(t) = \sqrt{E_b} \sum_{j=-\infty}^{\infty} b_{\lfloor j/N_f \rfloor}^k \sum_{n=0}^{N_c-1} c_n^k w_{tr}(t - jT_f - nT_c)$$

Spreading code used to enable multiple access

Constant channel excitation

DSSS - Receiver

Treat MAI as noise!

Decorrelate using known PN sequence

- Matched filter
- RAKE Receiver
- MMSE

DSSS

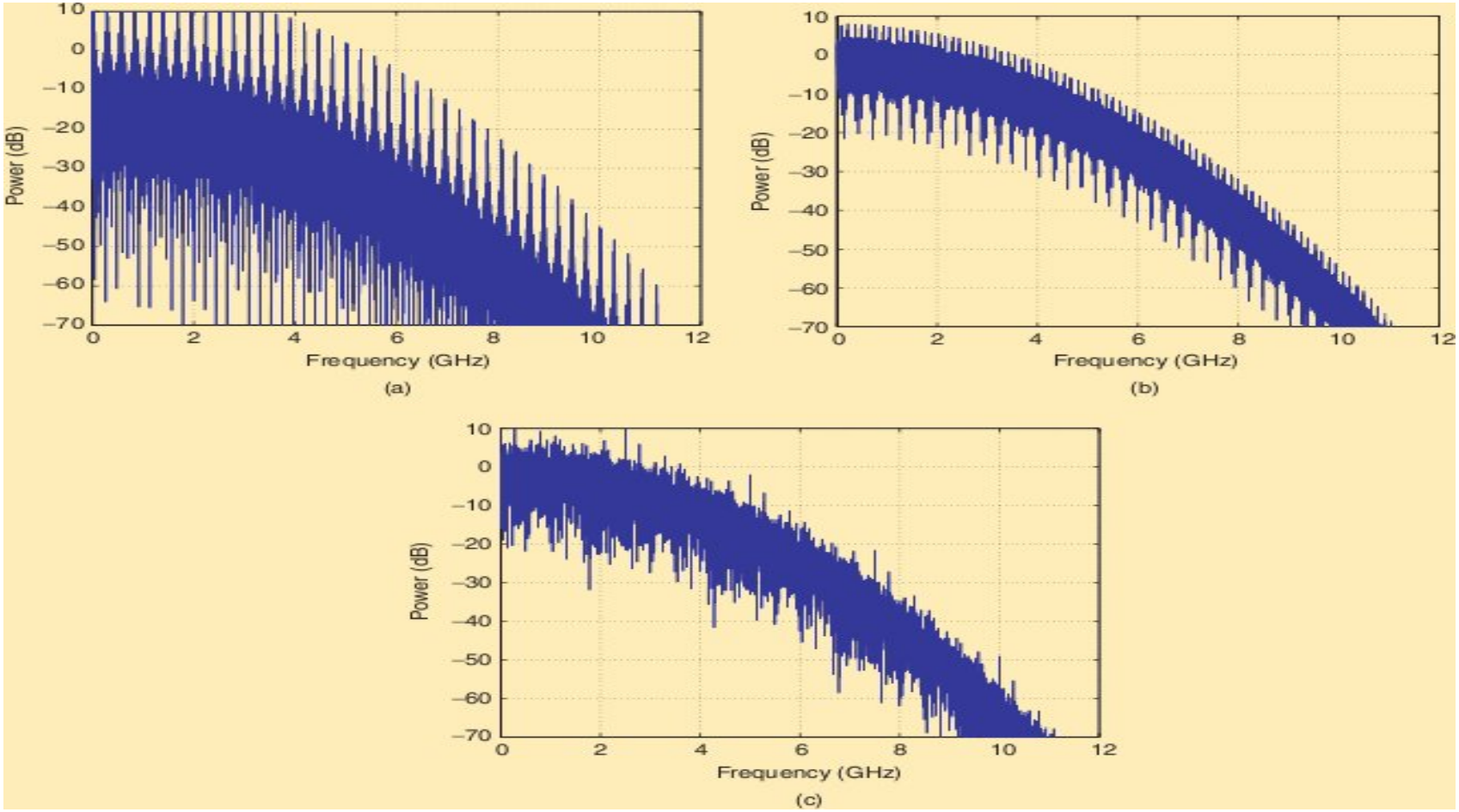
Advantages

- Resistance to interference
- High processing gain possible
- High data rates

Disadvantages

- Continuous sampling needed
- Near-far effect

TH and DS spectrum



Coded systems

$$s_{tr}^k(t) = \sqrt{\frac{E_k}{N_f}} \sum_{j=-\infty}^{\infty} d_j^k b_{\lfloor j/N_f \rfloor}^k w_{tr}(t - jT_f - c_j^k T_c)$$

