UNIVERSITY OF MICHIGAN
DEPARTMENT OF ELECTRICAL ENGINEERING : SYSTEMS

EECS 555 DIGITAL COMMUNICATION THEORY

Study Of IEEE P802.15.3a physical layer proposals for UWB:

DS-UWB proposal
and
Multiband OFDM proposal

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OUTLINE

- **Introduction**
- DS UWB
- MB-OFDM UWB
- Channel Models
- Conclusion

What is UWB?

- ‘Ultra Wide Band’ is defined by FCC as applications having more than 25% bandwidth of center frequency or above 500 MHz.
- Low power, high bandwidth signal.
- Utilizes 3.1-10.6 GHz bandwidth, data rates ranging from 28-1320 Mbps.

II

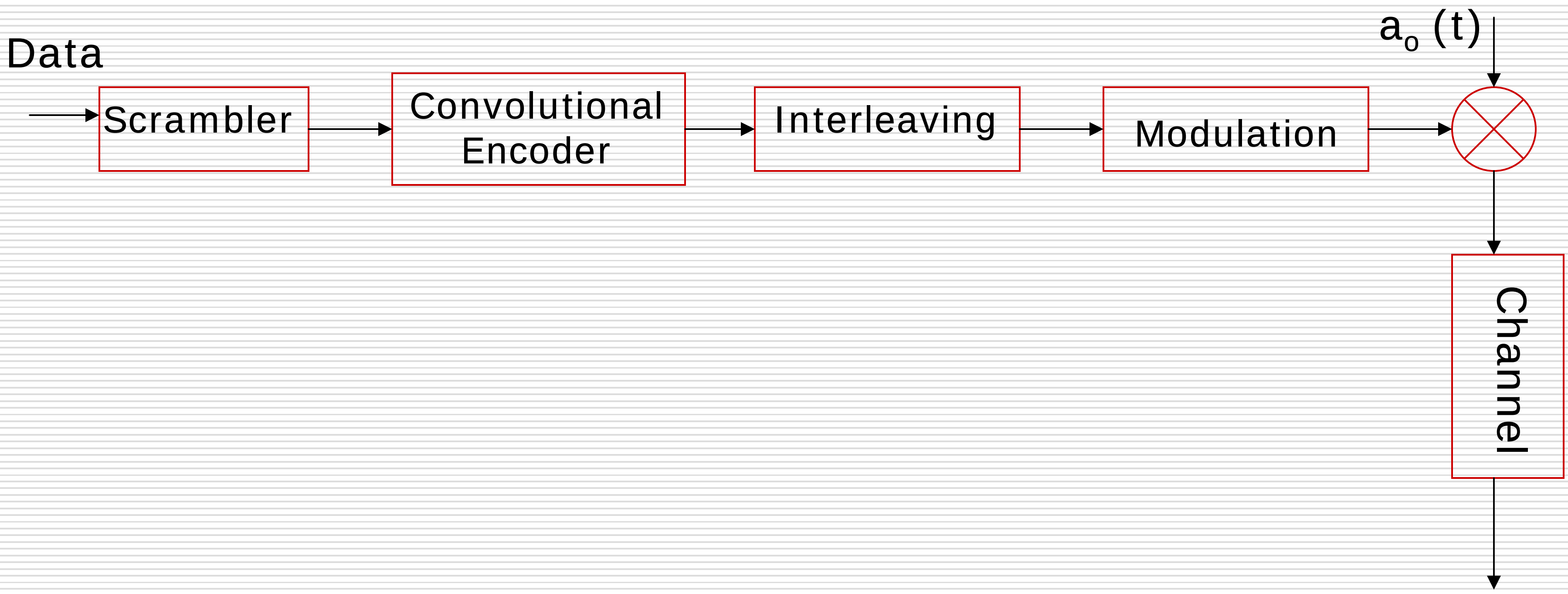
- Introduction
- **DS UWB**
- MB-OFDM UWB
- Channel Models
- Comparison & Analysis
- Conclusion

- Based on direct sequence spreading.
- Spreading impulses used.
- Different data rates achieved through different spreading sequences.

Physical Layer Frame Format

Preamble	PHY Header	MAC Header	HCS	Frame Body and FCS	SB & TS

Building blocks of DS-UWB Transmitter

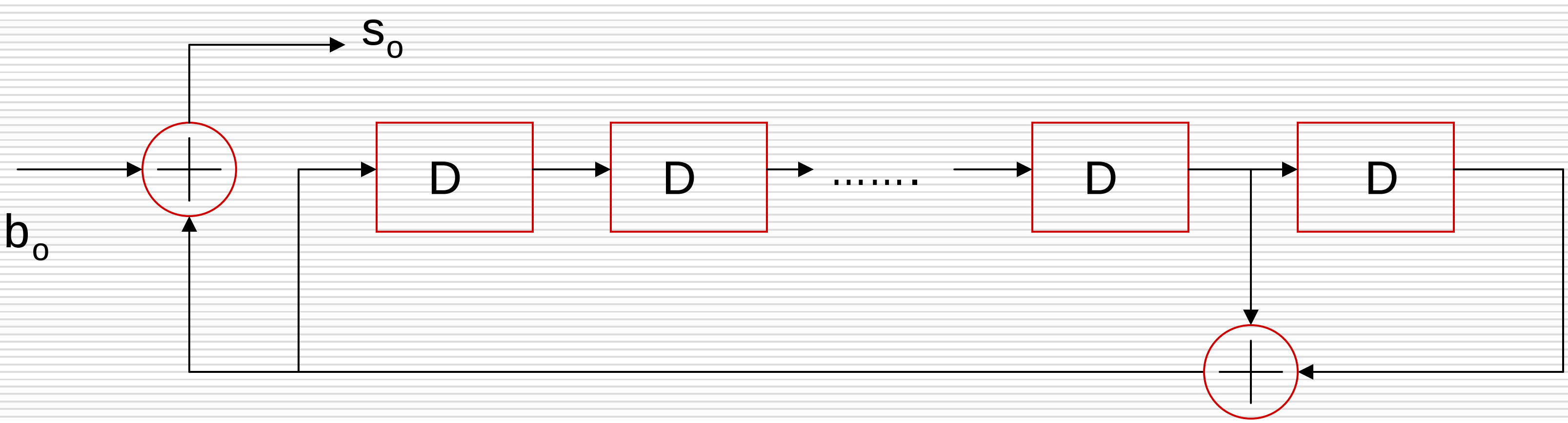


Scrambler

- Employed to ensure adequate number of bit transitions to support clock recovery.

- Generator polynomial used:

  $g(D) = 1 + D^{14} + D^{15}$



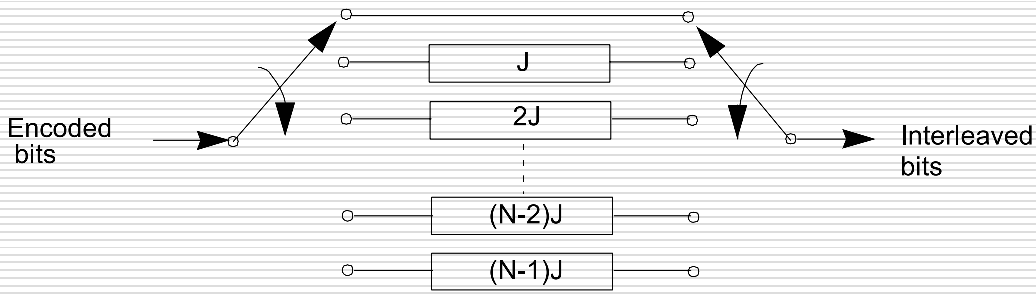
$s_o = b_o + x_o$; where x_o represents pseudo-random binary sequence

Convolutional Encoder

- Constraint Length K = 4
- Generator Polynomial (15,17)
- Rate ½ or ¾
  (punctured coding causes rate = ¾)

Convolutional Interleaving

- To make data robust against the burst errors
- Convolutional interleaving has lower latency and memory requirements.



