Performance Evaluation of Coded UWB-IR on Multipath Fading Channels

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Overview of Presentation

- What is Ultra-wideband (UWB)?
- Regulatory Issues
- Unique Properties of UWB
- UWB vs. Other Technologies
- Potential Applications of UWB
- Research Challenges
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- UWB-IR Receiver Model
- UWB Channel Model
- Performance Evaluation
- Summary

What is Ultra-wideband (UWB) ?

- UWB technology is a generic term describing radio systems having very large bandwidth.

- Two definitions under consideration by the FCC:

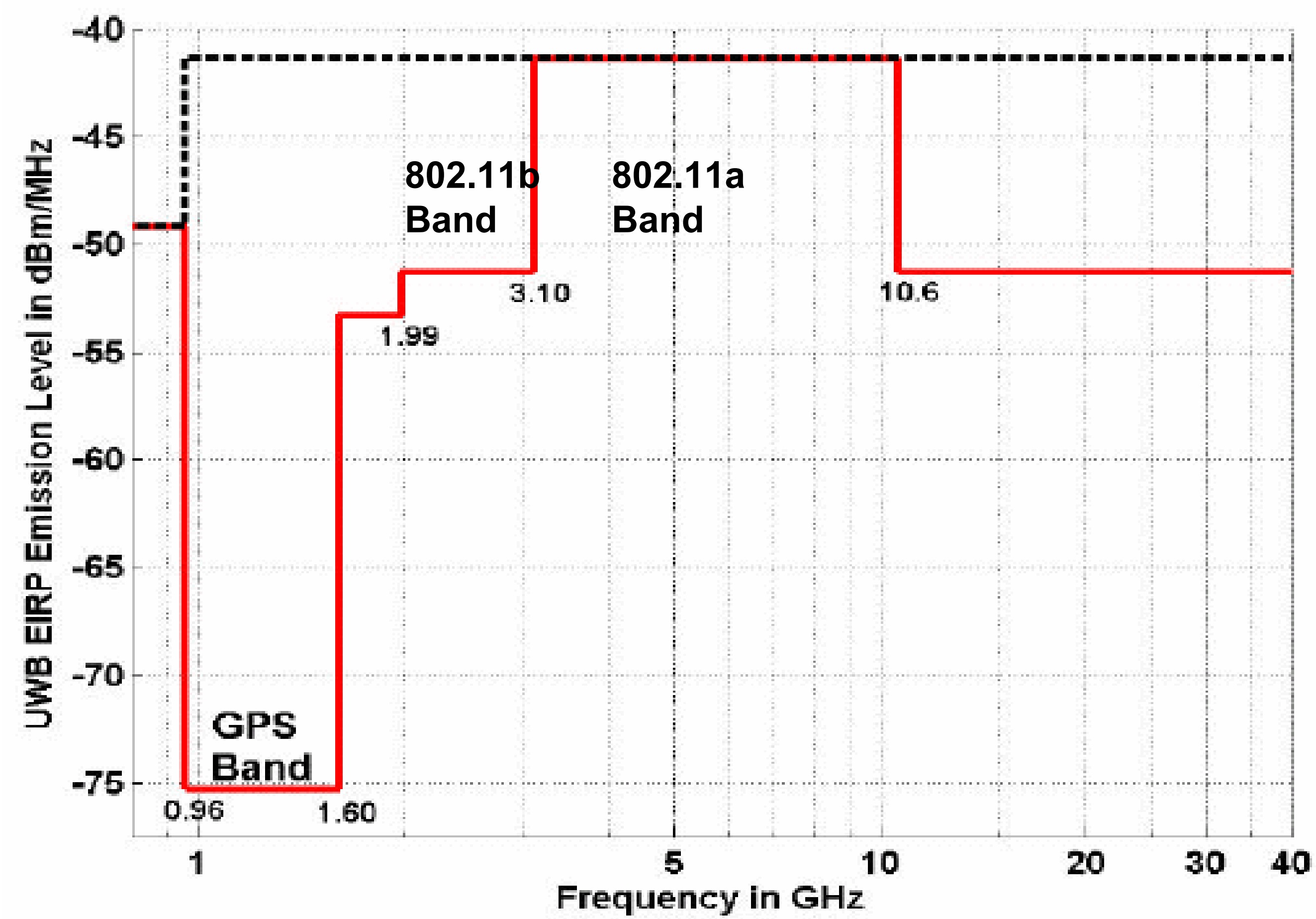
  - fractional bandwidth of a radio signal becomes 20% or more of the signal's center frequency

$$B = 2\left(\frac{f_H - f_L}{f_H + f_L}\right) \geq 0.20$$

f_H is the upper 10 dB and f_L is the lower 10 dB cut-off frequency of the signal spectrum.