- Can model both RCDMA and TH systems
- Timehopping is RCDMA with generalized spreading sequence (-1, 0, 1)

TH and DS

Processing gain ($N = N_f N_c$) used to describe characteristics of MA systems

Timehopping:

Use one chip per frame, transmit pulse multiple times ($N_c = 1$)

DS-CDMA:

Transmit one symbol per frame, use all chips ($N_f = 1$)

What if N is fixed and $N_f \neq 1$ and $N_c \neq 1$?

TH and DS

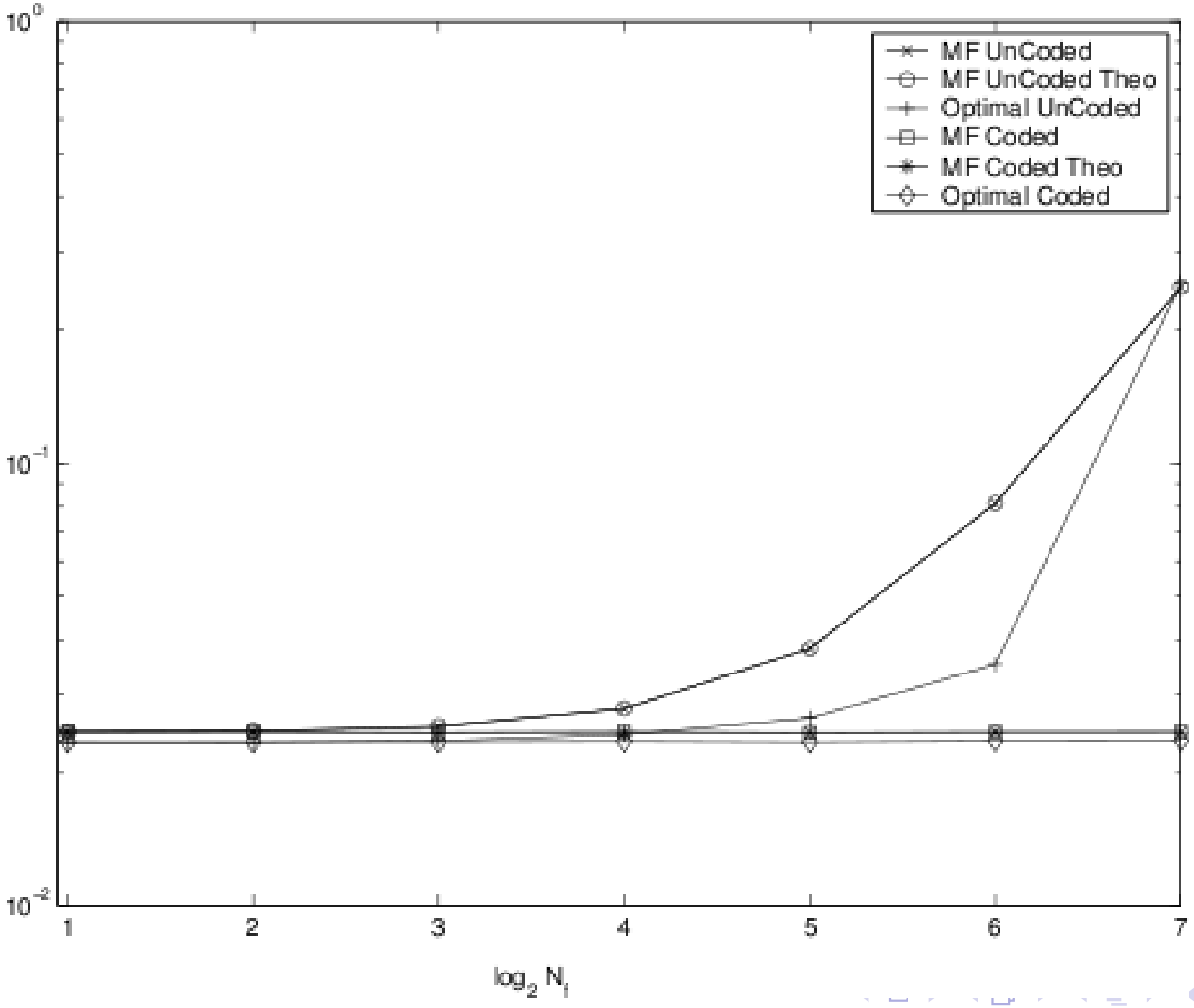
BER

BER does not depend on N_f/N_c in coded systems (for linear MUD)
Low pulse rate preferable in uncoded systems