- Here, J=7 and N=10

Modulation and Spreading

BPSK or 4-BOK modulation is employed.

- In BPSK, each symbol carries a single bit. It is mapped into +/-1.
- In 4-BOK, data stream is divided into block of two bits and then mapping of two bits is done to +/-1.

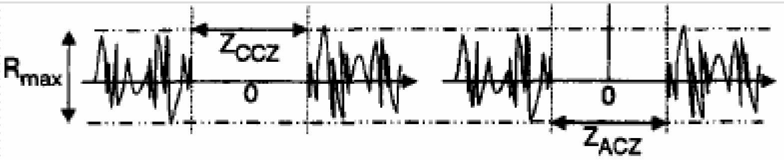
Binary or Ternary Spreading is employed.

Brief note on ternary codes

- Binary sequences – antipodal in nature.
- Ternary sequences – bi-orthogonal in nature.
- Zero Crossing Zones:

  - These are the sequences which have a zero valued window around the zero shift, in the autocorrelation (AC) and cross-correlation (CC) function.

  - Interference between users separated by delays that are within this window or interference due to delayed replicas of a users signal due to the multi-path channel will be eliminated.



Code Set Numbers	**L=6 Codes**	**L=4 Codes**	**L=3 Codes**	**L=2 Codes**	**L=1 Code**
1 through 6	1,0,0,0,0,0	1,0,0,0	1,0,0	1,0	1

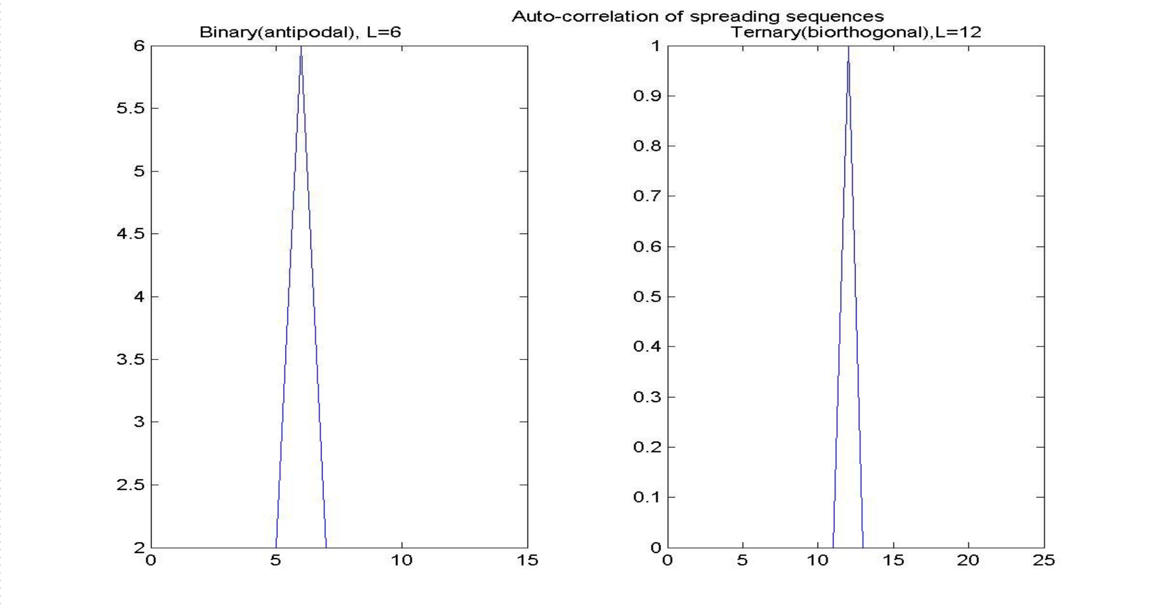
Length 6 and shorter spreading codes for BPSK

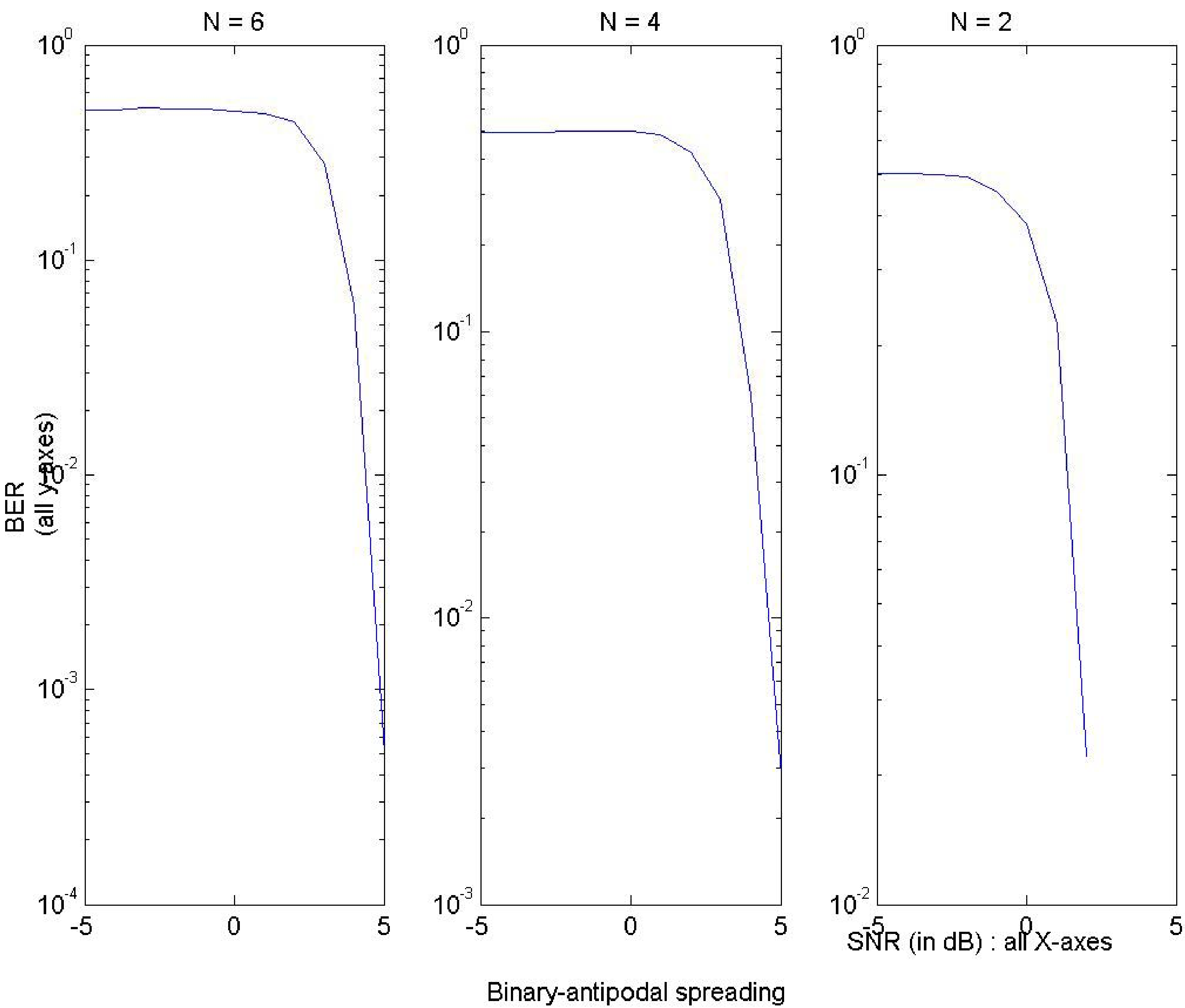
Input data: Gray coding (First in time on left)	**Input data: Natural coding** (First in time on left)	**L=12 4-BOK Codes**	**L=6 Codes**	**L=4 Codes**	**L=2 Codes**
00	00	1,0,0,0,0,0,0,0,0,0,0,0	1,0,0,0,0,0	1,0,0,0	1, 0
01	01	0,0,0,0,0,0,1,0,0,0,0,0	0,0,0,1,0,0	0,0,1,0	0, 1
11	10	-1,0,0,0,0,0,0,0,0,0,0,0	-1,0,0,0,0,0	-1,0,0,0	-1, 0
10	11	0,0,0,0,0,0,-1,0,0,0,0,0	0,0,0,-1,0,0	0,0,-1,0	0, -1

