INNOVATIONS IN OFDM AND DSSS FOR VERY HIGH-PERFORMANCE, VERY HIGH BIT RATE WLAN/802.11

Dr. Carl R. Nassar, Dr. Zhiqiang Wu, and David A. Wiegandt

RAWCom Laboratory
Department of ECE
Colorado State University
Fort Collins, CO - 80523-1373

Introduction

- WLAN's Motivation
- Part I.
  - IEEE 802.11b PHY and DSSS
- Part II.
  - IEEE 802.11a PHY and OFDM

WLAN's Motivation…

Then:

- Cost Effectiveness
  - Major portion of cost in LANs is interconnecting end users
- Growth and Reconfiguring Flexibility
  - Recabling cost and planning for additional nodes is minimized
  - Upgrades to the network become easier
- Portability
  - Computer and Printers no longer need designated network connections
- Need
  - Popularity of portable notebook computers

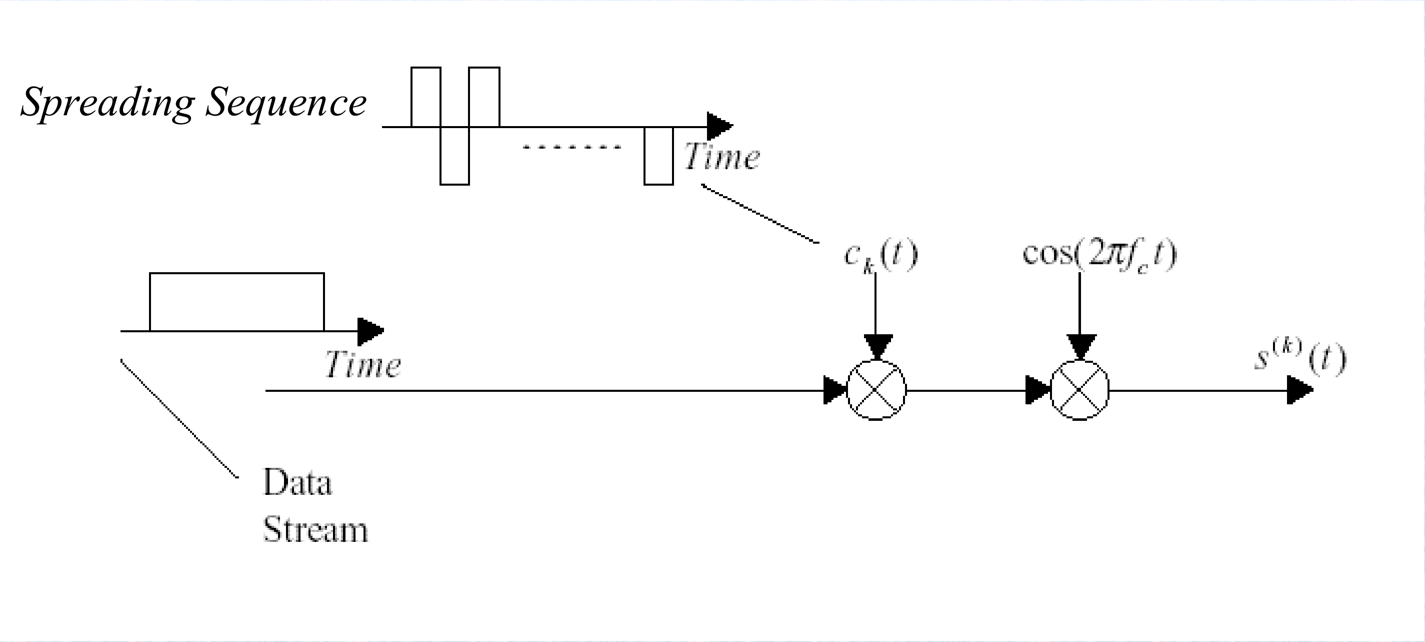
Now:

- Wireless connectivity to the internet
  - Voice over IP
  - Wireless home devices

Part I: Introduction to IEEE 802.11b

- Quick Hits on DSSS
- IEEE 802.11 and its use of DSSS
- Quick Taste of the CI chip shaping benefits
- What is CI-DSSS with respect to 802.11 WLAN
- What does CI-DSSS mean at the receiver
- Simulation
- Performance Benefits and Analysis
- Conclusions

Quick Hits on DSSS



Quick Hits on DSSS (II)

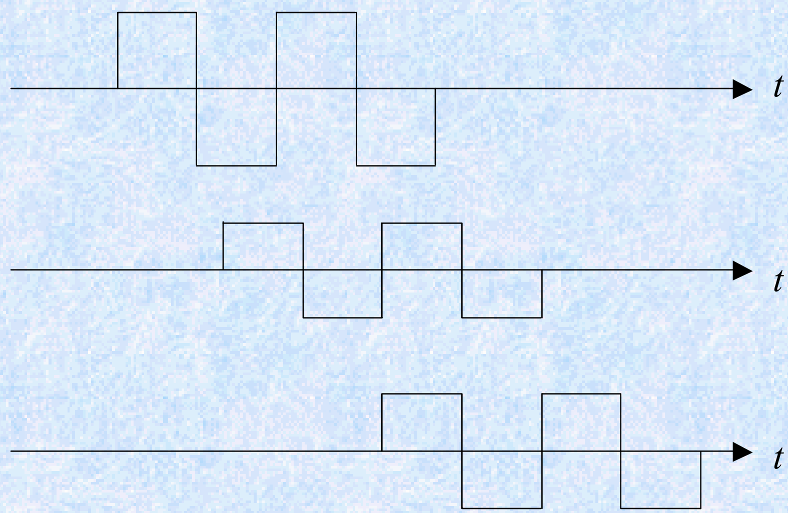
What happens after the transmission through a wireless channel?

Multipath Fading

Path 0:

Path 1:

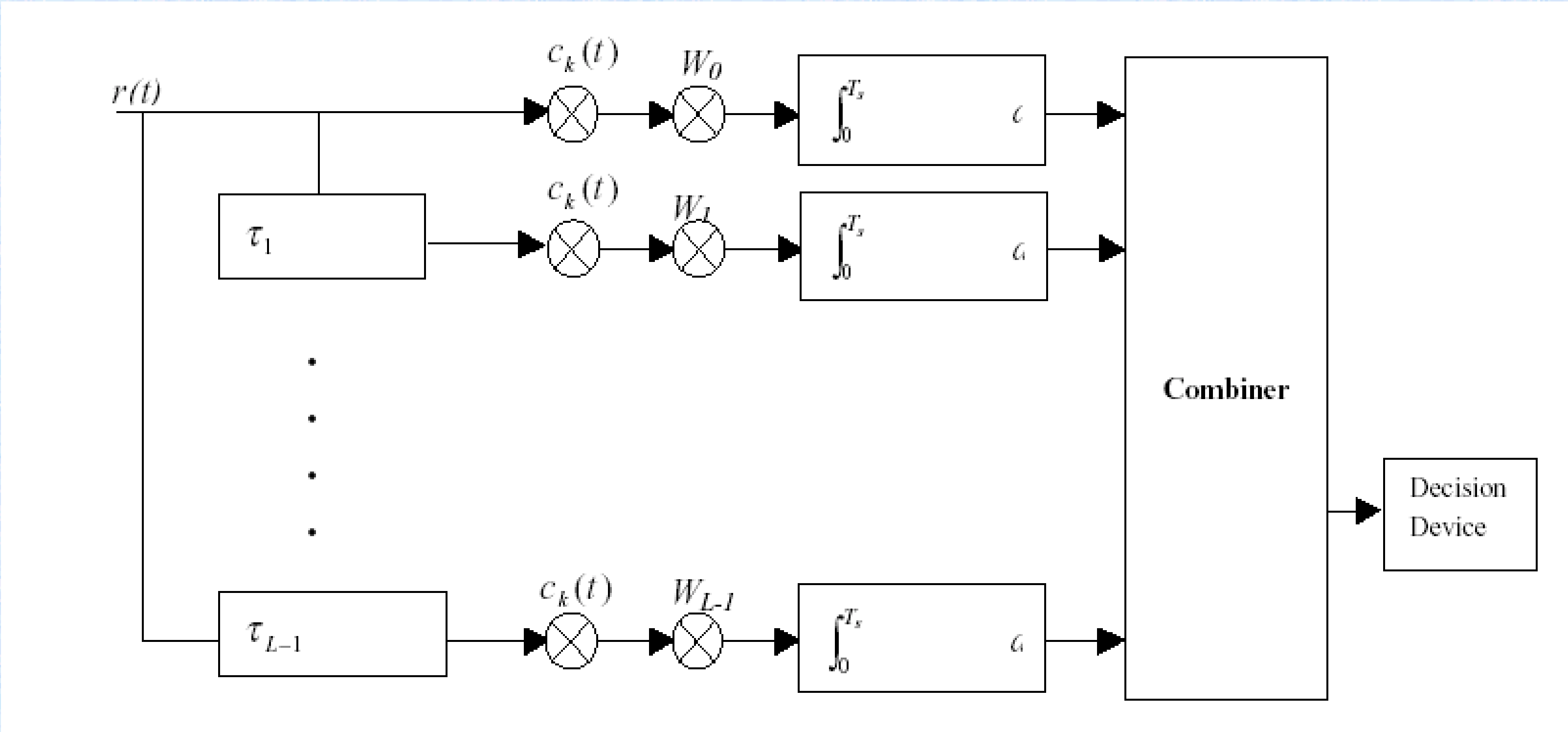
Path 2:



Quick Hits on DSSS (III)

How to deal with Multipath Fading?

