ICT course:

Mobile Wireless Communications

Lecturers:
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Course Schedule

- Lectures:

1. Introduction
2. Characteristics of mobile radio environment:
   - Propagation
   - Fading and mitigations
3. Cellular concept
4. Channel assignment (optional)
5. Modulation techniques
6. Multiple Access techniques
7. Coding for error detection and correction
8. Applications – Mobile network Generations:
   - GSM
   - 3G/LTE-4G
   - 5G and future of mobile networks (discussion)

- Exercises
- References:

[1]. Mischa Schwartz: Mobile Wireless Communication, CAMBRIDGE UNIVERSITY PRESS, 1st Edition (2005)

[2]. Wireless Communications: Principles and Practice (2nd Edition) by Theodore S. Rappaport

[3]. Widjaja, Indra, and Alberto Leon-Garcia. "Communication Networks Fundamental Concepts and Key Architectures." *Mc GrawHill: USA* (2004).

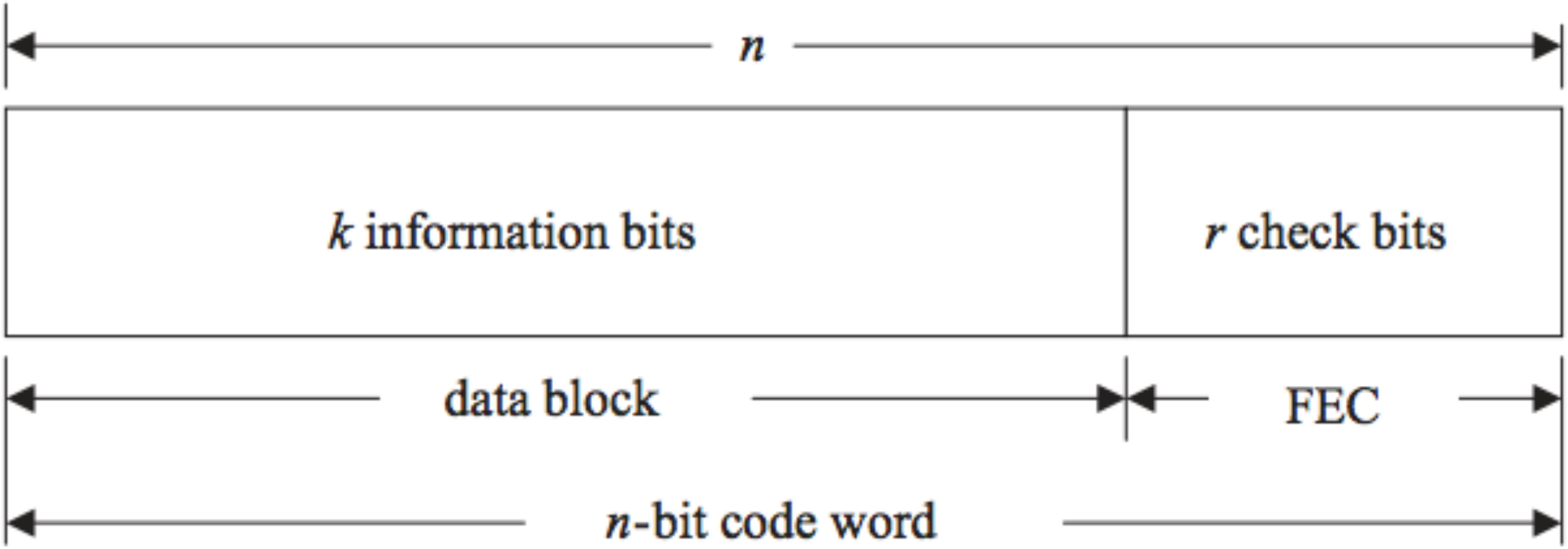
Lecture 6: Coding for error detection and correction

- Introduction
- Coding techniques in 2G and 3G:
  - Block coding
  - Convolutional coding

Introduction of coding

- By “coding” is meant the purposeful introduction of additional bits in a digital message stream to allow correction and/or detection of bits in the message stream that may have been received in error

Block coding



- (n,k) code
- Parity check bits

Block Coding

- Cyclic codes:
  - k-bit data: d $= (d_1, d_2, d_3, \ldots, d_\mathrm{k})$
  - Codeword: $c = (c_1, c_2, c_3, \ldots, c_k, c_{k+1}, \ldots, c_n)$
  - In systematic code:

$$c_1 = d_1, c_2 = d_2, \ldots, c_k = d_k$$
$$c_{k+1} = h_{11}d_1 \oplus h_{12}d_2 \oplus \ldots \oplus h_{1k}d_k$$
$$c_{k+2} = h_{21}d_1 \oplus h_{22}d_2 \oplus \ldots \oplus h_{2k}d_k$$
$$\cdots$$
$$c_n = h_{r1}d_1 \oplus h_{r2}d_2 \oplus \ldots \oplus h_{rk}d_k$$