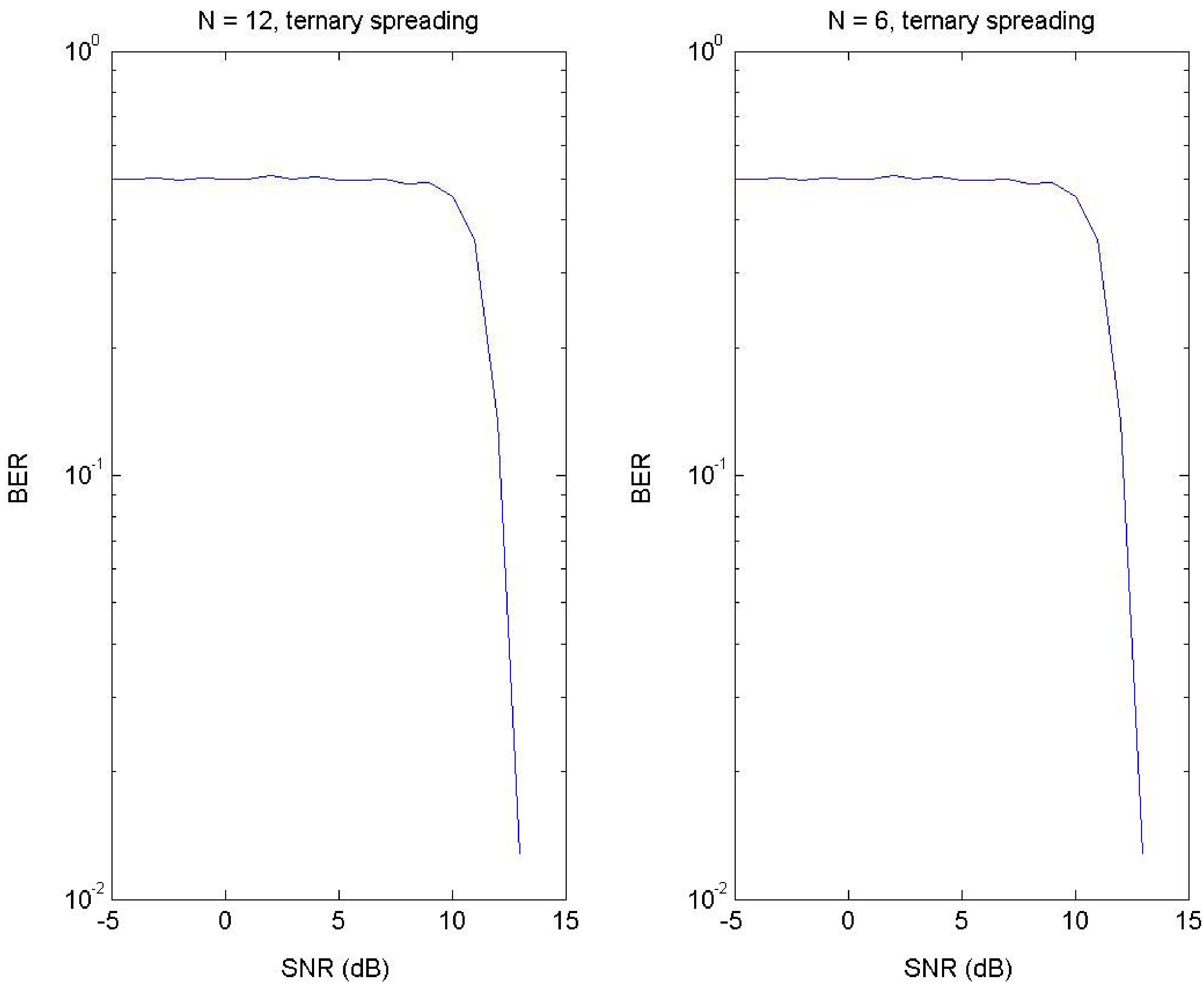
Length 12 and shorter spreading codes for 4-BOK, Code Sets 1 through 6.

Comparison of binary and ternary spreading sequences

- Ternary sequences allow for ‘0’ in the spreading sequence.
- Leads to improvement in auto-correlation properties of the sequence.




N = 6
N = 4
N = 2
BER
(all y-axes)
SNR (in dB) : all X-axes
Binary-antipodal spreading



N = 12, ternary spreading
BER
SNR (dB)
N = 6, ternary spreading
BER
SNR (dB)

•Data Rate	•FEC Rate	•Code Length	•Bits per Symbol	•Symbol Rate
•28 Mbps	•½	•L=24	•1	•F_{chip}/24
•55 Mbps	•½	•L=12	•1	•F_{chip}/12
•110 Mbps	•½	•L=6	•1	•F_{chip}/6
•220 Mbps	•½	•L=3	•1	•F_{chip}/3
•500 Mbps	•¾	•L=2	•1	•F_{chip}/2
•660 Mbps	•1	•L=2	•1	•F_{chip}/2
•1000 Mbps	•¾	•L=1	•1	•F_{chip}
•1320 Mbps	•1	•L=1	•1	•F_{chip}

Available data rates using BPSK in the lower operating band.

•Data Rate	•FEC Rate	•Code Length	•Bits per Symbol	•Symbol Rate
•110 Mbps	•½	•L=12	•2	•F_{chip}/12
•220 Mbps	•½	•L=6	•2	•F_{chip}/6
•500 Mbps	•¾	•L=4	•2	•F_{chip}/4
•660 Mbps	•1	•L=4	•2	•F_{chip}/4
•1000 Mbps	•¾	•L=2	•2	•F_{chip}/2
•1320 Mbps	•1	•L=2	•2	•F_{chip}/2

Available data rates using 4-BOK in the lower operating band

•Data Rate	•FEC Rate	•Code Length	•Bits per Symbol	•Symbol Rate
•55 Mbps	•½	•L=24	•1	•F_{chip}/24
•110 Mbps	•½	•L=12	•1	•F_{chip}/12
•220 Mbps	•½	•L=6	•1	•F_{chip}/6
•500 Mbps	•¾	•L=4	•1	•F_{chip}/4
•660 Mbps	•1	•L=4	•1	•F_{chip}/4
•1000 Mbps	•¾	•L=2	•1	•F_{chip}/2
•1320 Mbps	•1	•L=2	•1	•F_{chip}/2