RAKE Receiver



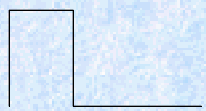
IEEE 802.11b DSSS Wireless LAN

- A system supporting 1, 2, 5.5 and 11 Mbps data rates
  - *1 Mbps Basic Access Rate*: 11-Chip Barker Sequence
  - *2 Mbps Enhanced Access Rate*: 11-Chip Barker Sequence
  - 5.5 *Mbps*: 8-Chip CCK
  - 11 *Mbps*: 8-Chip CCK
- Utilizes 11 Channels within the 2.400-2.4835 GHz ISM band
  - i.e., (Channel 1: 2.412 GHz) to (Channel 11: 2.462 GHz)
  - Supports 3-4 coexisting channels with little interference at 30 MHz separation
- 22 MHz bandwidth (Corresponding to 2 x Chip Rate)

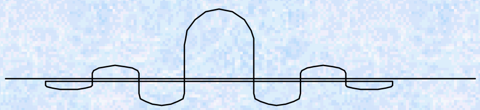
What is the CI-DSSS Modification?

Novel chip shaping filter: exploit frequency diversity

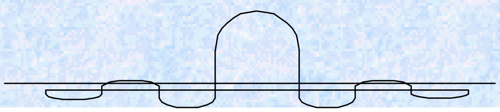
$$x^i(t) = \sum_{n=0}^{N-1} (-1)^{c_n^i} P_{T_c}(t - nT_c)$$



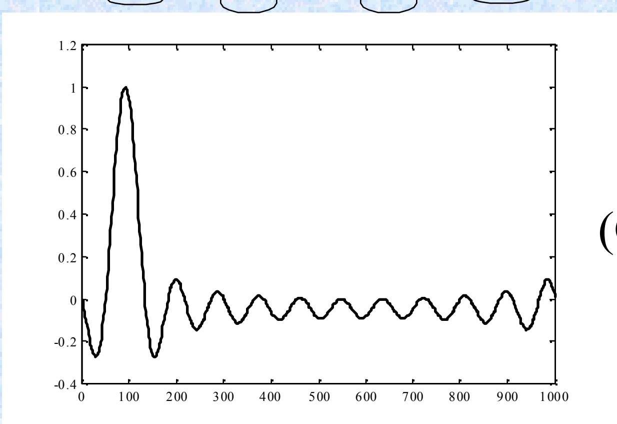
(conceptually)



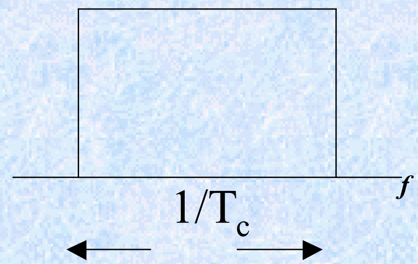
(sinc)

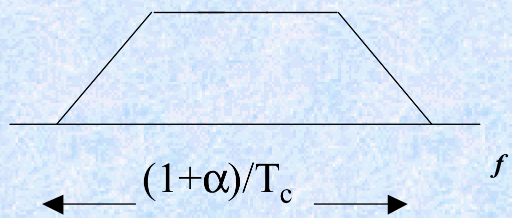


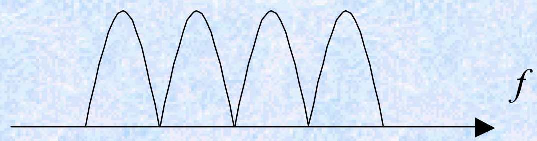
(raised cosine)



(CI)

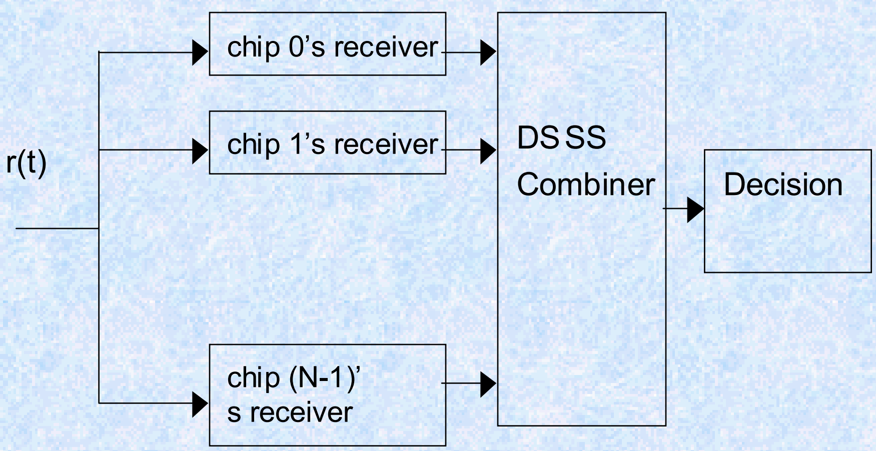




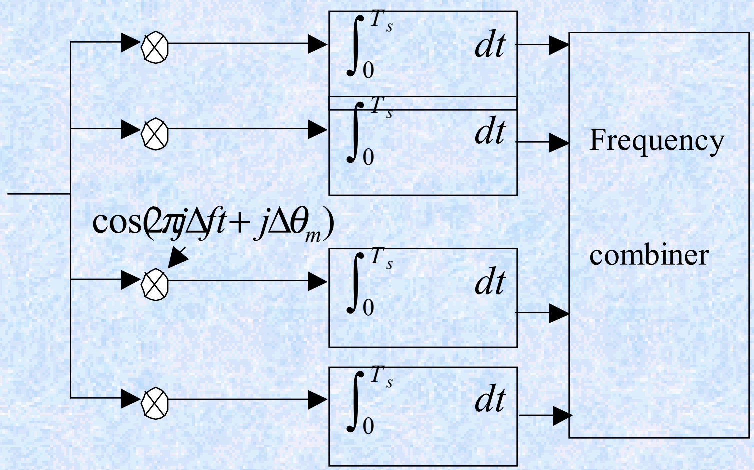


What does this mean at the receiver?

- CI-DSSS Receiver must
  - Receive each chip and remove the phase offsets
  - Recombine the signal while effectively dealing with inter-chip interference
  - Combine the chips and make final decision

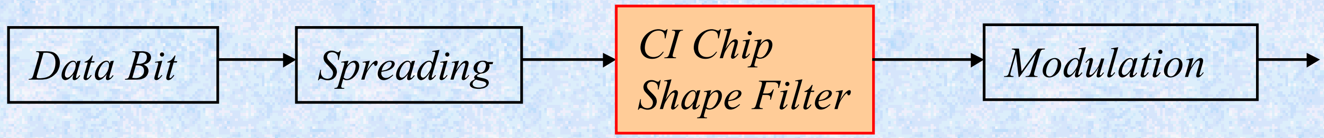


Generalized CI-DSSS Receiver

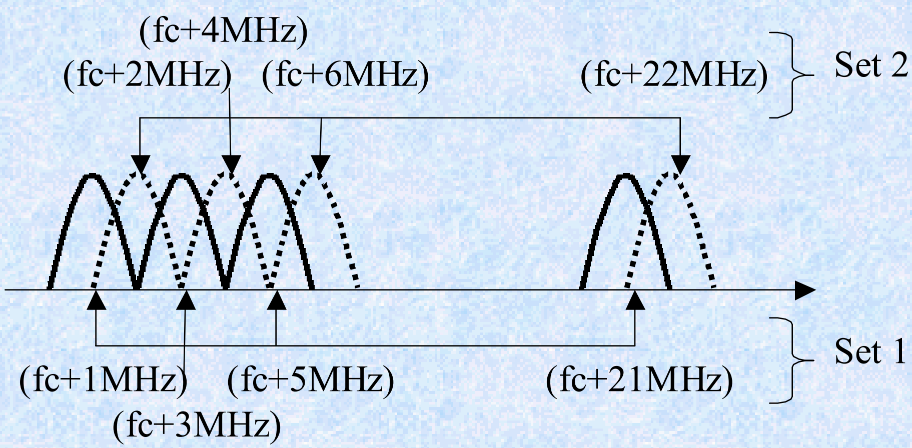


Chip Receiver

But what about in IEEE 802.11?



