802.11a OFDM PHY

Coding and Interleaving

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Outline

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- Puncturing codes
- Decoding
- Weighting metric
- Interleaver
- Simulations
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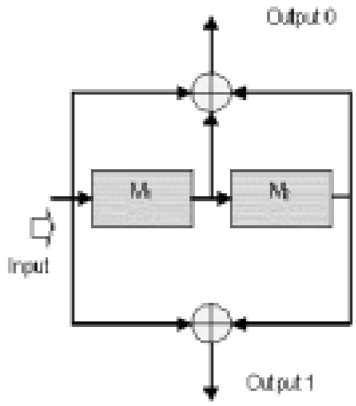
Introduction

- Shannon's Noisy Channel Coding Theorem
  - *"With every channel we can associate a "channel capacity" C (bits/sec). There exist such error control codes that information can be transmitted at a rate below C (bits/sec) with an arbitrarily low bit error rate."*
- Error Control Coding
  - The function of the encoder is to introduce redundancy in the binary information sequence.
  - Such redundancy is used in the receiver to overcome the effects of noise, interference and (fading) encountered when transmitting the signal through the channel.

Convolutional Codes

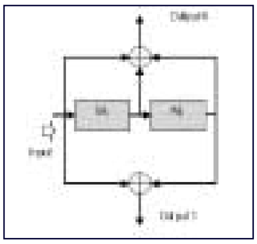
- Characteristics
  - The output is a function of not only the input bit but also the previous inputs.
  - Parameters
    - n is the number of output bits.
    - k is the number of input bits.
    - m is the number of memory registers.
    - k / n code rate.
    - Constraint Length L= k (m-1)

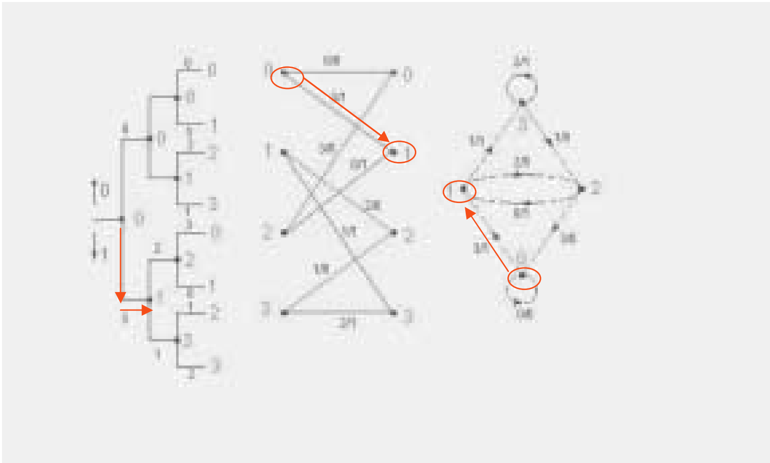


Convolutional Codes

- Graphical representation

Input bit	Current state	Next state	Output
0	0	0	0
1	0	1	3
0	1	2	2
1	1	3	1
0	2	0	3
1	2	1	0
0	3	2	1
1	3	3	2





Convolutional codes

- Free distance
  - The minimum free distance of the code determine the performance of the convolutional code.
  - The minimum free distance is the minimum Hamming distance between all pairs of code words.
- Coding Gain
  - Reduction of required SNR to achieve a certain bit error rate (BER) in AWGN channel.

$$C_{gain} = 10\log_{10}(CR.d_{free})$$

Convolutional codes

- IEEE802.11a
  - M=6 , $g_1=133_8$ $g_2=177_8$
  - Code rate =1/2
  - Modulation : BPSK, QPSK, 16QAM, 64QAM
  - Example
    - Data Rate = 12 Mbps
      - BPSK, no coding
      - QPSK , coding ½ code rate.
  - IEEE 802.11a
    - Data Rate = 6 , 9, 12, 18, 24, 36, 48, 54 Mbps