  - RF bandwidth of the signal is greater than 0.5 GHz.

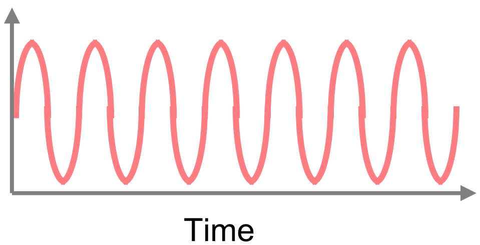
Regulatory Issues

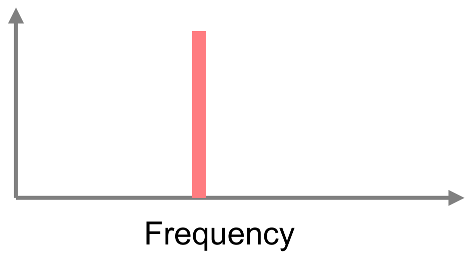


Emission limits for UWB indoor communication systems set by the FCC.

Narrowband vs. Different UWB Approaches

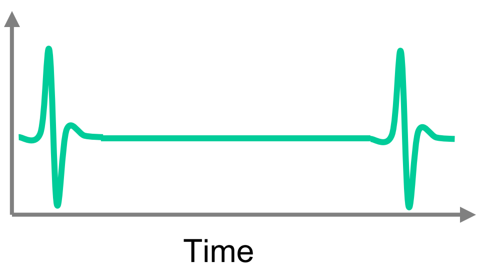
Narrowband Systems