Timehopping in DS-CDMA systems

- Relaxed sampling requirements
- Larger DR requirement
- Reduced system complexity

TH and DS


MF UnCoded
MF UnCoded Theo
Optimal UnCoded
MF Coded
MF Coded Theo
Optimal Coded
10^0
10^{-1}
10^{-2}
1
2
3
4
5
6
7
$\log_2 N_t$

Spreading sequence

- Maximal Length Sequences
  - Simple to generate
  - Favorable autocorrelation
- Walsh-Hadamard codes
  - Perfectly orthogonal
- Gold codes
  - Extension to Maximal Length Sequences
- Kasami codes

Performance comparison

Analytic performance evaluation of TH-PPM, TH-PAM and DS-PAM

Assumptions

- Spreading code consists of i.i.d random variables
- Perfect power control
- Single user matched filter
- Optimally spaced PPM
- Gaussian monocycles

Performance comparison - Model

Gaussian noise model (MPI, MAI and AWGN)

$$P_e = Q((\frac{1}{SNR} + ((N_u - 1)L^2 + \frac{L-1}{L})R_s C)^{-\frac{1}{2}})$$

N_u ... Number of users

L ... Number of multipaths

R_s ... Symbol rate

SNR ... Single User SNR

Performance comparison - Model

$$P_e = Q((\frac{1}{SNR} + ((N_u - 1)L^2 + \frac{L-1}{L})R_s C)^{-\frac{1}{2}})$$

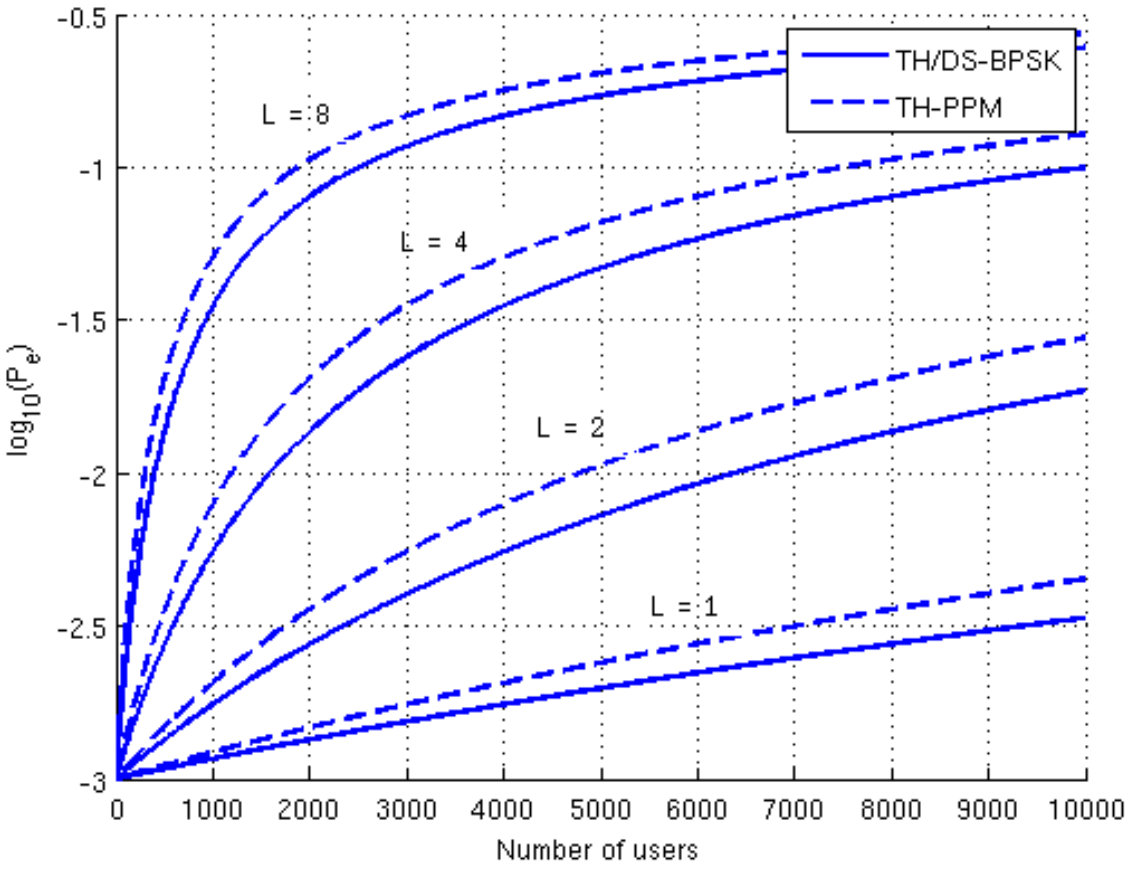
$$\frac{\rho_2^2}{\rho_1^2} = R_s C = \begin{cases} R_s \dfrac{\int_{-\infty}^{\infty} [\int_{-\infty}^{\infty} w(t)w(t-s)dt]^2 ds}{[\int_{-\infty}^{\infty} w(t)^2 dt]^2} & \text{for TH/DS-BPSK} \\ R_s \dfrac{\int_{-\infty}^{\infty} [\int_{-\infty}^{\infty} v(t)w(t-s)dt]^2 ds}{[\int_{-\infty}^{\infty} v(t)w(t)dt]^2} & \text{for TH-PPM} \end{cases}$$