Available data rates using BPSK in the higher operating band

•Data Rate	•FEC Rate	•Code Length	•Bits per Symbol	•Symbol Rate
•220 Mbps	•½	•L=12	•2	•F_{chip}/12
•660 Mbps	•¾	•L=6	•2	•F_{chip}/6
•1000 Mbps	•¾	•L=4	•2	•F_{chip}/4
•1320 Mbps	•1	•L=4	•2	•F_{chip}/4

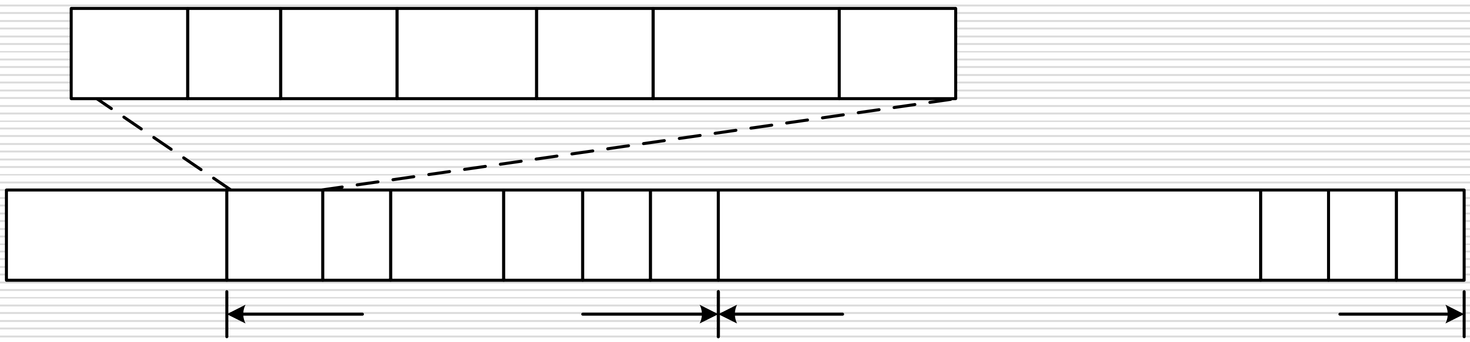
Available data rates using 4-BOK in the lower operating band

- Introduction
- DS UWB
- **MB-OFDM UWB**
- Channel Models
- Comparison & Analysis
- Conclusion

- Based on Orthogonal Frequency Division Multiplexing
- Possible data rates:

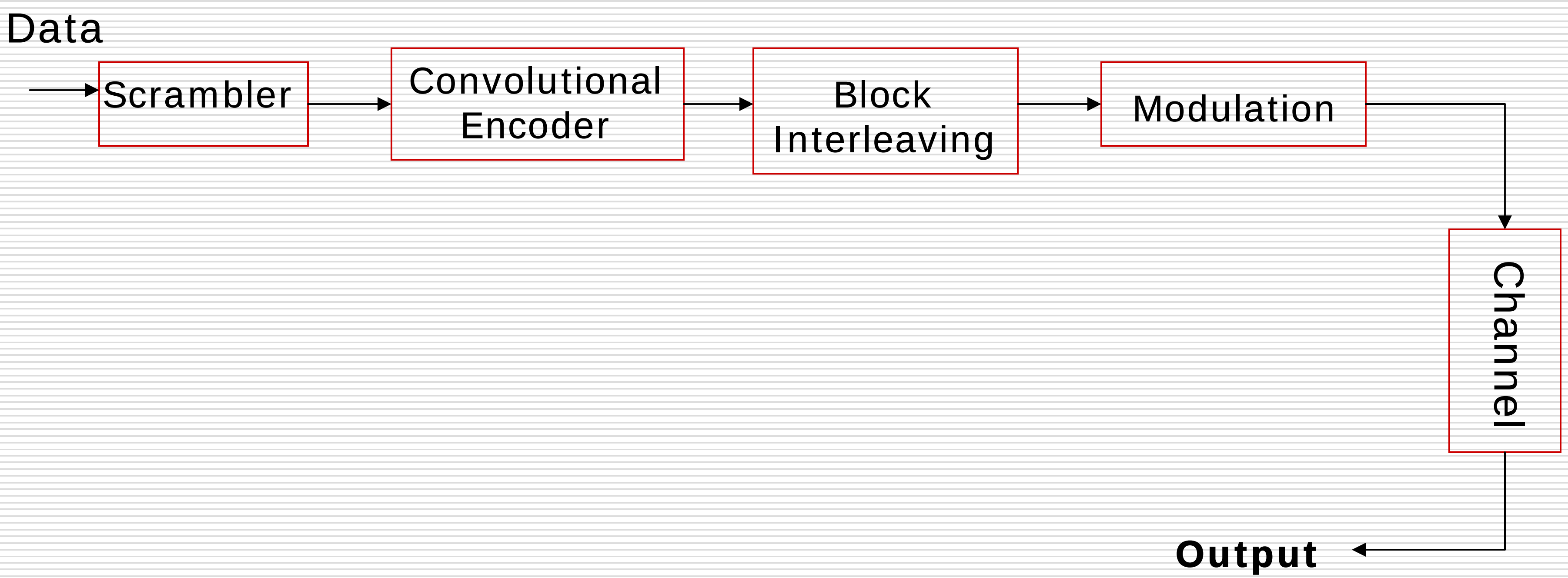
  53.3, 55, 80, 106.7, 110, 160, 200, 320, 400, 480 Mb/s
- Different data rates achieved through different FEC coding rates, conjugate symmetry of symbols and time domain spreading

Frame Format for Multi-band OFDM



Reserved 2 bit | RATE 5 bits | Reserved 2 bit | LENGTH 12 bits | Reserved 2 bit | Scra

Building blocks of MB-OFDM



Scrambler

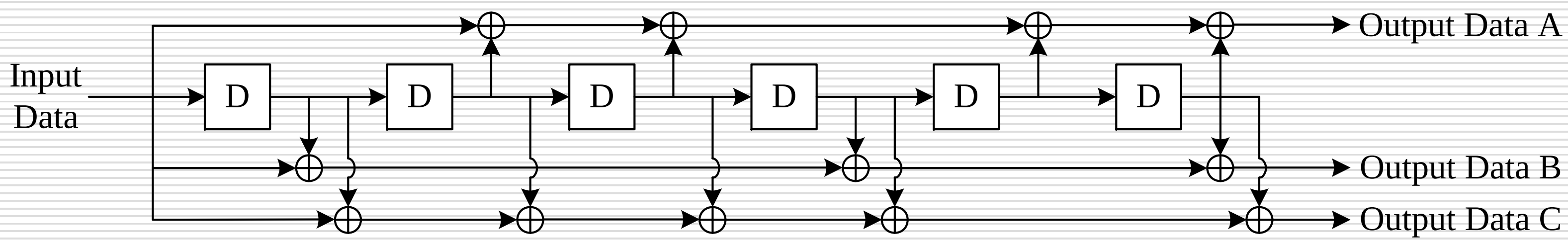
- To ensure adequate number of bit transitions to support clock recovery.