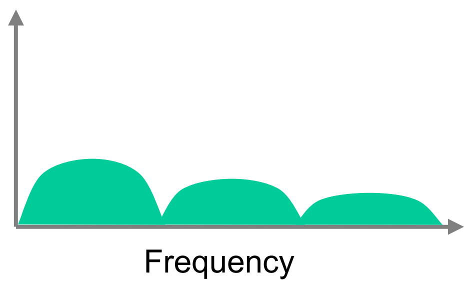




UWB

- UWB –IR



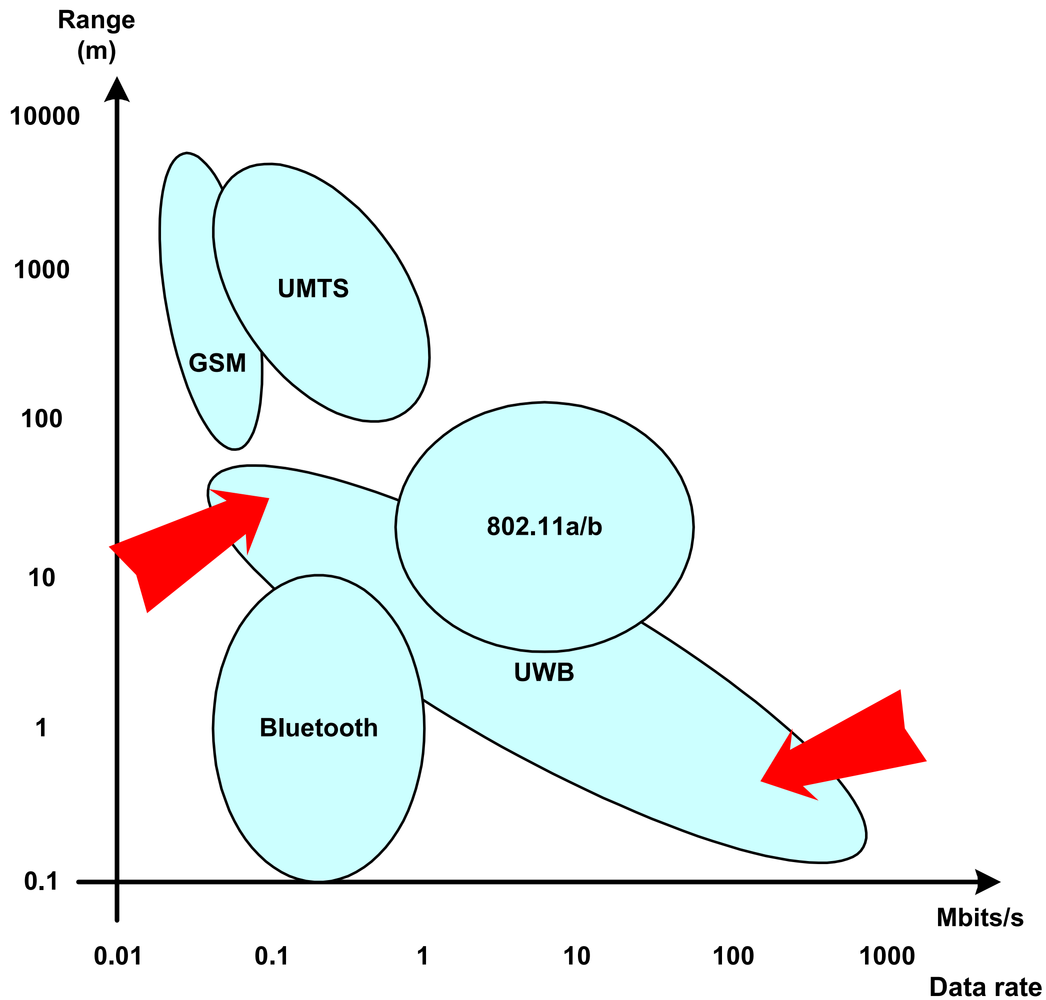


- UWB-FM
- UWB-OFDM

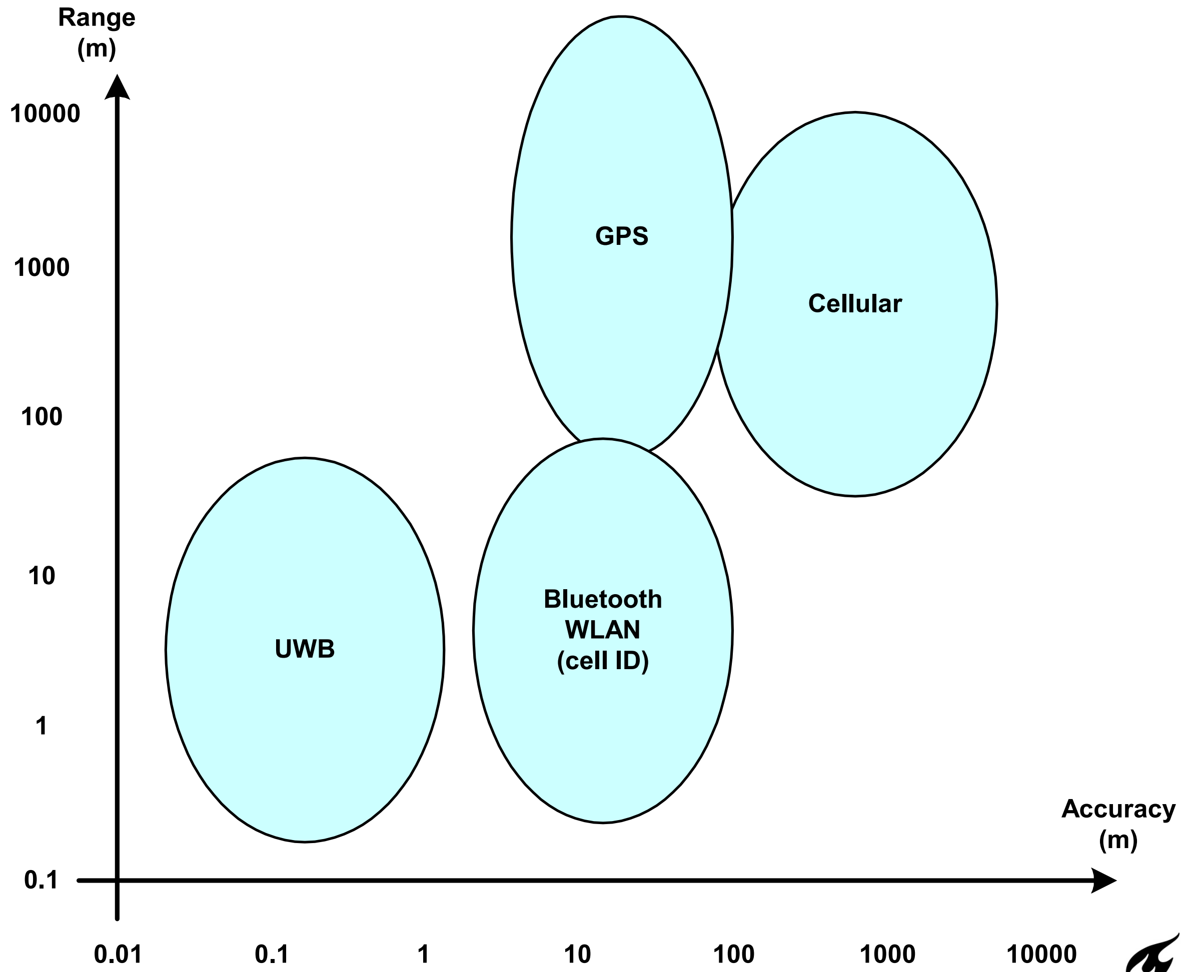
Unique Properties of UWB

- High data rate capability for communications
- Fine range resolution capability
- Multipath immunity
- Extremely difficult to intercept (LPD/I)