Transmitter: CI Chip Shaping Filter prior to modulation and 2 sets of orthogonal frequency carriers



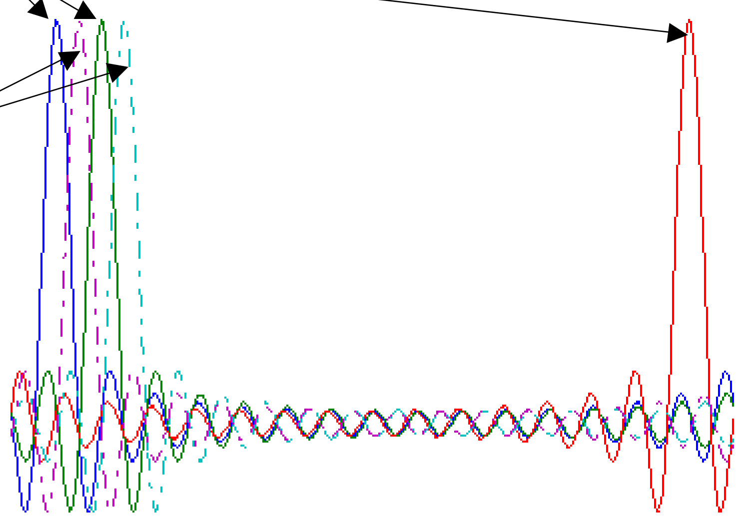
Receiver: Replace equalizer or sophisticated RAKE with CI-DSSS Receiver

Pseudo-Orthogonal CI Chips

Support 2N chips within one symbol duration?

solid line: first set of N chips

dashed line: second set of N chips



Pseudo-Orthogonal Chips

Orthogonal CI Chip Shape Set 1 ⟷ *Orthogonal CI Chip Shape Set 2*

Pseudo-orthogonal

Interference between two sets

Bandwidth Efficient Orthogonal Carriers

Orthogonal Carrier Set 1 ⟷ *Orthogonal Carrier Set 2*

No Interference between two carrier sets

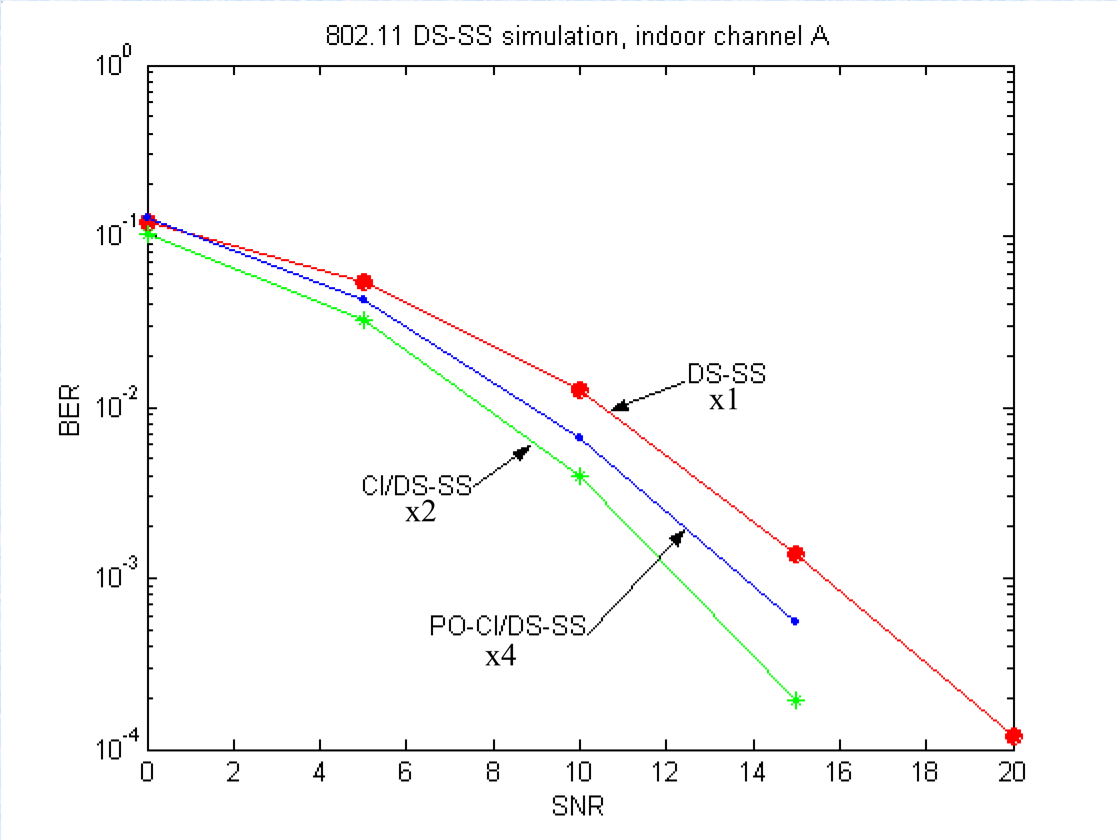
What was the system for simulation?

- **Traditional DSSS**
  - DBPSK
  - Used 6 finger RAKE receiver
- **CI-DSSS**
  - CI chip shaping filter with DBPSK (Therefore allowing use of orthogonal carriers and giving x4 data rate)
  - Frequency Combining scheme: Mimimum Mean Squared Error Combining (MMSEC)

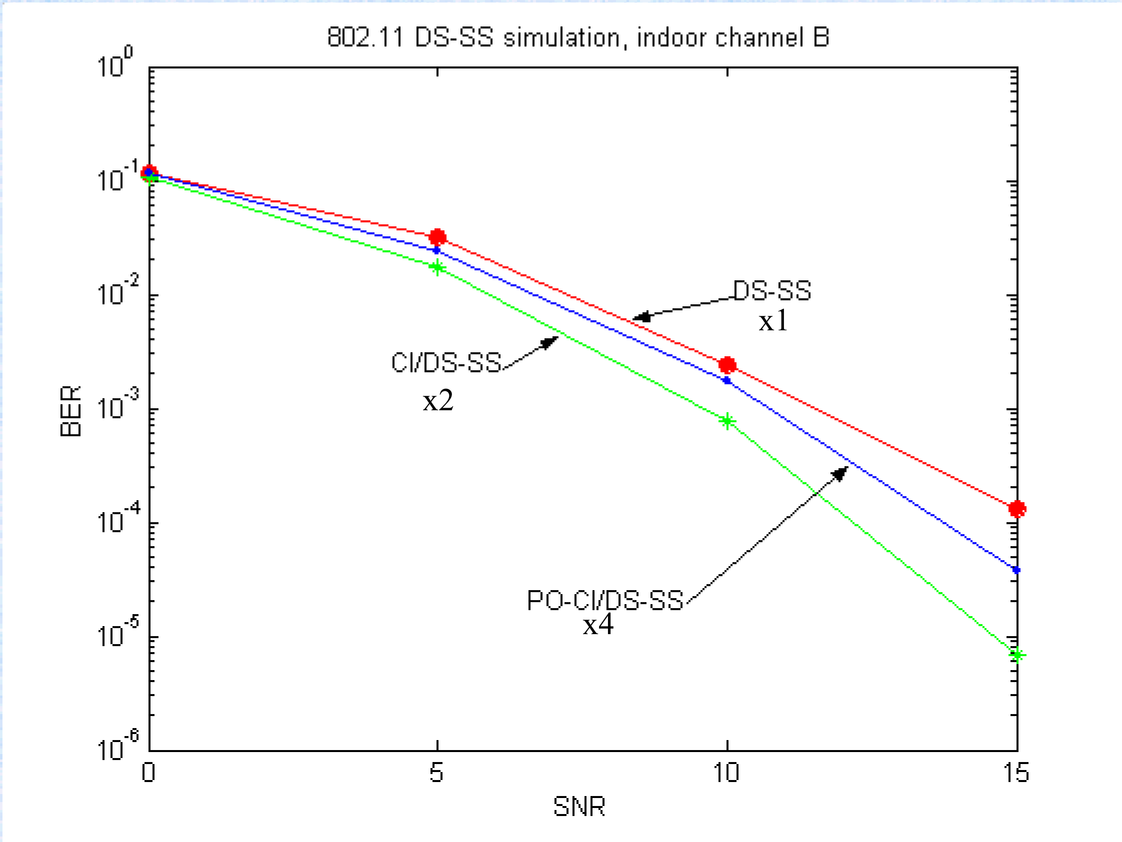
What was the channel model employed?