- Generator polynomial used: $g(D) = 1 + D^{14} + D^{15}$

$s_n = b_n + x_n$

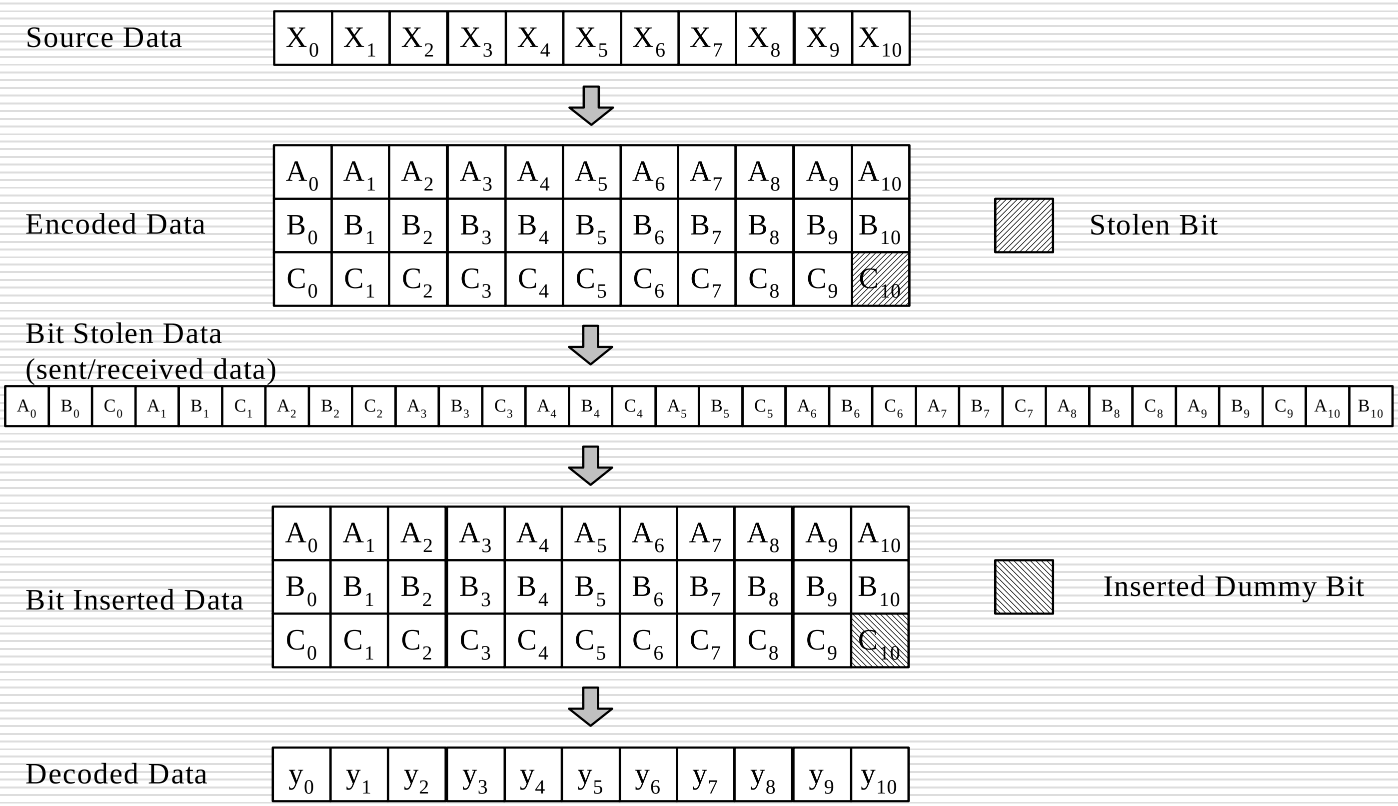
Convolutional Encoder

- Rate: R = 1/3, constraint length: K = 7
  generator polynomials: $(133)_8$, $(145)_8$, $(175)_8$



- By puncturing, coding rate can be increased to,
  11/32, 1/2, 5/8, 3/4
  Used to achieve different data rates

Puncturing



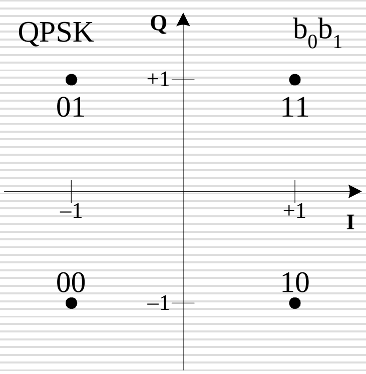
Bit stealing and bit-insertion procedure for R=11/32

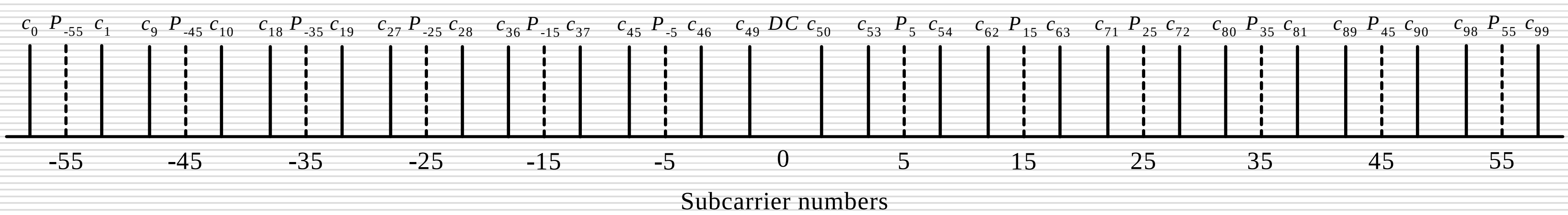
Interleaving

- Makes Viterbi decoding robust against burst errors
- Block Interleaving
  - Symbol Interleaving (on block size $6N_{cbps}$)
  - Tone interleaving (on block size N_{cbps})
- Pad bits added to the output of the encoder, in each frame, to fit interleaver block which adds to the overhead

QPSK and OFDM modulation

- Interleaved bits divided into groups of 2 bits and mapped to complex numbers **$d = (I + jQ) \times 1/\sqrt{2}$**
- Complex numbers are divided into groups of 50 (conjugate symmetric) or 100
- Allocated orhthogonal subcarrier frequencies separated by Δ_F=528MHz/128=4.125MHz





Band numbering

Band Group	BAND_ID	Lower frequency	Center frequency	Upper frequency
1	1	3168 MHz	3432 MHz	3696 MHz
	2	3696 MHz	3960 MHz	4224 MHz
	3	4224 MHz	4488 MHz	4752 MHz
2	4	4752 MHz	5016 MHz	5280 MHz
	5	5280 MHz	5544 MHz	5808 MHz
	6	5808 MHz	6072 MHz	6336 MHz
3	7	6336 MHz	6600 MHz	6864 MHz
	8	6864 MHz	7128 MHz	7392 MHz
	9	7392 MHz	7656 MHz	7920 MHz
4	10	7920 MHz	8184 MHz	8448 MHz
	11	8448 MHz	8712 MHz	8976 MHz
	12	8976 MHz	9240 MHz	9504 MHz
5	13	9504 MHz	9768 MHz	10032 MHz
	14	10032 MHz	10296 MHz	10560 MHz

Time domain spreading

- Time and frequency diversity for data rates, 55, 88, 110, 160, 200 Mbps
- Different logical channels are obtained

Channel Number	Preamble Pattern	Mode 1: Length 6 Time Frequency Code					
1	1	1	2	3	1	2	3
2	2	1	3	2	1	3	2
3	3	1	1	2	2	3	3
4	4	1	1	3	3	2	2