- Suitable for ad hoc resource allocation/selection
- Common architecture for communications, radar and positioning (software re-definable)
- Low power consumption
- Low cost

UWB vs. Other Technologies (1)



UWB vs. Other Technologies (2)



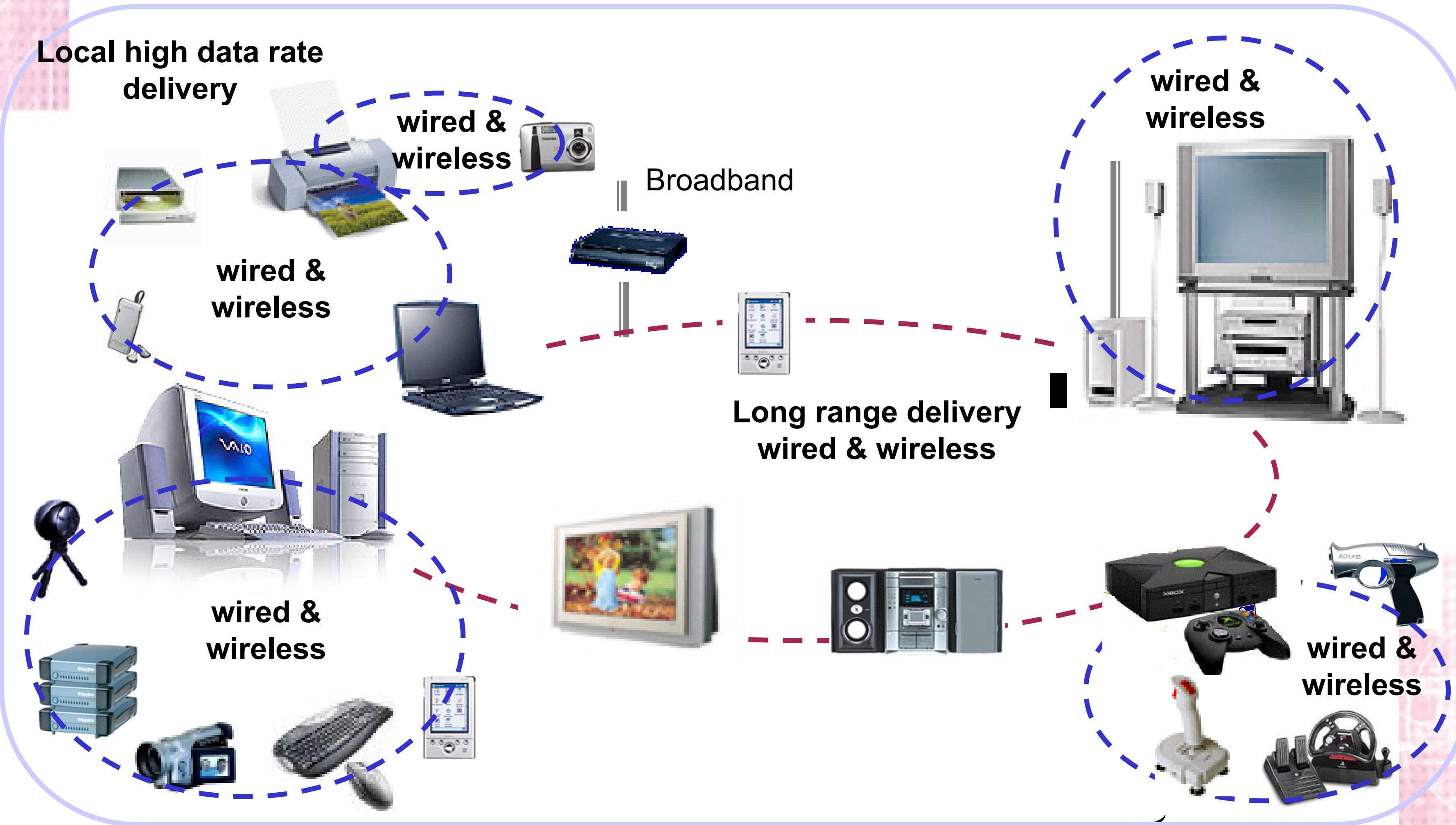
Potential Applications of UWB (1)