Performance depends on crosscorrelation to autocorrelation ratio

Performance comparison - Results

Bit Error Probability vs. Number of users

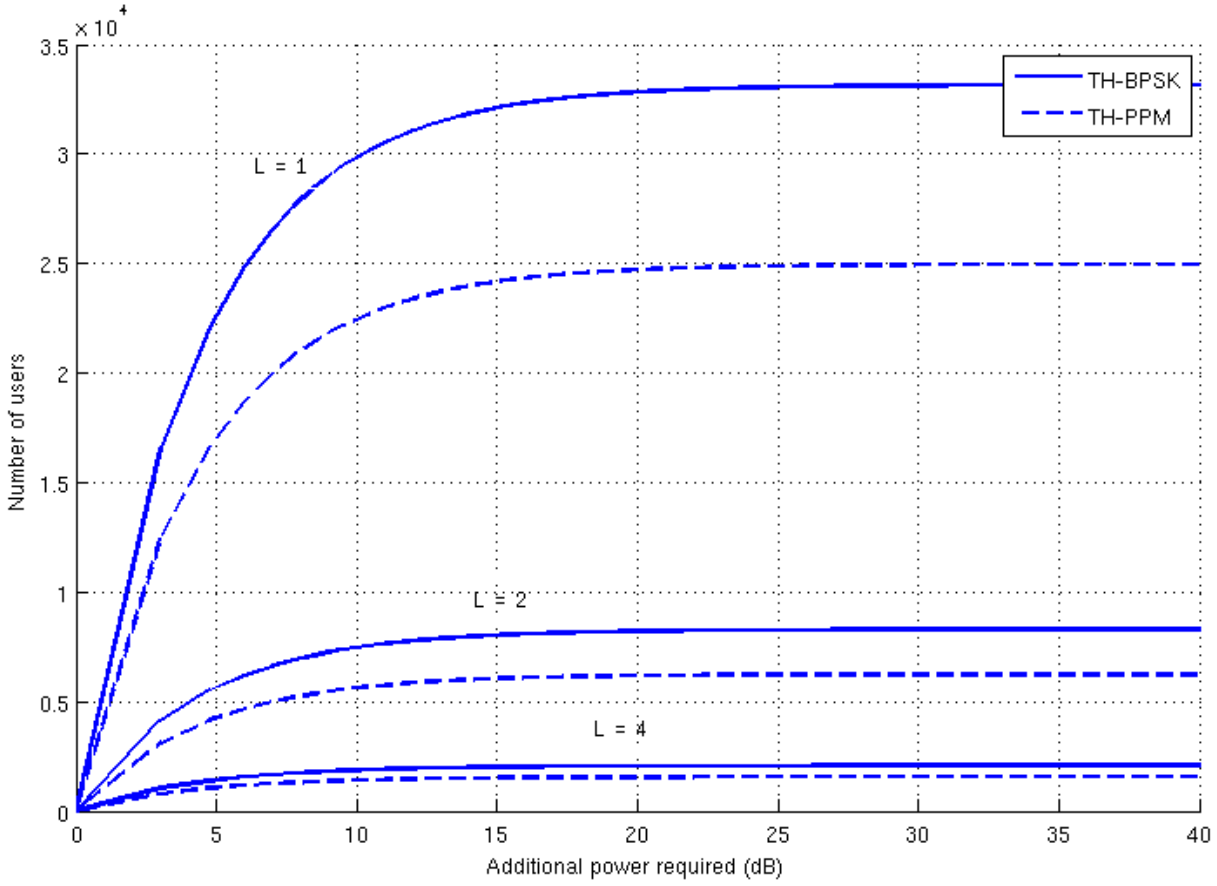
(R_s=19.2kbps, $P_e(1) = 10^{-3}$)