Bits per carrier — No. of carriers — Code Rate

$$Rate = \frac{bits_{carrier} N_{carrier} CR}{T_{OFDM}}$$

Symbol Duration

Puncturing Codes

- Different Data Rate
  - Different size constellation.
  - Different convolutional encoders.
  - Puncturing encoders
    - Some of the outputs bits are not transmitted.
    - The bit selection rule is changed to

$$CR = \frac{1}{CR_{or}.PR}$$

Puncturing Rate =2/3
Code rate=3/4

Puncturing Rate =3/4
Code rate=2/3

Puncturing Codes

Code rates	Punctured Free Distance	Punctured Coding Gain	Optimum Free Distance	Optimum Coding Gain
½	-	-	10	10.0 dB
2/3	6	6.0 dB	7	6.7 dB
3/4	5	5.7	6	6.5

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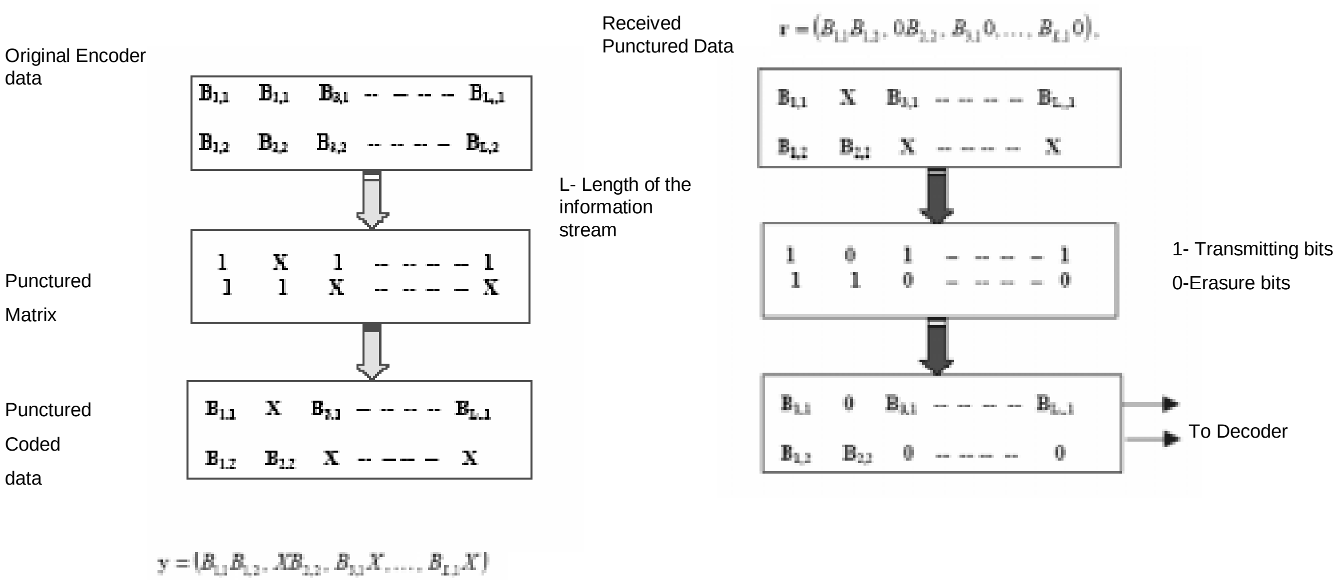
Puncturing Codes



23.3.2004
IEEE 802.11
Coding and Interleaving

Decoding

- The principle of the Viterbi Algorithm is:
  - Examine the received and compute the metric for each path and make a decision based in this metric.
  - All paths are followed until to paths converge on one node.
  - The path with the lower metric is kept.

Decoding

- Viterbi decoding
  - Maximum likelihood estimator
  - Hard decoding
    - The received symbols at the output of the demodulator are quantized into two levels; zero and one, and fed to the decoder. The Hamming distance is calculated.
  - Soft decoding
    - The received symbols at the output of the demodulator are quantized into more than two levels or the unquantized value (analog value) is used and fed to the decoder. The Euclidian distance is calculated.