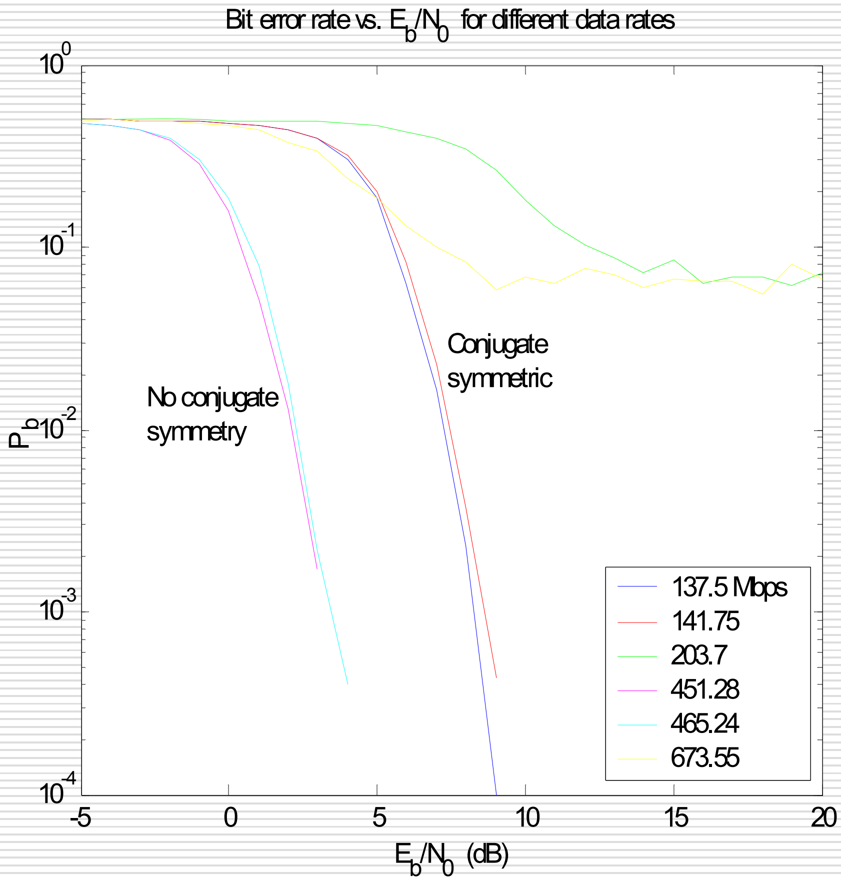
An example of a length-6 time-frequency code

Summary of rates

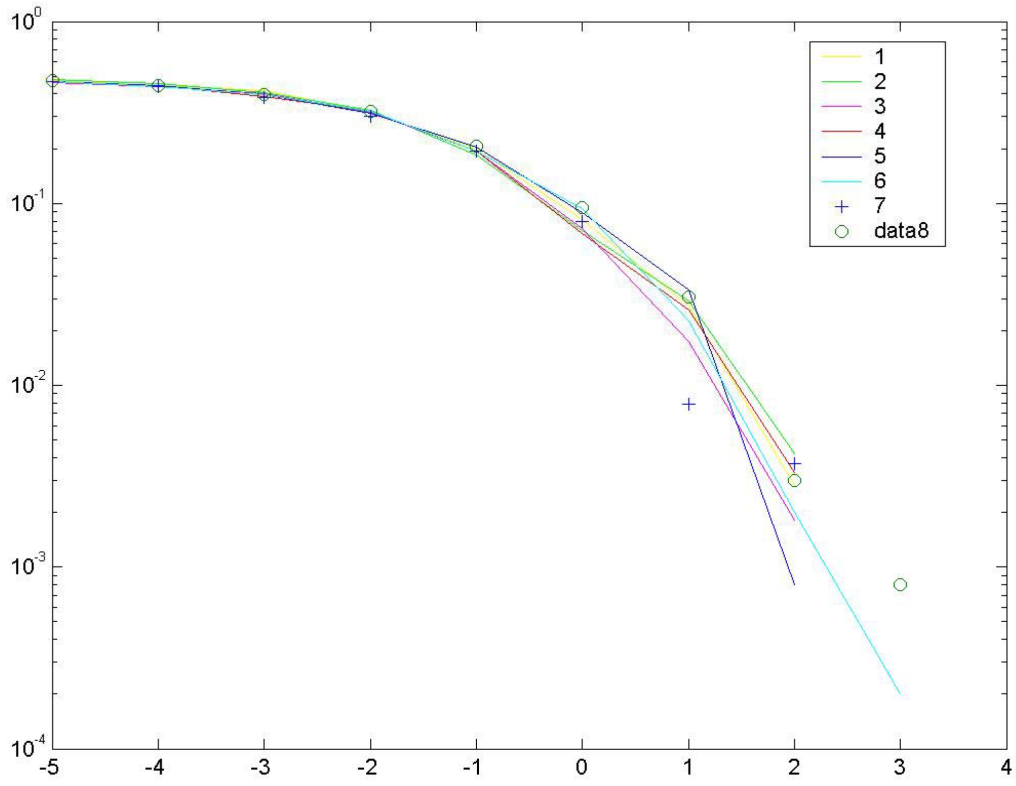
Data Rate (Mb/s)	Modulation	Coding rate (R)	Conjugate symmetric input to IFFT	Time spreading Factor	Overall Spreading gain	Coded bits per OFDM symbol (N_{CBPS})
53.3	QPSK	1/3	Yes	2	4	100
55	QPSK	11/32	Yes	2	4	100
80	QPSK	½	Yes	2	4	100
106.7	QPSK	1/3	No	2	2	200
110	QPSK	11/32	No	2	2	200
160	QPSK	½	No	2	2	200
200	QPSK	5/8	No	2	2	200
320	QPSK	½	No	1 (No spreading)	1	200
400	QPSK	5/8	No	1 (No spreading)	1	200
480	QPSK	¾	No	1 (No spreading)	1	200

Simulation results

- Channel: AWGN
- Receiver:
  - FFT Block
  - QPSK demodulator (hard detector)
  - De - interleaver
  - Viterbi decoder (hard)
- Data rates:
  - 137.5 Mbps to 673.55 Mbps



DS-UWB



- Introduction
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- **Channel Models**
- Comparison & Analysis
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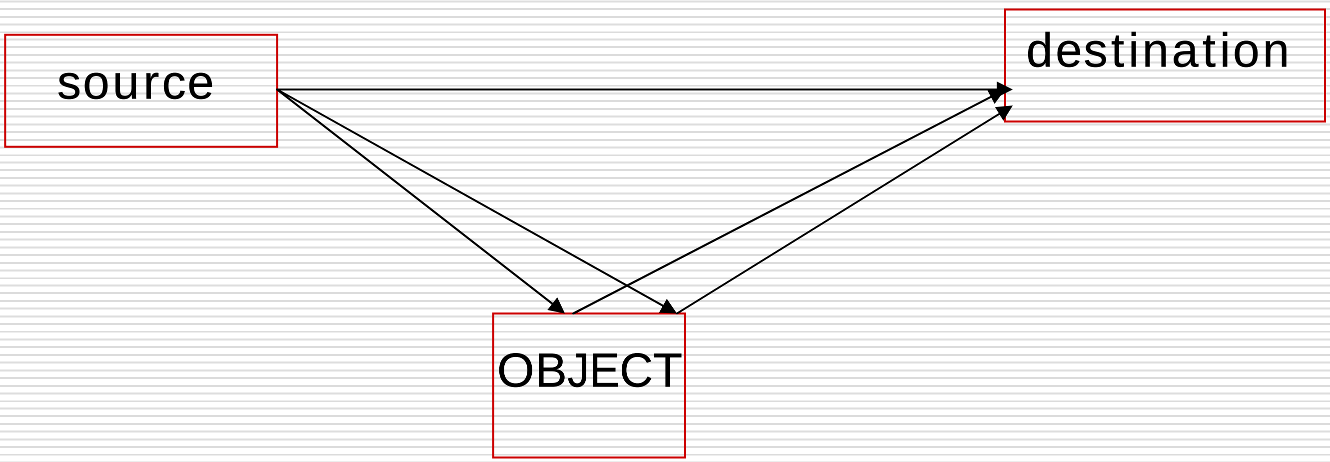
- As the bandwidth of UWB channels is very large, only few multipath components overlap within each resolvable delay bin.