- Collision avoidance radars
- Tags (Intelligent Transportation Systems, electronic signs)
- Precision geolocation systems
- Surveillance systems
- Tactical handheld & network LPD/I radios
- Medical imaging
- High Speed WPANs and WLANs

Example use of collision avoidance radar.

Example use of UWB through-wall surveillance radar. Courtesy of Time Domain Inc.

Potential Applications of UWB (2)



Source: Communication and Interconnect Technology Lab., Intel Research and Development

Research Challenges

Interference issues pose restrictions on the maximum data rate that can be supported. One way to overcome the destructive effects of ISI and IFI and simultaneously maintaining a certain performance level is to apply error correction coding.

An error correction coding scheme dedicated for UWB-IR communications should

- be of low complexity
- be scalable
- provide reasonable BER performance
- introduce small delay.

Potential candidates include

- superorthogonal convolutional (SOC) coding
- turbo superorthogonal convolutional (TSOC) coding
- TCH (Tomlinson, Cercas, and Hughes) coding.

There are methods for further BER performance improvements like e.g.

- proposed interleaved coding-modulation (ICM) technique
- polarity randomization (PR).

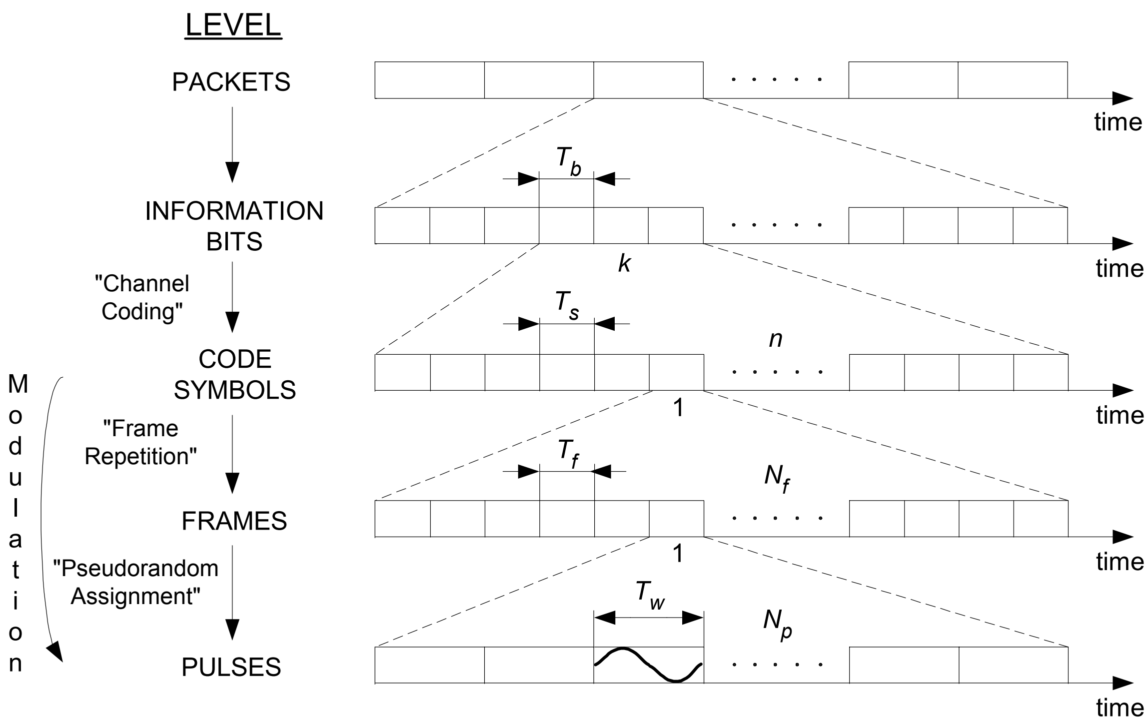
Research Problem

What is the performance of a feasible UWB-IR system with error correction coding in a severe multipath environment ?