- Hamming distance and Coding theory
- Error detection:
  - Vector codeword:

$$c = dG$$

where G is code-generator matrix,

$$G = [I_k P]$$

Where I_k is identity matrix,

$$P = \begin{bmatrix} h_{11} & h_{21} & \dots & h_{r1} \\ h_{12} & h_{22} & \dots & h_{r2} \\ \dots & \dots & \dots & \dots \\ h_{1k} & h_{2k} & \dots & h_{rk} \end{bmatrix}$$

- $c = dG = d[I_k P] = [d\ dP] = [d\ C_p]$
- How error is detected:
  - Receiving codeword: $r = d' * C'_p$
  - Separate d' and C'_p
  - If $d'P \oplus C'_p \neq 0$ → error
- Parity Check matrix:

$$H = [P^T I_{n-k}]$$

- Error correction:
  - Error vector: $e = (e_1, e_2, \dots, e_k)$
  - Tx: c
  - Rx: $r = c \oplus e$
  - Syndrome vector: $s = rH^T$
    - If s is non-zero: one or more error occur
    - If s is zero: not guarantee no error
  - Correctable cases:
    - To correct t errors, number of parity check bits, r, should be:

$$2^r \geq \sum_{i=0}^{t} \binom{n}{i}$$

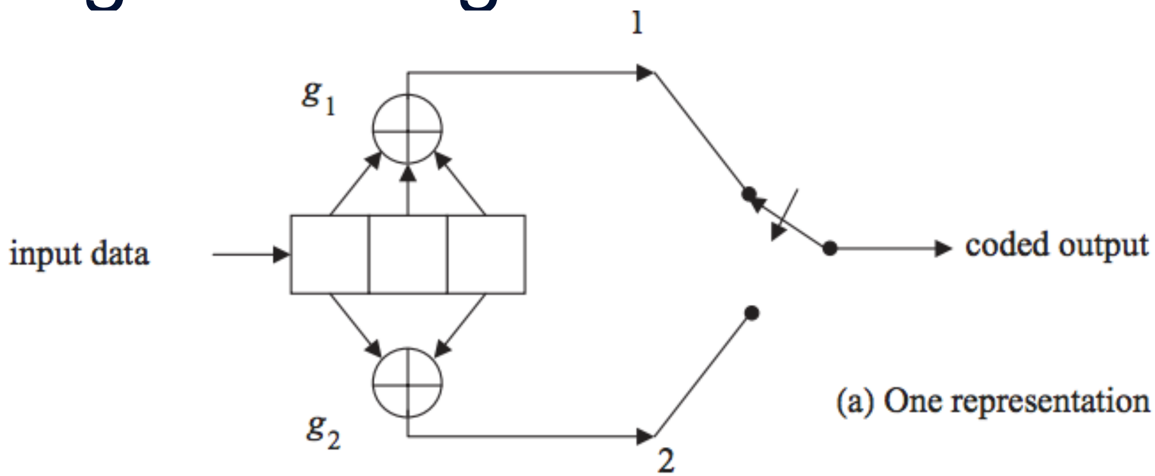
Block coding

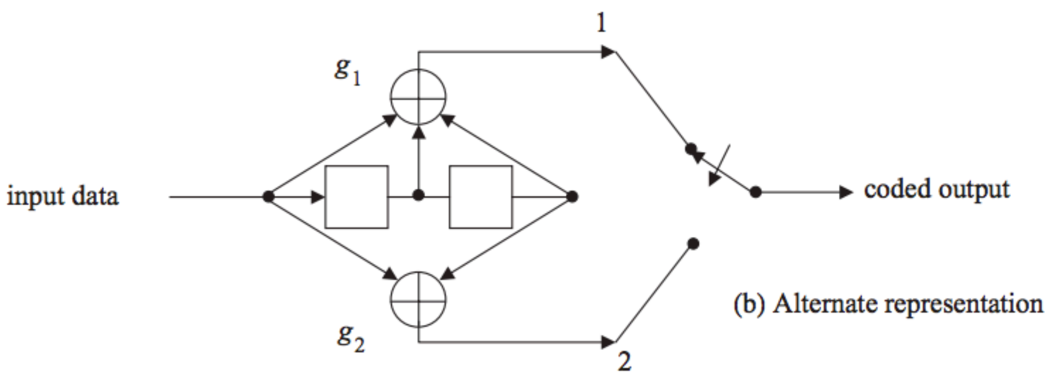
- Disadvantages:
  - Redundancy
    - Code efficiency
    - Increasing bandwidth

Convolutional coding

- A sliding sequence of data bits is operated on, modulo-2, to generate a coded stream of bits
- Recovering/decoding the sequence at the destination?