- UMTS Indoor Channel Models A and B (6 Path Models)
  - Channel Model A with 35ns delay spread
  - Channel Model B with 100ns delay spread
- Demonstrating frequency selectivity over the entire bandwidth (BW)
- Demonstrating flat fading over each of the *N* carriers

Performance



Performance



Analysis

(1) 4x throughput by

a) Double bandwidth efficiency

b) Double chips/symbol via PO positioning

(2) Novel Chip Shaping is introduced to exploit frequency diversity instead of path diversity.

(3) Better performance is achieved by exploiting frequency diversity, even with 4x throughput.

(4) Complicated RAKE receiver structure is avoided.

(5) The novel chip shaping can be implemented via FFT algorithm.

PART II

CI Enhanced IEEE 802.11a

Part II: Introduction to IEEE 802.11a

(Extendible to 802.11g)

- IEEE 802.11a PHY and its use of OFDM
- Quick Hits on OFDM
- Carrier Interferometry's (CI) Introduction
- What is CI/OFDM (and therefore CI/WLAN)
- What does CI mean at the receiver
- Simulation
- Performance Benefits and Analysis
- Conclusions

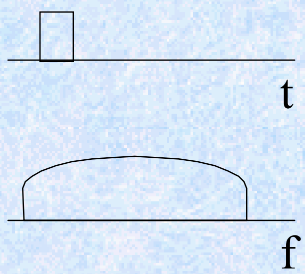
Quick Hits on IEEE 802.11a?

- A high speed system operating in 20 MHz bands in the 5 GHz region
- OFDM system modulation scheme
  - 52 Subcarriers (48 information bearing and 4 pilot for coherent detection)
    - Subcarrier spacing: 312.5 kHz
  - System bandwidth: 16.25 MHz (Occupied BW = 16.6 MHz)
  - Subcarrier modulations: BPSK, QPSK, 16-QAM, and 64-QAM
  - Rate 1/2, constraint length 7 convolutional coding (generator polynomials 133, 171)
    - Rate 2/3 and 3/4 achieved through puncturing the rate 1/2 mother code
- Supports 6, 9, 12, 18, 24, 36, 48 and 54 Mbps data rates
  - i.e., BPSK subcarrier modulation with rate 1/2 CC = 6 Mbps data rate
- Channel coded bits are interleaved to benefit from frequency diversity in the channel

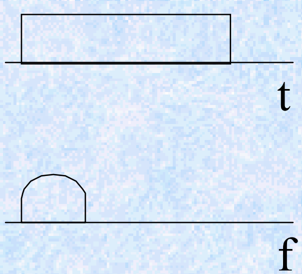
Binary Input → Coder → Interleaver → Mapper → Modulator → Channel

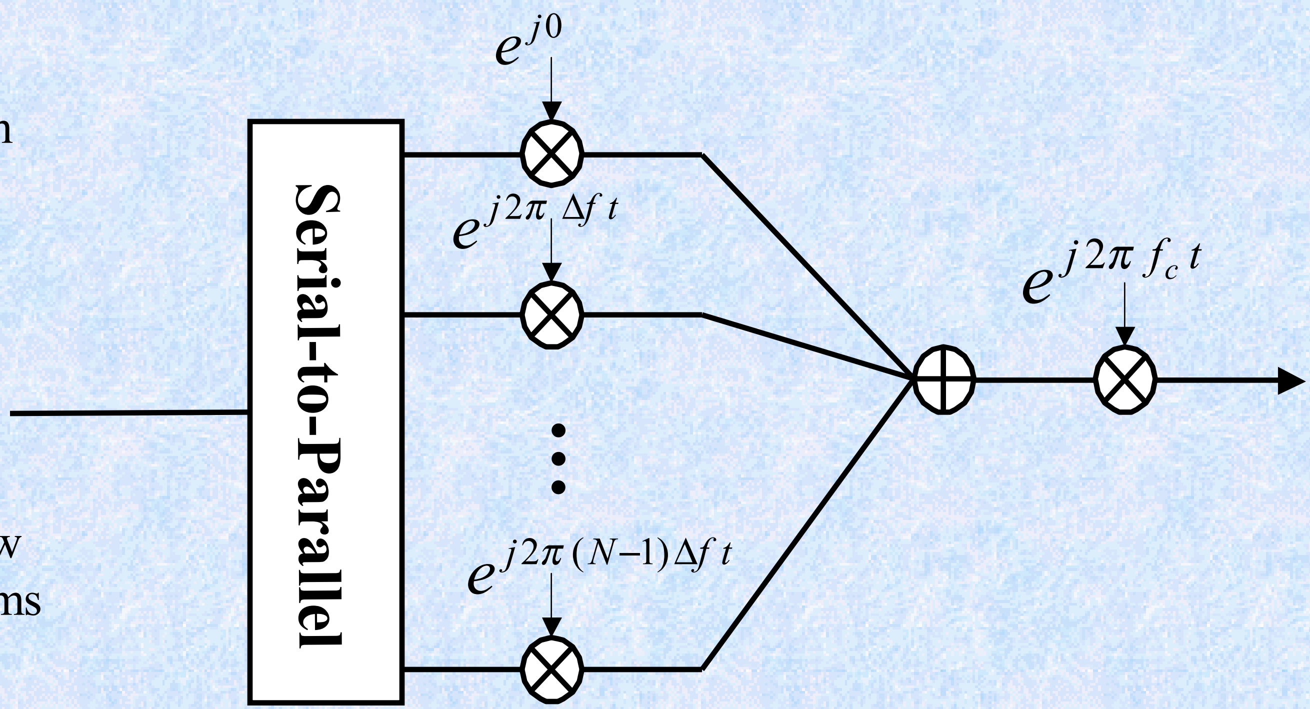
Quick hits on OFDM (Transmitter)