Data input=[0 1 1 1 0 1 1 1 0 0 0 1 1]

Data output convolutional encoder= [1 1 -1 -1 1 -1 -1 1 1 -1 1 1 1 -1 -1 1 1 -1 -1 -1 1 1 -1 -1 1 -1 1 -1]

Data output channel (SNR=2dB)= [1.08 2.78 0.36 -1.48 0.33 -1.10 -0.93 1.55 1.80 0.61 1.55 0.61 0.14 -0.77 -1.09 0.77 0.85 -2.59 -0.69 0.72 0.84 1.56 -1.06 -1.52 0.59 0.11 1.05 -1.99]

Metric accumulated hard decoding table

State	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0	1	2	3	3	3	4	4	5	3	3	4	4	5
1	0	4	2	2	2	3	3	4	2	5	4	5	4	4
2	2	1	2	3	2	2	4	4	5	3	5	3		
3	0	2	1	1	2	3	2	2	4	4	4	5		

Surviving predecessor states table (hard decoding)

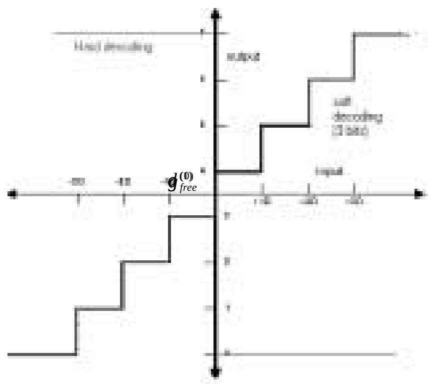
State	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	0	0	0	0	0	0	0	1	0	1	0	1	0	5
1		2	3	2	3	2	3	2	3	2	2	3	3	4
2		0	0	0	1	1	0	1	0	1	0	0	0	5
3		2	2	3	3	2	2	3	2	3	2	3	2	5

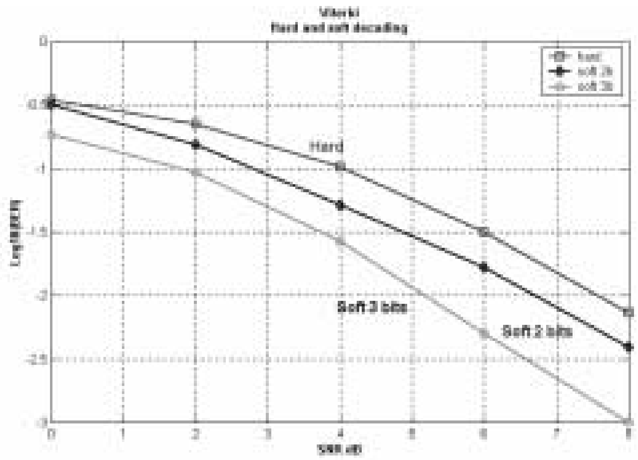
Selected states (hard decoding)

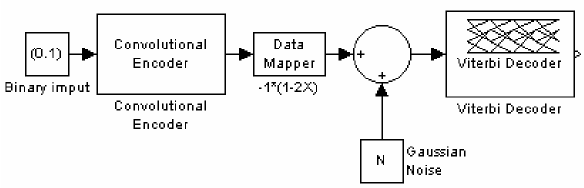
0	1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	4	4	2	3	4	4	2	1	1	3	1	2