- K-stage shift register:



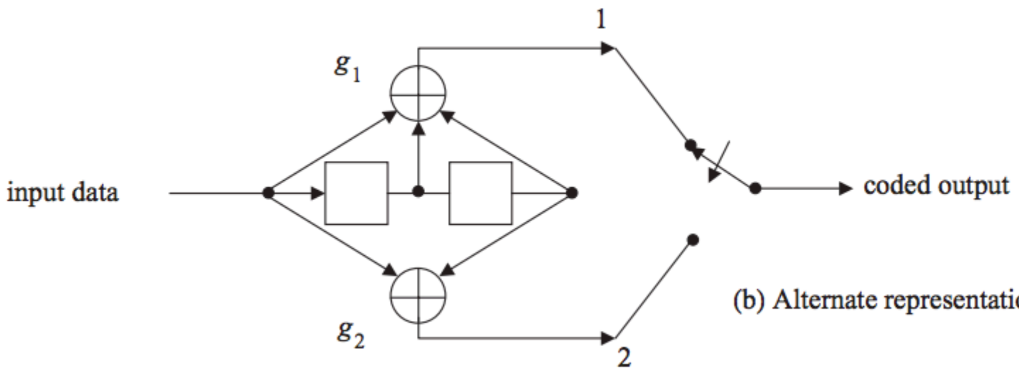


K-1 delay stages representing the encoder

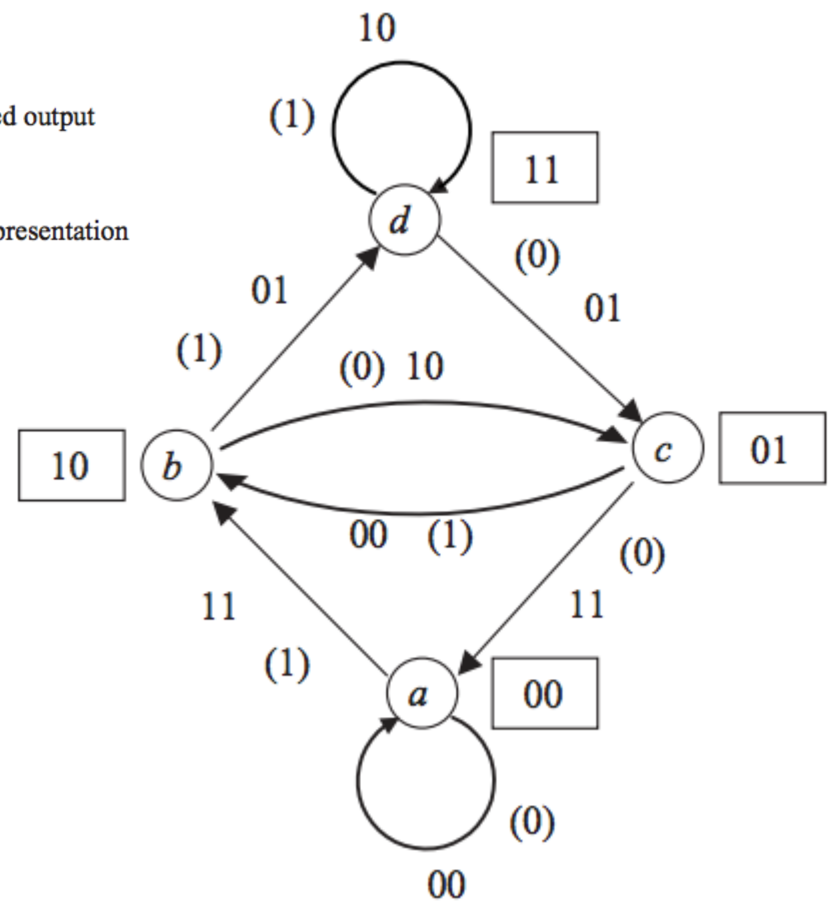
  - Example: K=3, rate-1/2 convolutional encoder
  - 1 bit input → 2 bits output
  - Function generators: $g_1 = [111], g_2 = [101]$