The UWB-IR system model incorporates:

- differential autocorrelation receiver
- realistic channel model proposed by the IEEE (802.15.3a)
- real antennas' characteristics
- distortions introduced by amplifiers, and filters modeled by a Chebyshev filter
- frame repetition or superorthogonal convolutional coding as methods of protection against transmission errors.

General Coding-Modulation Scheme



UWB-IR Receiver Model

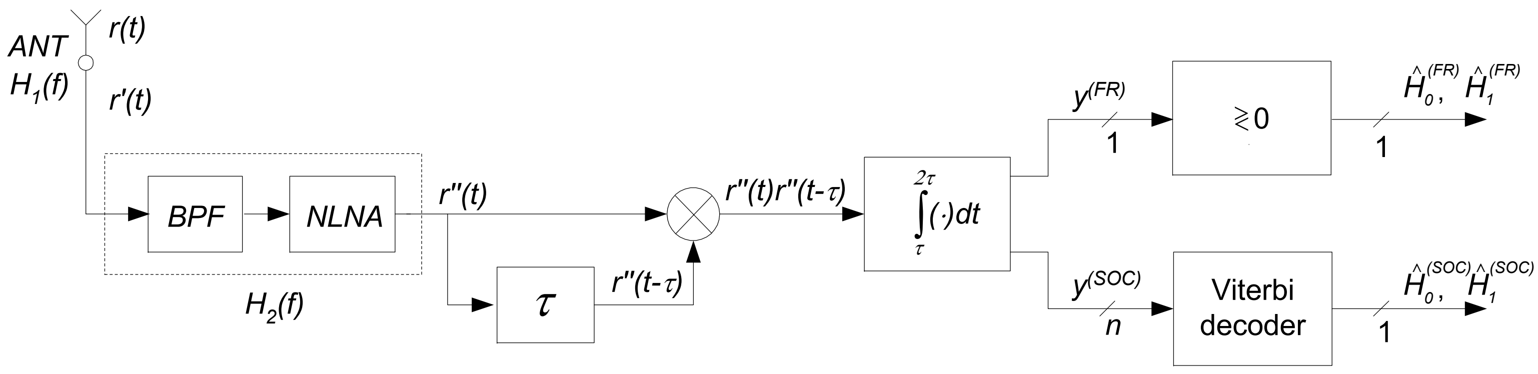


Fig. 1. The modeled UWB-IR receiver architecture.

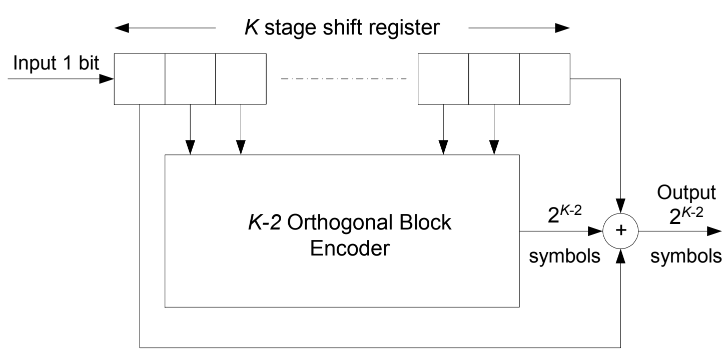


Fig. 2. Superorthogonal convolutional encoder.

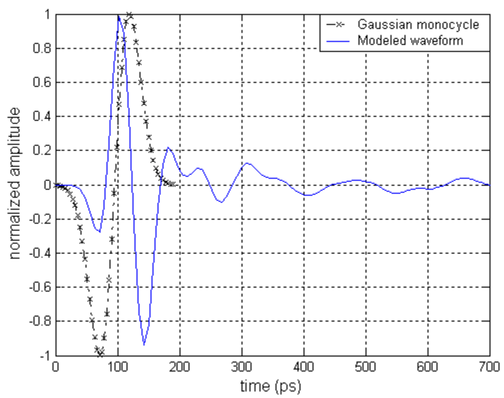


Fig. 3. The Gaussian monocycle and the received waveform.