Hard decoding

Decoding



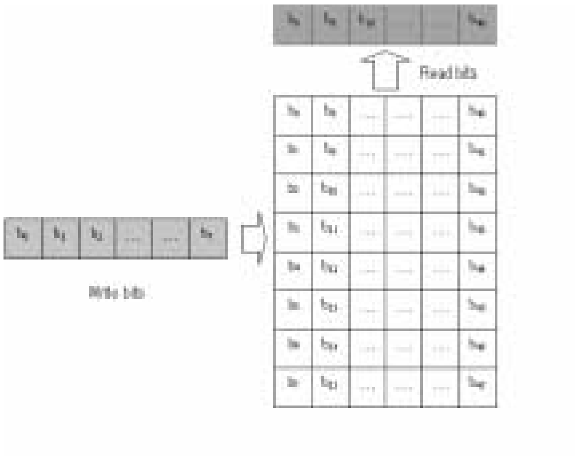


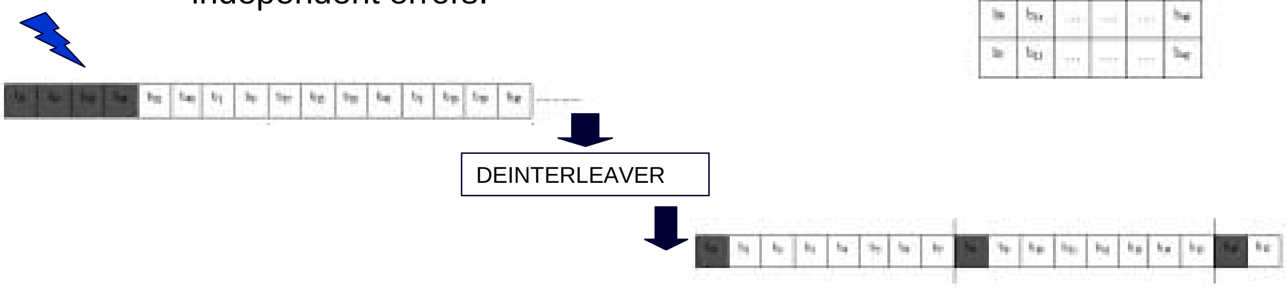


K	g_o	g_1	d_{free}
7	554(octal) 1011011(binary)	744(octal) 1111001(binary)	10

Interleaver

- Burst of errors
- Error correction capacity
- Interleaver
  - The bursty is transformed into a channel having independent errors.

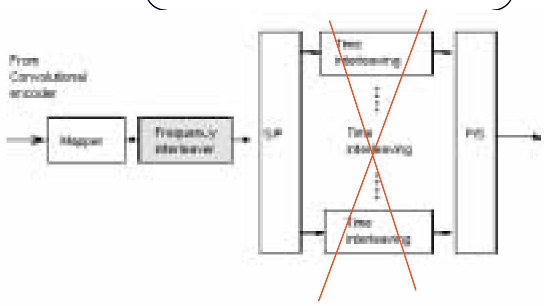




Interleaver – IEEE802.11a

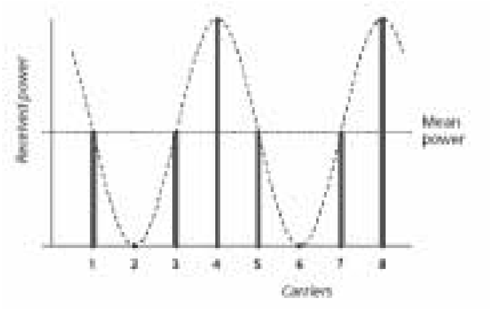
- Frequency interleaving
  - Depth: 1 OFDM symbol
  - Channel
    - Quasi-static.
    - Frequency selective fading
    - Time interleaving is not applied

BPSK → 48 bits
QPSK → 96 bits
16-QAM → 192 bits
64-QAM → 288 bits



Metric weighting

- Data conveyed by carriers having a high SNR are *a priori* more reliable than those conveyed by carriers having low SNR.
  - Extra *a priori* information is usually known as *channel-state information* (CSI).
- The Viterbi metrics for each bit should be weighted according to the SNR of the carrier by which it traveled. The bits from the nulled carriers are effectively flagged as having "no confidence".

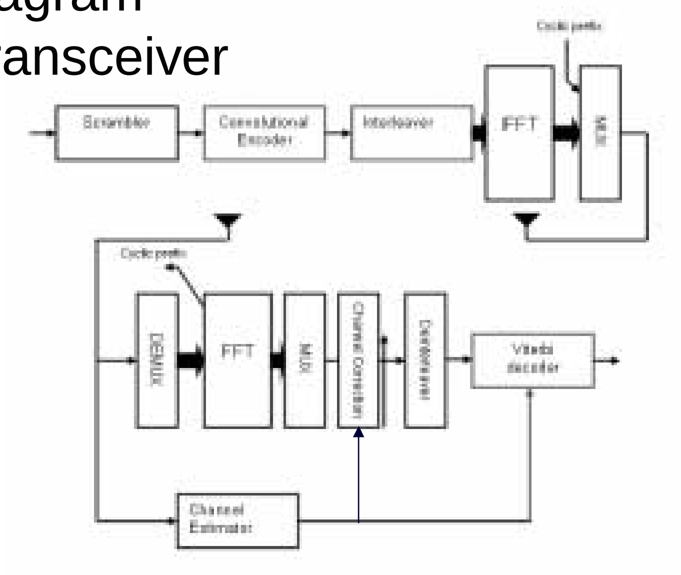


$$p_n = |H_k|^2 \left| \hat{b}_n - b_n \right|^2$$

Simulations

- Block Diagram
  OFDM transceiver

Simulation software from "OFDM Wireless LANs" book.