(1) incoming high data rate bit stream

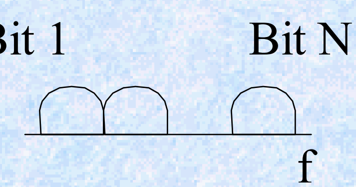


(2) output is N low data rate bit streams

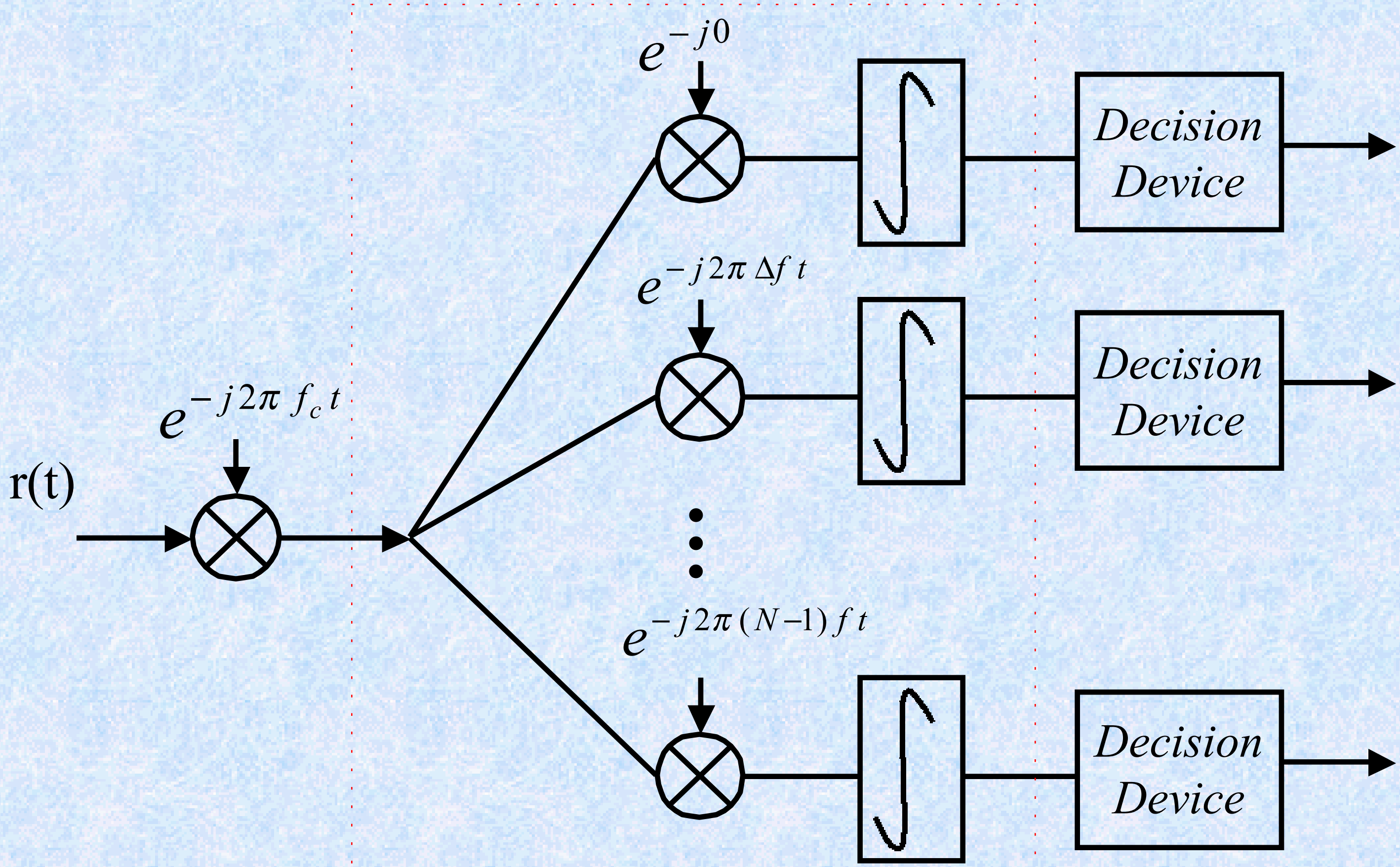




(3) Each data bit gets its own carrier, then all are added together and sent out over the carrier frequency



Quick hits on OFDM



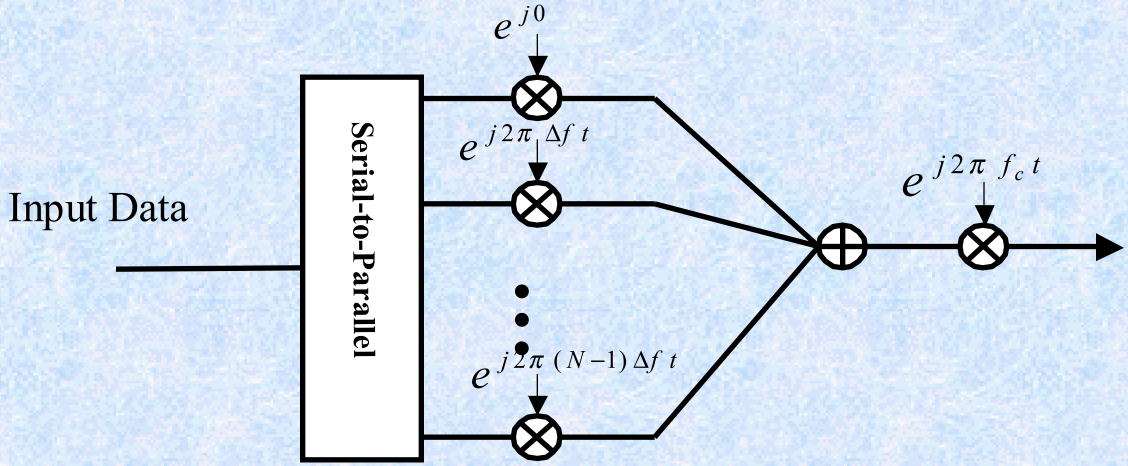
(1) return to baseband

(2) separate frequency components (each with a different data bit)

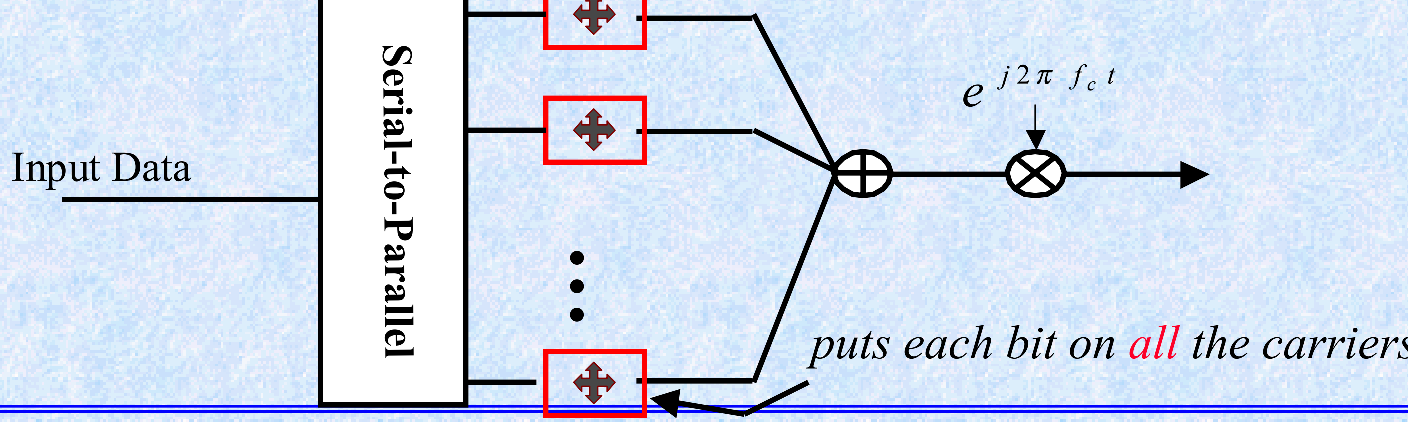
(3) make a decision on the bit on each carrier

What is CI/OFDM?

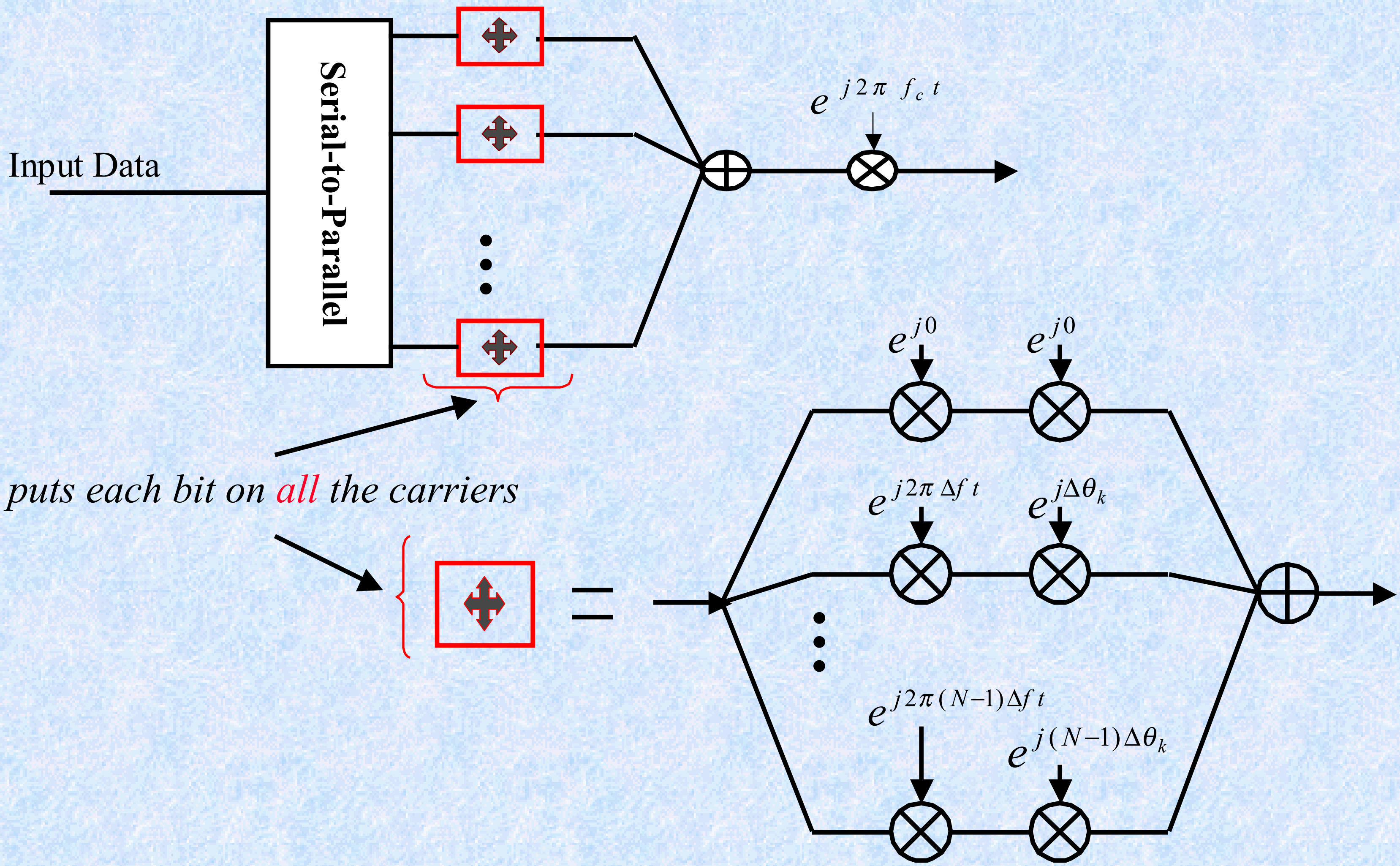
In OFDM, serial to parallel convert (S/P) your bits then put one bit per carrier