UWB Channel Model

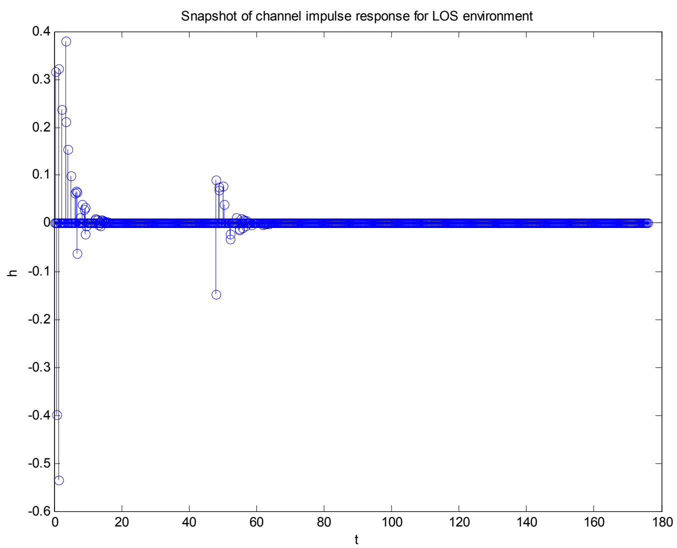


Fig. 4. Channel impulse response for the case of LOS environment.

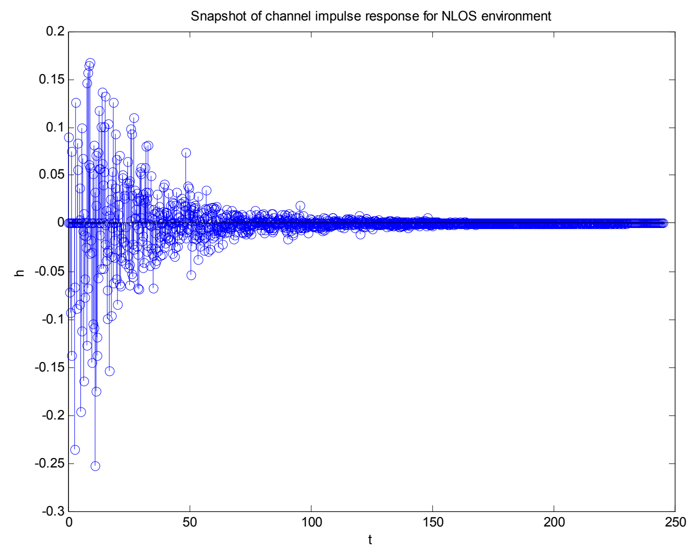


Fig. 5. Channel impulse response for the case of NLOS environment.

Main parameters (LOS and NLOS):

a) RMS delay spread: 9 and 15 ns

b) *Np_10dB*: 7 and 35.

UWB-IR System Parameters

Bandwidth		$B = 6$ GHz
Modulation		Differential Autocorrelation
Pulse Width		$T_w \simeq 0.167$ns
Bit Rate		$R_b = 125$ Mbps
Processing Gain		$G_p = 48$
SOC Channel Coding	Coding Scheme	SOC
	Constraint Length	$K = 4, 5$
	Code Rate	$R = 1/4, 1/8$
	Decoding Algorithm	Soft-Input Viterbi Algorithm
Frame Repetition	Coding Scheme	None
	Number of Frame Repet.	$N_f = 4, 8$
Number of Pulse Positions		$N_p = 12, 6$
Channel Model		AWGN, LOS, NLOS

Performance Evaluation (1)

The upper bound on the bit error probability of the UWB-IR system with the SOC code is given by

$$P_b < \frac{W^{K+2}}{(1-2W)^2}\left(\frac{1-W}{1-W^{K-2}}\right)^2$$

For a Gaussian channel and a rectangular pulse shape we have

$W = \exp(-\gamma)$, where

$\gamma \cong \frac{G_p \gamma_{in}}{1+(2\gamma_{in})^{-1}}$, and $\gamma_{in} = \frac{E_b}{N_0} G_p^{-1}$. [M. Pausini '04]