- Central Limit Theorem cannot be applied. Amplitude fading statistics are no longer Rayleigh.

- Hence the need to obtain time-of-arrival statistics.

Paths separated by more than 133ps (4cm path length) can be resolved.



- The model uses Saleh - Valenzuela (S-V) approach: clusters and rays
- Arrival of rays is modeled as Poisson process with rate λ
- Cluster arrival is modeled as Poisson process with rate Λ

- Impulse response is described by,

$$h_i(t) = X_i \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha_{k,l}^{i} \delta(t - T_l^i - \tau_{k,l}^{i})$$

where, $\{T_l^i\}$: delay of the l^{th} cluster

$\{\tau_{k,l}^i\}$: delay of k^{th} multipath component relative to l^{th} cluster arrival time (T_l^i)

$\{\alpha_{k,l}^i\}$: multipath gain coefficients

$\{X_i\}$: lognormal shadowing, i : i^{th} realization

T_l = arrival time of the first path of l^{th} cluster,

Λ = cluster arrival rate

$\tau_{k,l}$ = delay of k^{th} path within l^{th} cluster relative to T_l

λ = ray arrival rate (within each cluster)

Distribution of cluster arrival time and ray arrival time,is given by,

$$p\left(T_l \middle| T_{l-1}\right) = \Lambda \exp\left[-\Lambda\left(T_l - T_{l-1}\right)\right], \quad l > 0$$

$$p\left(\tau_{k,l} \middle| \tau_{(k-1),l}\right) = \lambda \exp\left[-\lambda\left(\tau_{k,l} - \tau_{(k-1),l}\right)\right], \quad k > 0$$

Channel coefficients are defined as product of small and large scale fading coefficients, $\alpha_{k,l} = p_{k,l}\xi_l\beta_{k,l}$,

Amplitude statistics matched with log-normal distribution.
Large-scale fading is also lognormally distributed.

$$20\log 10(\xi_l\beta_{k,l}) \propto \text{Normal}(\mu_{k,l}, \sigma_1^2 + \sigma_2^2),$$

where, $\mu_{k,l} = \frac{10\ln(\Omega_0) - 10T_l/\Gamma - 10\tau_{k,l}/\gamma}{\ln(10)} - \frac{(\sigma_1^2 + \sigma_2^2)\ln(10)}{20}$

In above equations, ξ_l reflects the fading associated with the l^{th} cluster, $\beta_{k,l}$ corresponds to fading associated with k^{th} ray of the l^{th} cluster.

The shadowing term is given by, $20\log 10(X_i) \propto \mathrm{Normal}(0, \sigma_x^2)$.

The total multipath energy is contained in X_i

Assumptions

Ray and cluster arrival rate are delay invariant.

Variance of lognormal fading is independent of delay.

Four different measurement environments,

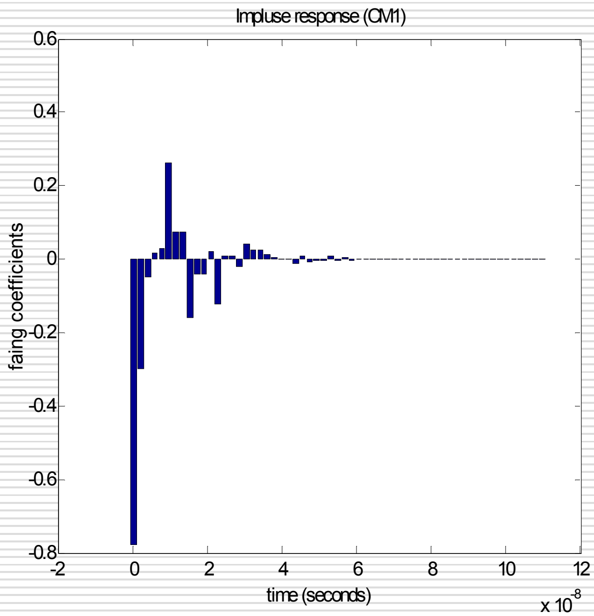
CM1 : LOS (less than 4 m)

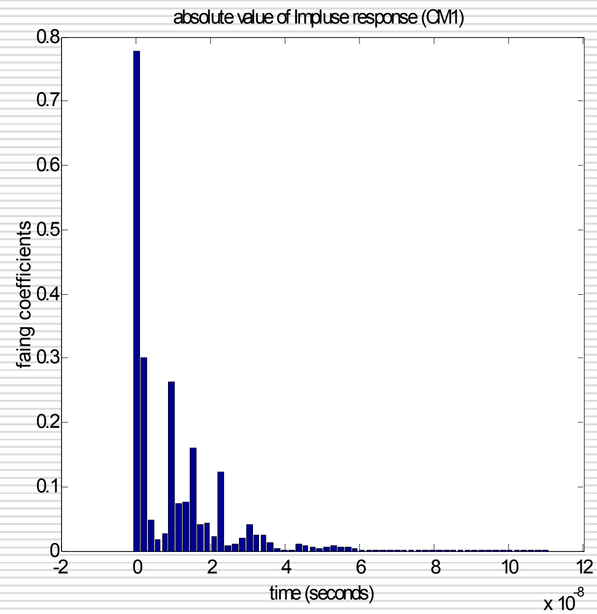
CM2 : NLOS (less than 4m)

CM3 : NLOS (between 4-10m)

CM4 : Strong delay dispersion, delay spread of 25ns.

Channel impulse response

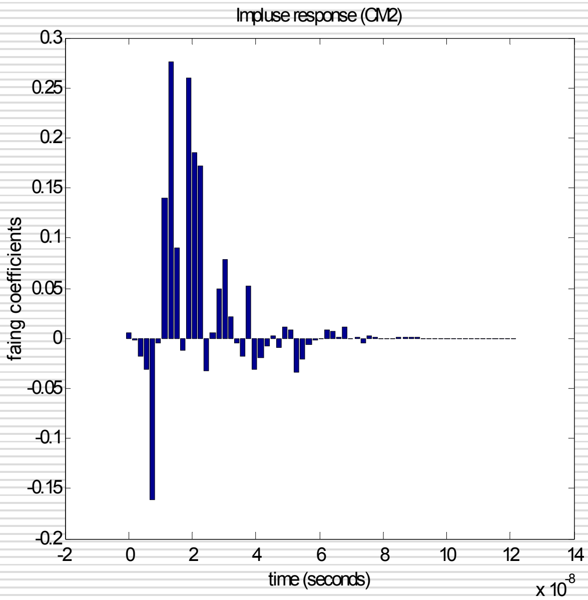


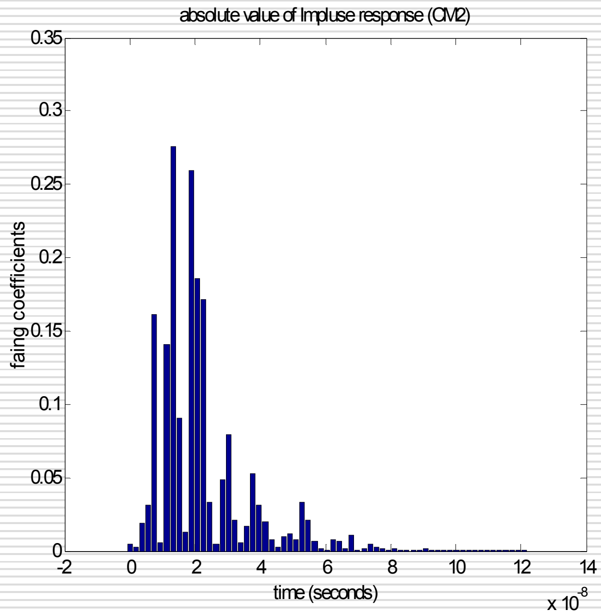


CM1: $\Lambda = 0.0233$, $\lambda = 2.5000$, $\Gamma = 7.1000$, $\gamma = 4.3000$