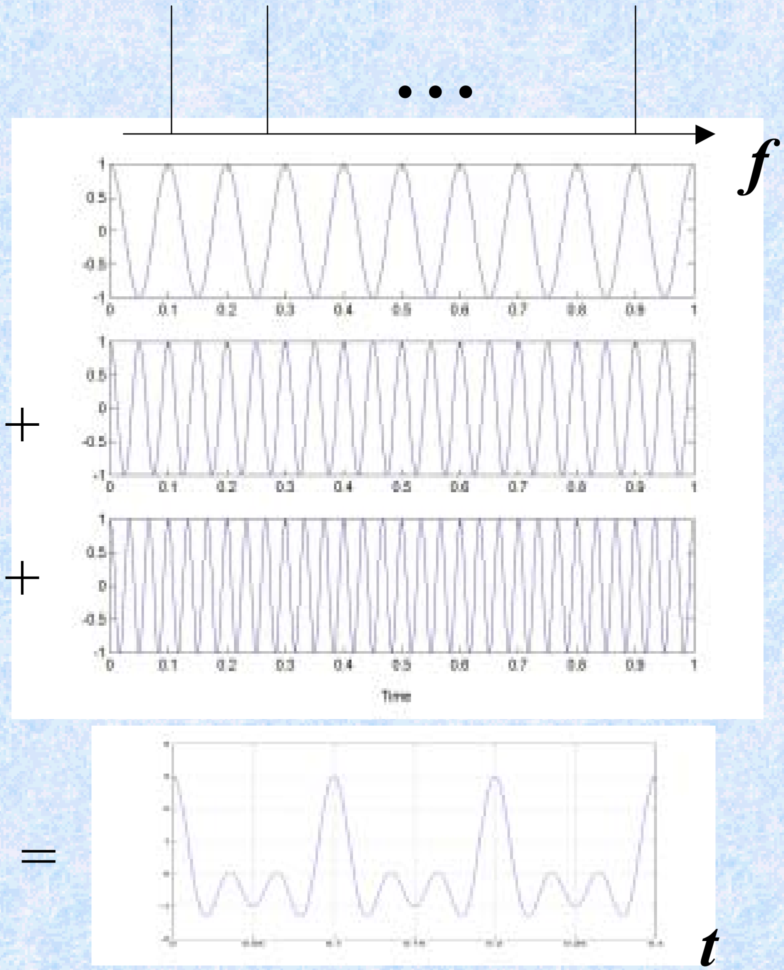
In CI/OFDM, serial to parallel convert (S/P) your bits then put all bits on all carriers at the same time.

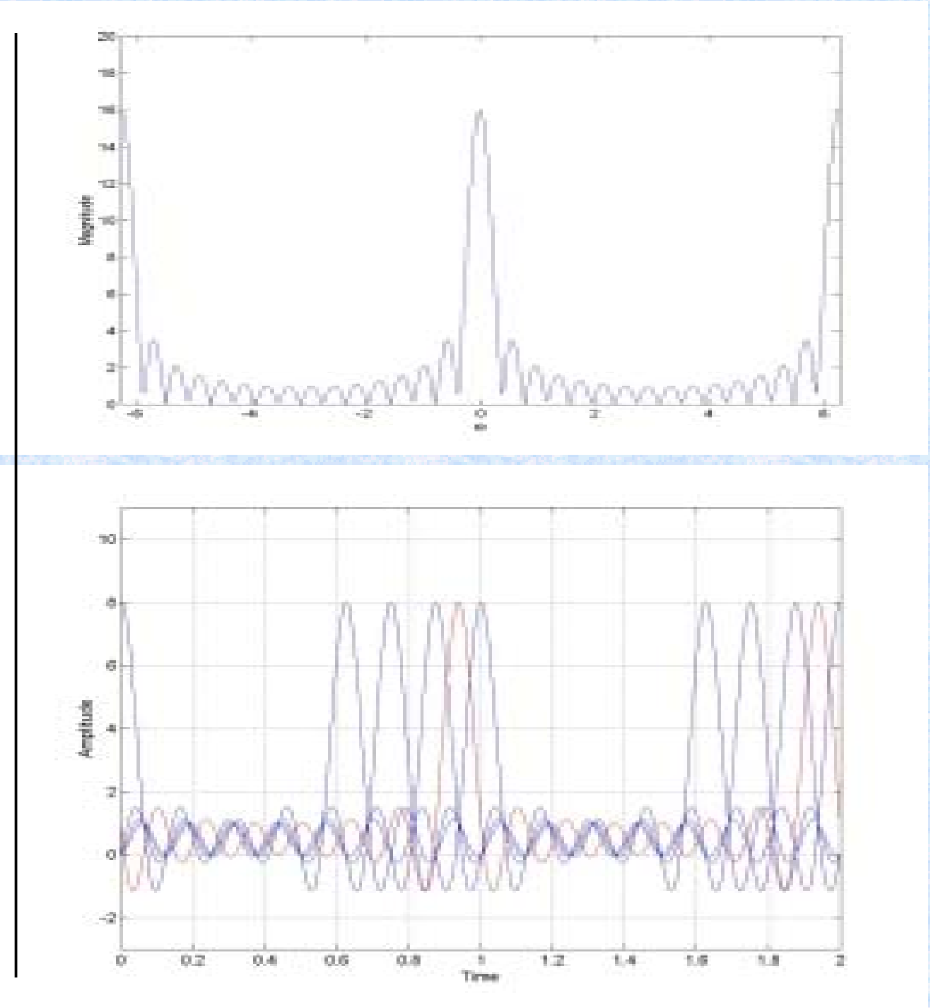


CI/OFDM Continued

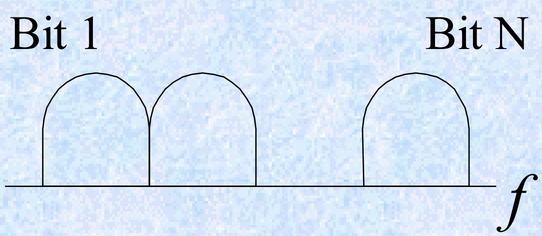


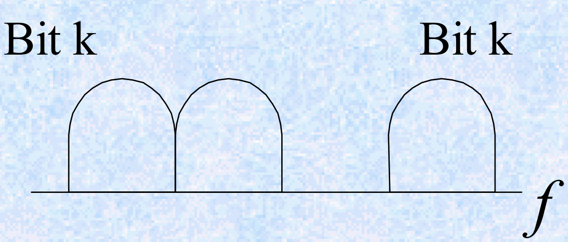
Introduction of CI to 802.11a





Send





Channel

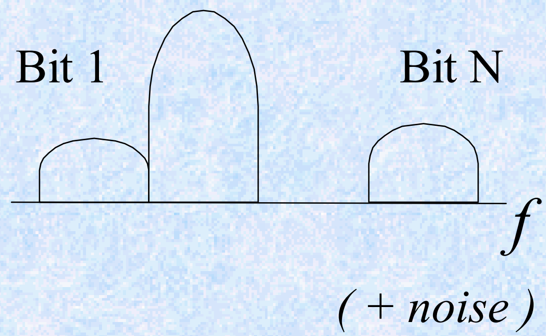
OFDM

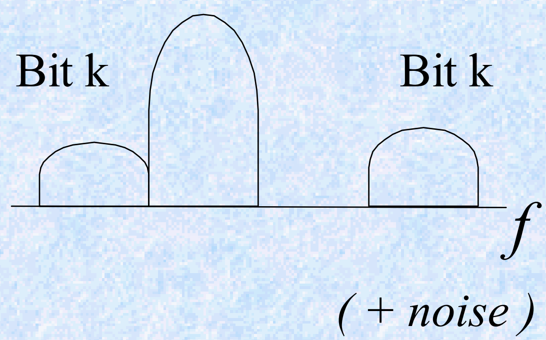
1. Frequency selective over the entire bandwidth
2. Flat over each of the individual carriers
3. Each carrier experiences a flat fade that is different than the flat fade of the other carriers

CI/OFDM

1. Frequency selective over the entire bandwidth
2. Flat over each of the individual carriers
3. Each bit experiences freq. DIVERSITY benefit.