- 3 ways of representation:
  - State diagram:
  - A Trellis
  - Ever-expanding tree

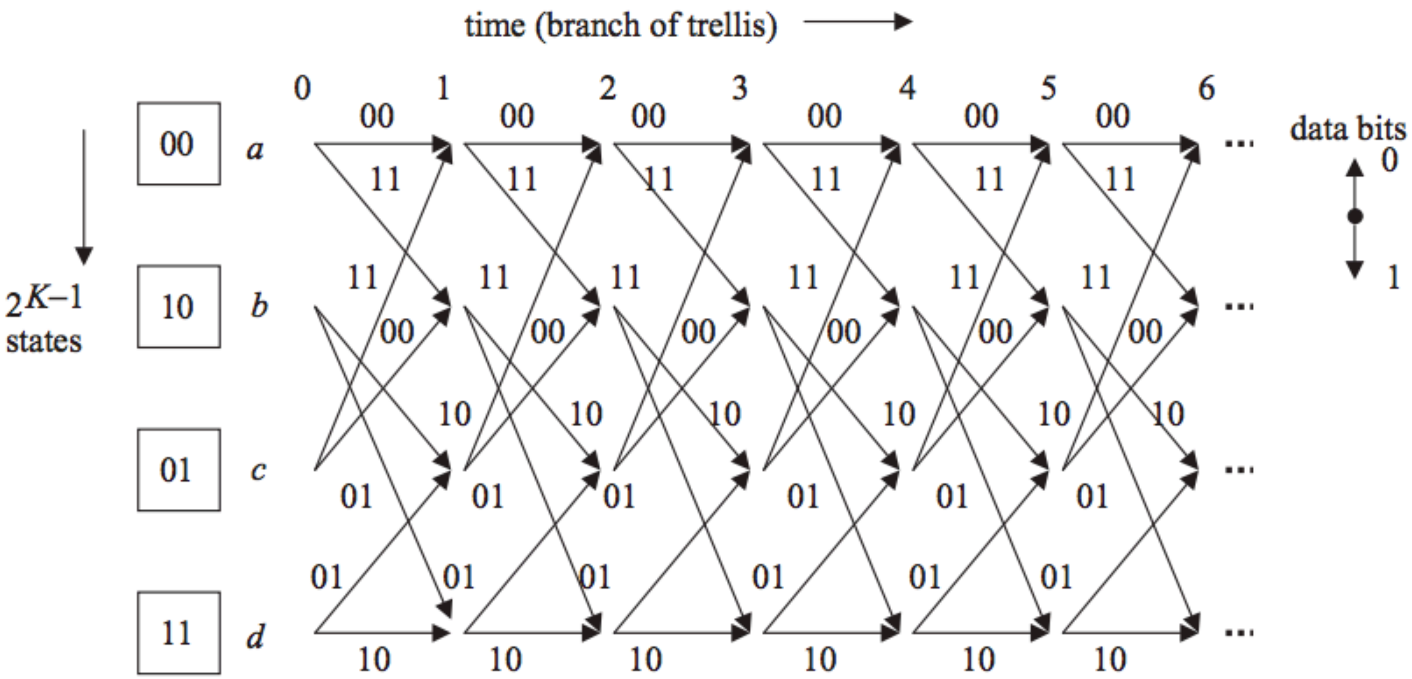
- State diagram



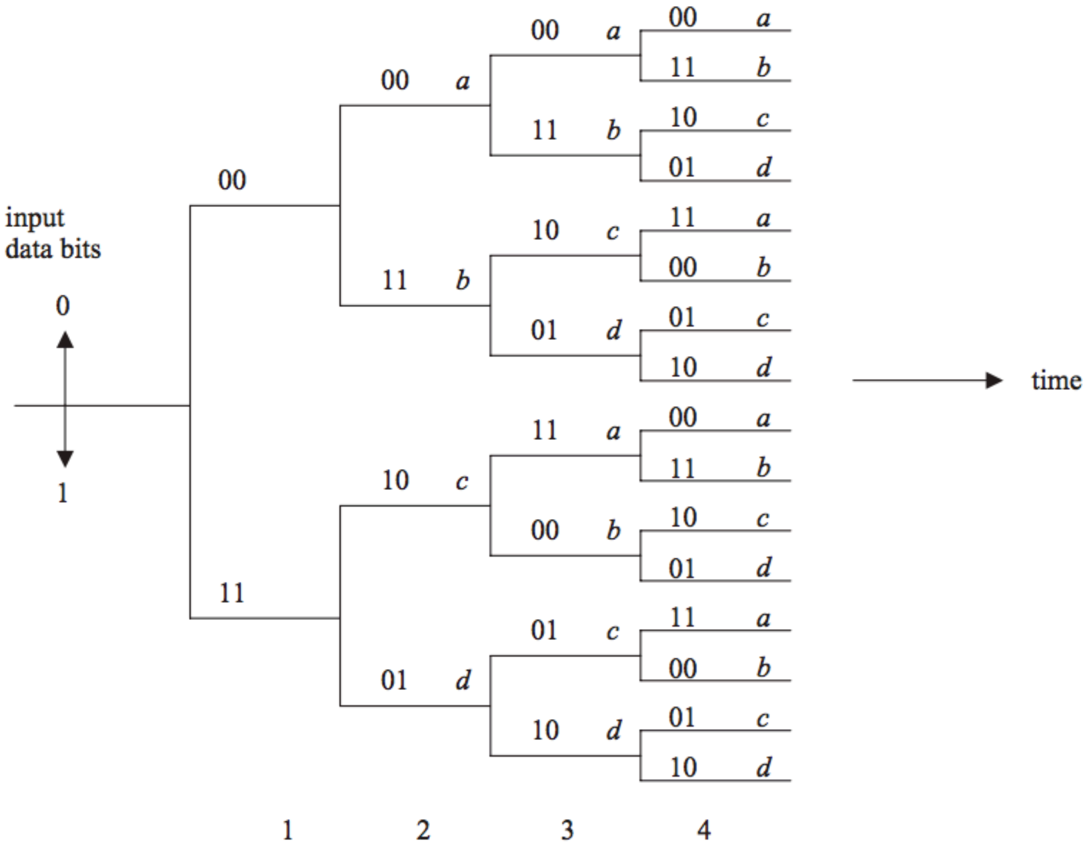
(b) Alternate representation



- Trellis representation:



- Ever-expanding tree



Decoding

- Input: L bits
- Received sequence: 2^L possible paths
- Maximum-likelihood decoder: the most probable of these paths is chosen
  - Viterbi algorithm

Exercise 6.1

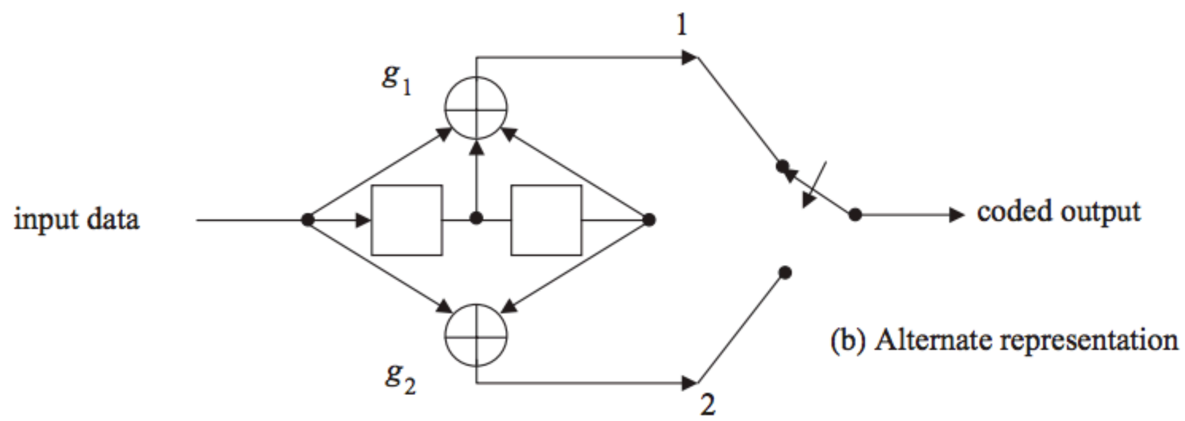
- (7,4) block code has the generator matrix G:

$$\mathbf{G} = \begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix}$$

(a) Find the $\boldsymbol{P}$ matrix of this code
(b) Find the parity-check matrix $\boldsymbol{H}$ and its transpose $\boldsymbol{H}^T$

Exercise 6.2

- Convolutional coder K=3, rate= 1/2:



(a) Initialize the encoder so that 0s only appear at its output. Trace the output bit sequence for the following input bit sequence after initialization

11001011

(b) Determine the state diagram representing this encoder. Trace through the various states through which this encoder moves for the input sequence of (a), starting at the 00 state. Show the output sequence obtained agrees with that found in (a).