Performance comparison - Results

Additional Power required vs. Number of users

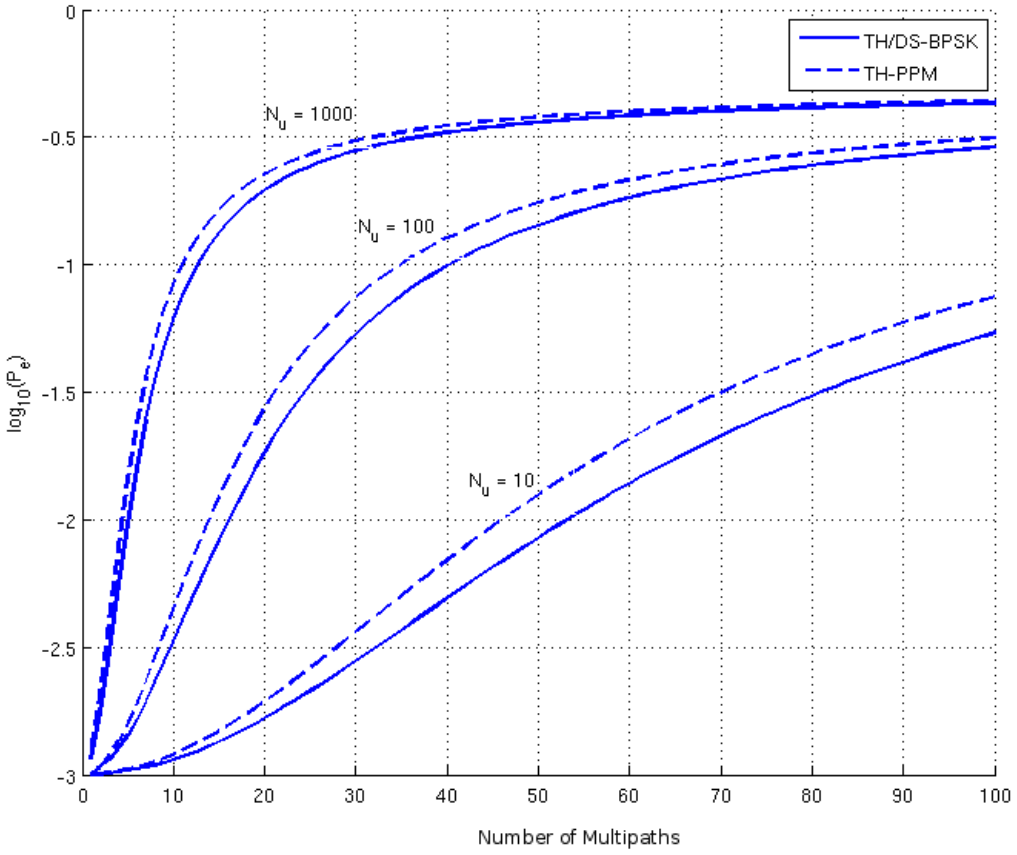
(R_s=19.2kbps, $P_e = 10^{-3}$ = const)



Performance comparison - Results

Bit Error Probability vs. Number of Multipaths

(R_s=19.2kbps, $P_e(1) = 10^{-3}$)



Conclusion

- Performance depends on modulation
- TH/DS-BPSK for high data rates
- DS is able to achieve higher data rates
- TH is more robust (near-far effect)
- Multipath interference degrades performance heavily
- Timehopping and DS-CDMA interchangeable in coded systems

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