$\sigma_1 = 3.3941$, $\sigma_2 = 3.3941$, $\sigma_x = 3.0000$, LOS

Channel impulse response

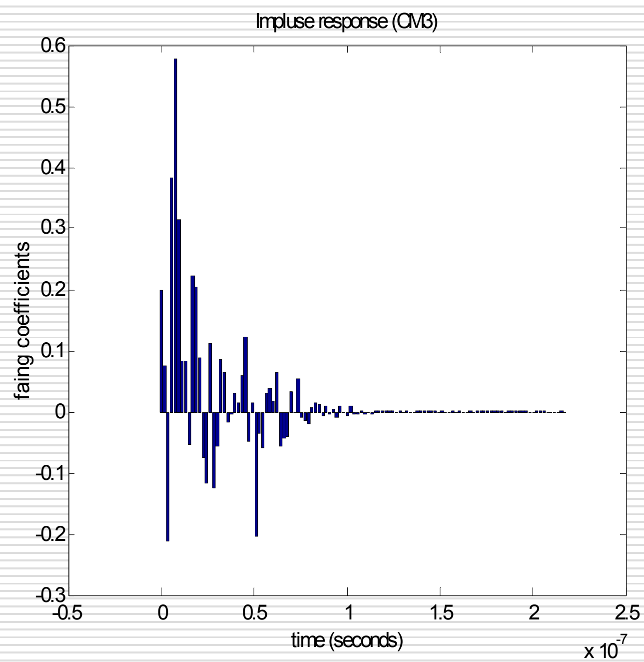


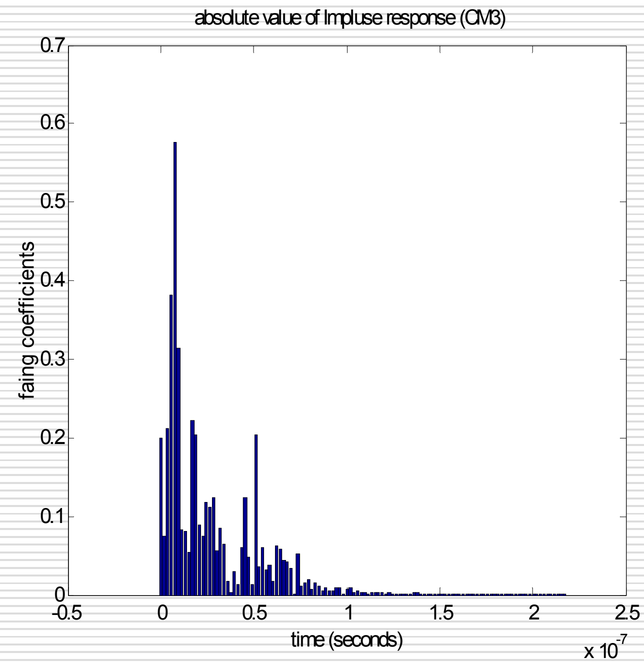


CM2: $\Lambda = 0.4000$, $\lambda = 0.5000$, $\Gamma = 5.5000$, $\gamma = 6.7000$

$\sigma_1 = 3.3941$, $\sigma_2 = 3.3941$, $\sigma_x = 3.0000$, NLOS

Channel impulse response

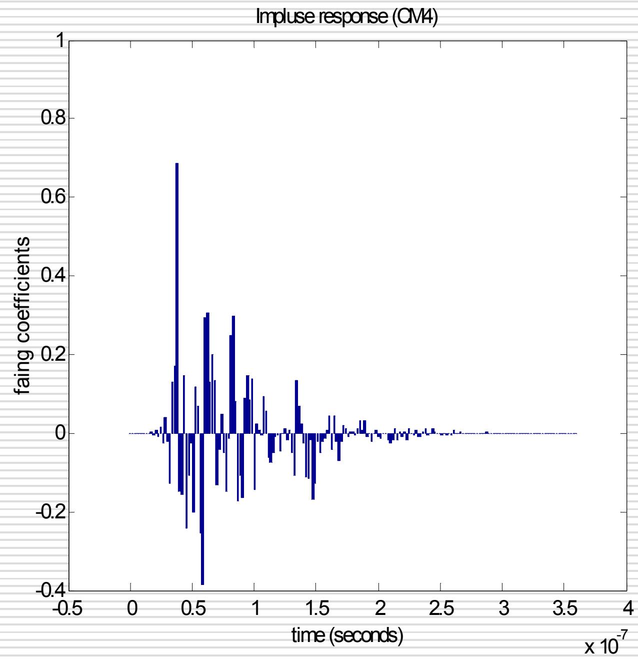


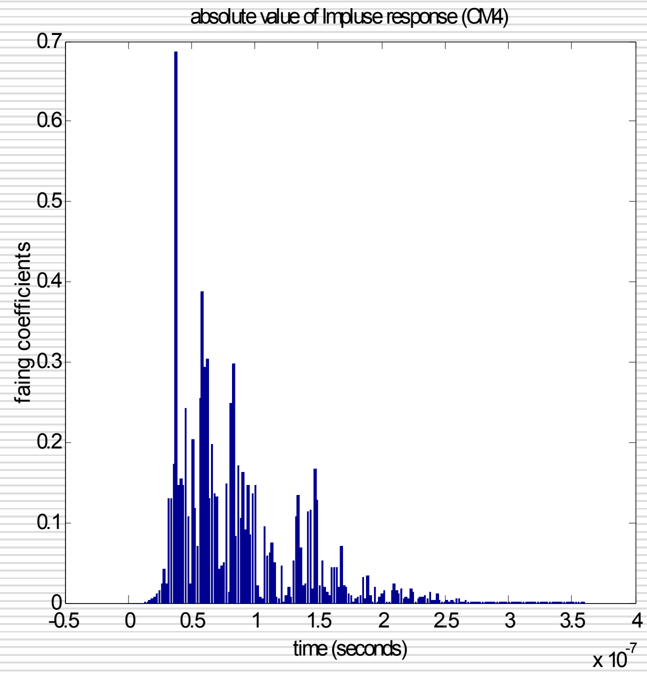


CM3: $\Lambda = 0.0667$, $\lambda = 2.1000$, $\Gamma = 14.0000$, $\gamma = 7.9000$

$\sigma_1 = 3.3941$, $\sigma_2 = 3.3941$, $\sigma_x = 3.0000$, NLOS

Channel impulse response





CM4: $\Lambda = 0.0667$, $\lambda = 2.1000$, $\Gamma = 24.0000$, $\gamma = 12.0000$

$\sigma_1 = 3.3941$, $\sigma_2 = 3.3941$, $\sigma_x = 3.0000$, NLOS

Conclusion

Conventional modulation techniques can be used to generate UWB signals.

Variable data rates can be achieved by employing different coding rates, spreading lengths, time-frequency diversity.

For lower data rates, diversity is high, hence the error rates are smaller.

Thank you

Questions ?