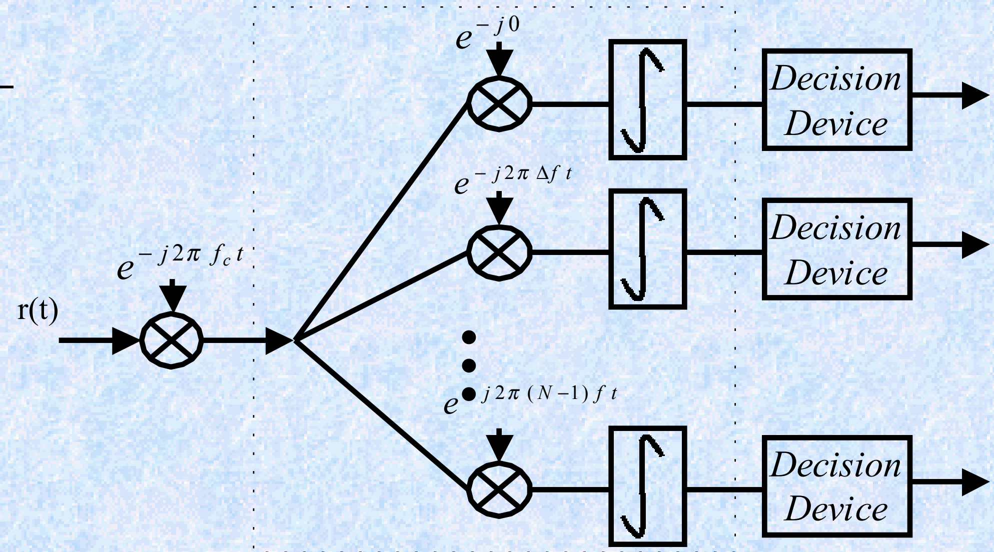
Receive



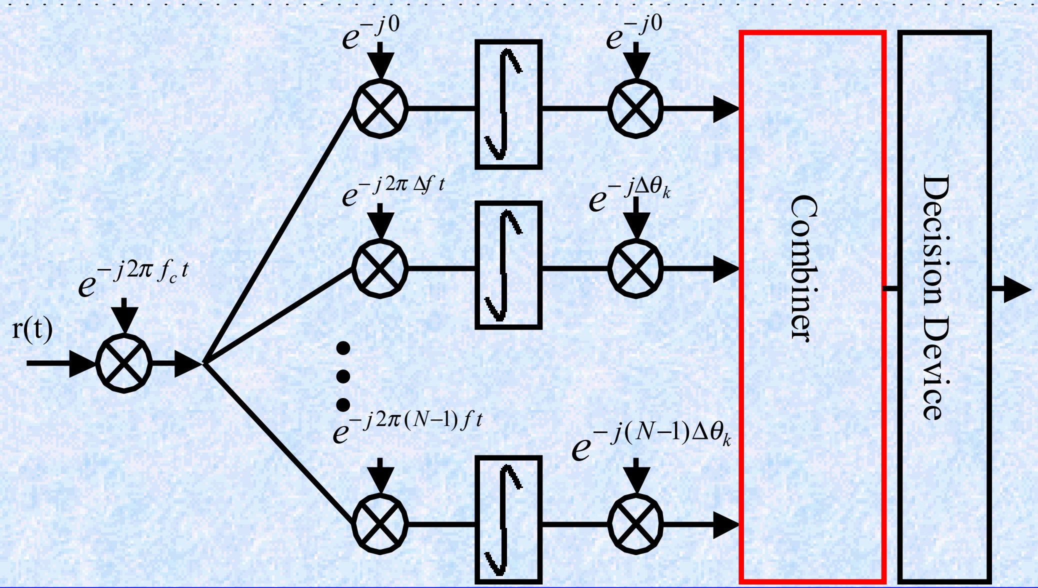


CI/OFDM Receiver

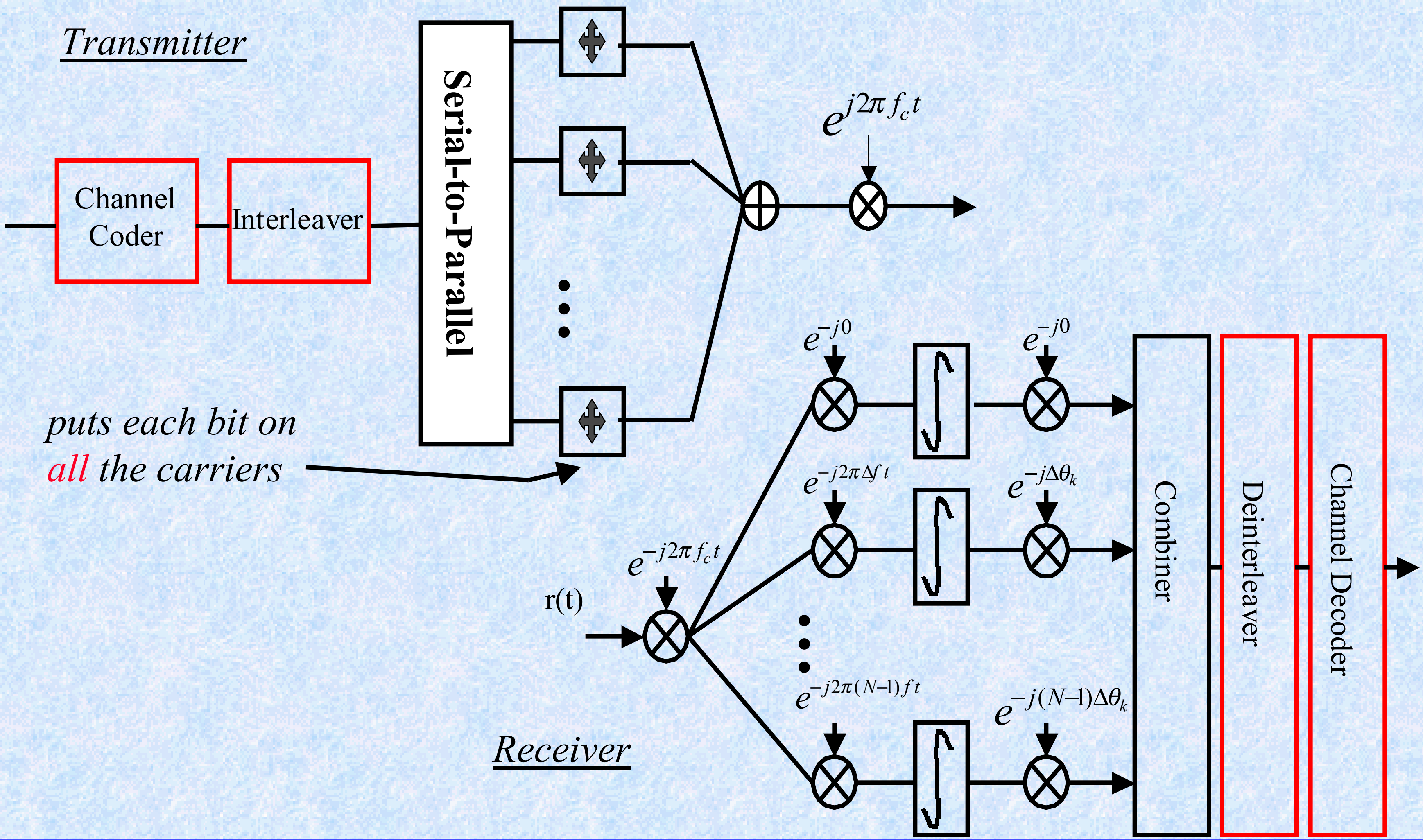
In OFDM receivers, we separate the received signal into carriers and then make a decision on each carrier.



In CI/OFDM receivers, we separate the received signal into carriers, then combine across carriers to create a frequency diversity benefit for each bit.



But what about in IEEE 802.11a?