Processing gain is defined as

$$G_p = \frac{B}{R_b} = B N_f N_p T_w \frac{n}{k}$$

Free distance of the SOC code is

$$d_f^{(SOC)} = 2^{K-3}(K+2)$$

Free distance of the FR scheme is

$$d_f^{(FR)} = 2^{K-2}$$

The lower bound on the bit error probability of the UWB-IR system with the SOC code is expressed as

$$P_b \geq Q\left(\left(\frac{\mu^2}{\sigma^2} d_f\right)^{1/2}\right)$$

Performance Evaluation (2)

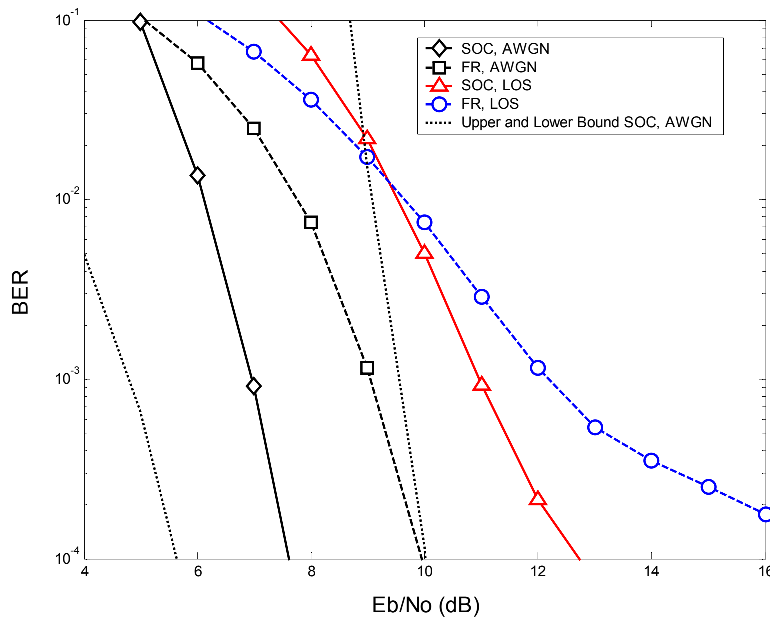


Fig. 6. BER performance of the UWB-IR systems with SOC coding and FR for *Nf* = 8, *Np* = 6, *K* = 5 in AWGN and LOS environments.

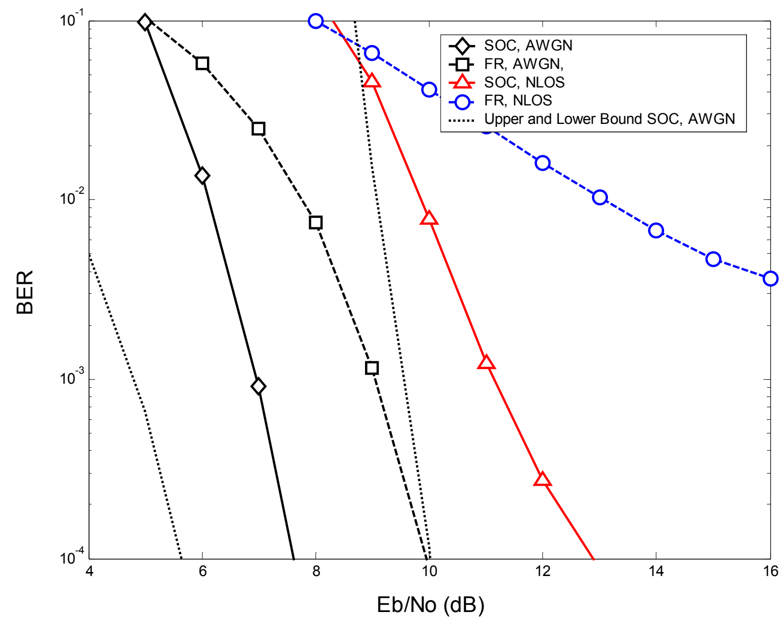


Fig. 7. BER performance of the UWB-IR systems with SOC coding and FR for *Nf* = 8, *Np* = 6, *K* = 5 in AWGN and NLOS environments.

Summary

1. Novel coding-modulation scheme.

   Performance investigated with the use of

   - a realistic channel model
   - real antennas' characteristics.

   The BER performance evaluated by theoretical and numerical analyses.

2. SOC coding constitutes a good alternative to frame repetition without costs in any additional bandwidth expansion.

3. Complexity of a SOC decoder grows linearly with *K* making the SOC decoder feasible.

Thank you