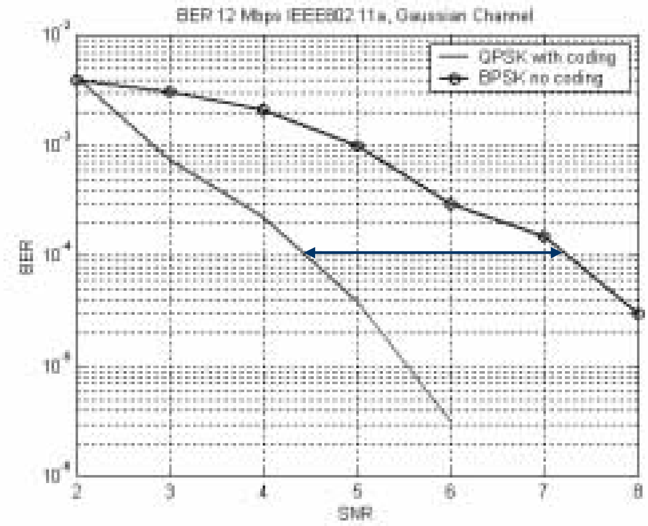


Simulations

- Coding

QPSK – code rate=1/2

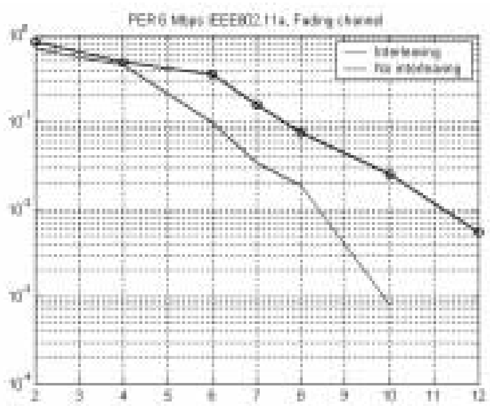
BPSK – No coding

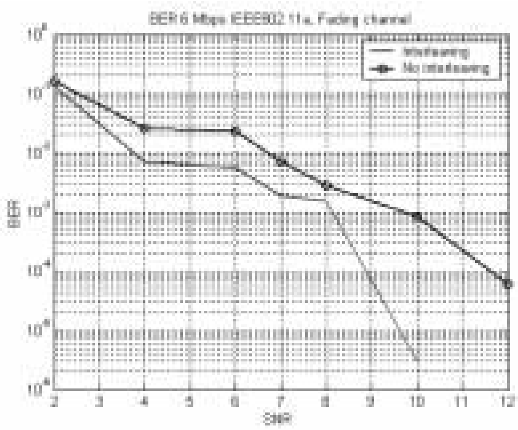


2.9 dB

Simulations

- Interleaver



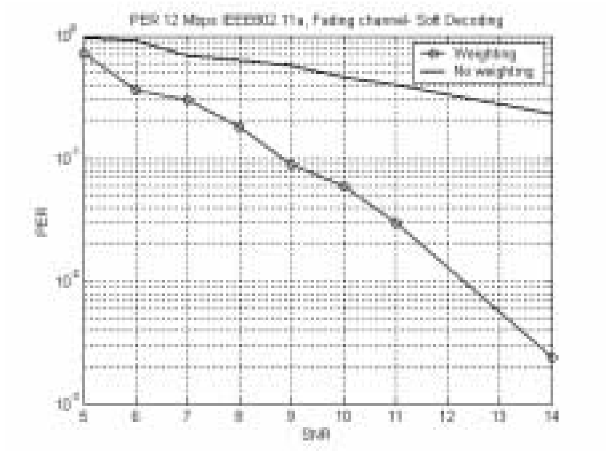


BPSK – code rate=1/2

Data Rate = 6 Mbps

Simulations

- Weighting



QPSK – code rate=1/2

12 Mbps

$$p_n = |H_k|^2 \left| \hat{b}_n - b_n \right|^2$$

Conclusions

- Coding and interleaving techniques was studied and their performance was evaluated in a WLAN (IEEE 802.11 a) environment.
- This work show the great importance of this techniques to improve the quality of service in a IEEE802.11 service.

References

- Heiskala J. and Terry J., OFDM Wireless LANs: A theoretical and Practical Guide, Sams Publishing, 2002.
- Glover I. and Grant P., Digital Communication, Prentice Hall, 2004.

Homework

- In IEEE802.11 only Frequency Interleaver is applied. Why?
- Justify