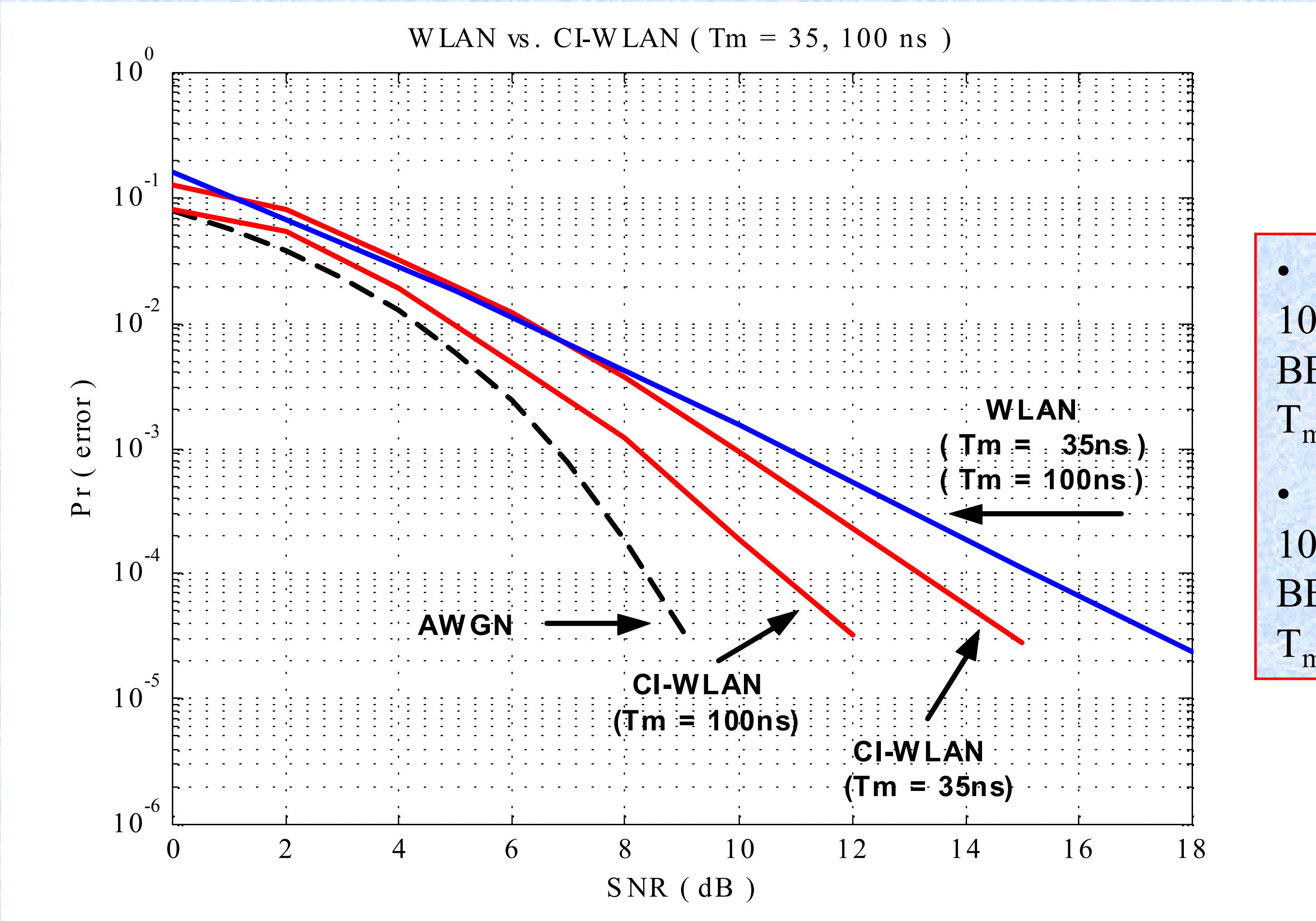
What was the system for simulation?

- $N = 48$ Carriers
- (Rate ½, Constraint Length 3 Convolutional Coder)
- Carrier Modulation: Binary Phase Shift Keying (BPSK)
- CI/OFDM utilized a Minimum Mean Squared Error Combining (MMSEC) architecture at the receiver
  - Offers good performance as shown in other multi-carrier system literature
  - Jointly minimizes the inter-bit interference and noise
  - Allows exploitation of frequency diversity in the channel

What was the channel model employed?

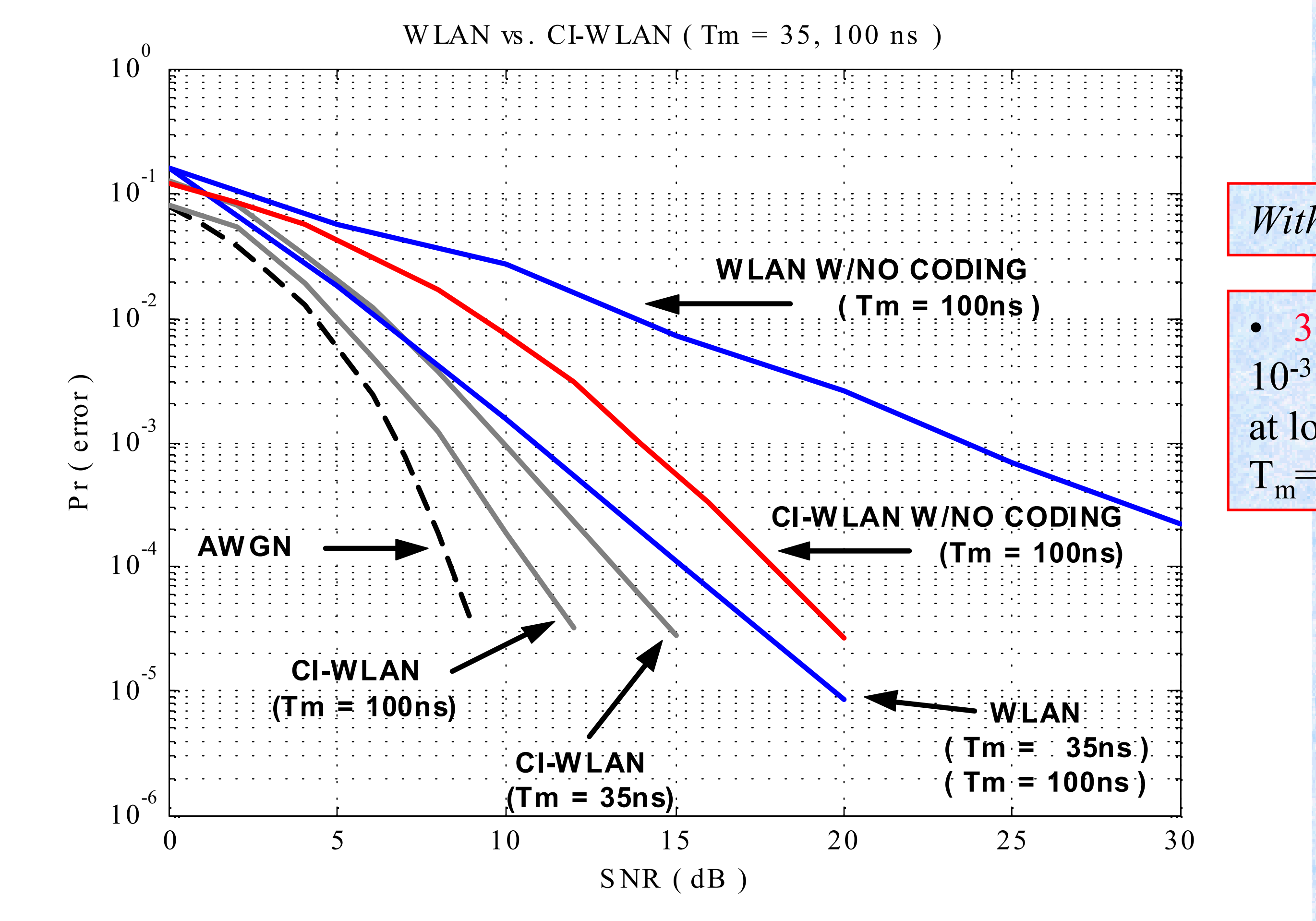
- UMTS Indoor Channel Models A and B
- Demonstrating frequency selectivity over the entire bandwidth (BW)
- Demonstrating flat fading over each of the *N* carriers

Performance



- 3 dB Gain at BER 10^{-3} and 4 dB gain at BER 10^{-4} for T_m=100ns
- 1 dB Gain at BER 10^{-3} and 2 dB gain at BER 10^{-4} for T_m=35ns

Performance



With NO CODING

- 3 dB loss at BER 10^{-3} and even less at lower BERs at T_m=100ns

CI Enhanced 802.11a Conclusions

- CI/OFDM has been introduced as an alternative for the current method of OFDM in IEEE 802.11a WLAN
  - Offers 3 dB gain over traditional WLAN at BER of 10^{-3}
- Benefits:
  - Offers greater range capabilities
  - Offers flexibility with the regard to coding
  - Minimum architectural complexity gains