EEEN 464 – DIGITAL COMMUNICATION

CHANNEL CODING - STUDY GUIDE/REVISION

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1. INTRODUCTION TO CHANNEL CODING

1. **What is Channel Coding?**
   Channel coding (or error-correcting coding) adds redundancy to data before transmission to detect and correct errors caused by noise in communication channels (e.g., Wi-Fi, satellite links).

2. **Why is it Important?**
   Without channel coding, data corruption would make modern communication (texts, videos, internet) unreliable. It ensures accuracy in noisy environments.

2. KEY CONCEPTS

1. **Error Detection vs. Correction**
   - **Detection:** Identifies errors (e.g., parity checks).
   - **Correction:** Fixes errors without retransmission (e.g., Hamming codes).

2. **Redundancy:** Extra bits added to the original data to enable error handling.

3. **Coding Rate (R*R*):**
   Ratio of useful data bits to total transmitted bits:

$$\boldsymbol{R = \frac{Data\ bits}{Data\ bits + Redundant\ bits}}$$

Example: Coding rate $\frac{1}{4}$ means 25% of transmitted bits are redundant.

4. **Hamming Distance (d_{min}):**
   Minimum number of bit flips between any two valid codewords. Determines error-handling capability:
   - Detect up to $d_{min} - 1$ errors.
   - Correct up to $\frac{d_{min}-1}{2}$ errors.

3. TYPES OF CHANNEL CODES

1. **LINEAR BLOCK CODES**
   - **How They Work:** Data is split into fixed-length blocks. Redundant bits are appended.

- **Examples:**
  - **Parity Check:** Adds 1 bit to make total 1s even (detects single errors).
  - **Hamming Codes:** Corrects single-bit errors (e.g., Hamming(7,4): 4 data + 3 redundancy bits).
- **Encoding:** Multiply data vector **d** by generator matrix **G**:

$$C = \mathbf{d} \cdot \mathbf{G}$$

2. CONVOLUTIONAL CODES

- **How They Work:** Encodes continuous data streams using shift registers. Output depends on current + past input bits.
- **Key Terms:**
  - **Constraint Length (KK):** Number of past bits affecting output.
  - **Trellis Diagram:** Maps state transitions for encoding/decoding.
- **Decoding:** Viterbi algorithm finds the most likely transmitted sequence.

3. MODERN CODES

- **Turbo Codes:** Parallel convolutional codes with iterative decoding (near-Shannon limit performance).
- **LDPC Codes:** Sparse parity-check matrices decoded with belief propagation (used in 5G, Wi-Fi 6).
- **Polar Codes:** Provably capacity-achieving (used in 5G control channels).

4. ENCODING & DECODING

- **Encoding Process:**
  `Data → Add Redundancy → Transmit Codeword`
- **Decoding Process:**
  `Received Word → Detect/Correct Errors → Recover Data`
  - **Syndrome Decoding (Block Codes):**
    Compute syndrome $= \mathbf{r} \cdot \mathbf{H}^T$ to identify errors ($\mathbf{H}$ = parity-check matrix).

5. PERFORMANCE METRICS

- **Bit Error Rate (BER):** Fraction of bits received incorrectly.
- **Frame Error Rate (FER):** Fraction of corrupted data blocks.
- **Coding Gain:** Reduction in signal-to-noise ratio (SNR) required to achieve the same BER as uncoded transmission.
- **Trade-offs:** Higher redundancy (lower RR) improves reliability but reduces data throughput.

6. EXAMPLES & PRACTICE PROBLEMS

- **Parity Check:**
  Data: 1100 → Even parity codeword: 11000 (appended 0). If received as 11010, error detected.
- **Hamming (7,4) Code:**
  - Encode 1011:
    Generator matrix **G** → Codeword 1011010.
  - Correct single error in received word 1010010 using syndrome.
- **Practice:**
  1. Calculate the coding rate for a (15, 11) Hamming code.
     Solution: R=11/15R=11/15.
  2. A code has d_{min} =5. How many errors can it detect and correct?
     Solution: Detect 4, correct 2.
  3. What is the difference between line coding and channel coding?

     Line coding converts digital data (bits) into **a suitable digital signal for transmission over a physical medium**, while channel coding **adds redundancy to the data to enable error detection and correction at the receiver**.