Module 3

Physical Layer

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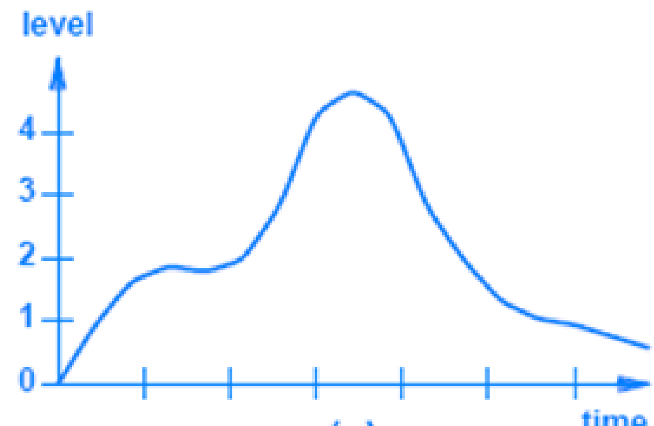
Module 1 Topics

- 3.1 Signal Levels: Baud rate and Bit rate
- 3.2 Channel Encoding Standards
  - RS-232 and Manchester Encoding
  - Delay during transmission
- 3.3 Transmission Order of Bits and Bytes
- 3.4 Modulation Techniques
  - Amplitude, Frequency and Phase modulation
- 3.5 Multiplexing Techniques
  - TDMA, FDMA, Statistical Multiplexing and CDMA

3.1 Analog and Digital Signals

- Data communications deals with two types of information:
  - analog
  - digital
- An analog signal is characterized by a continuous mathematical function
  - when the input changes from one value to the next, it does so by moving through all possible intermediate values
- A digital signal has a fixed set of valid levels
  - each change consists of an instantaneous move from one valid level to another



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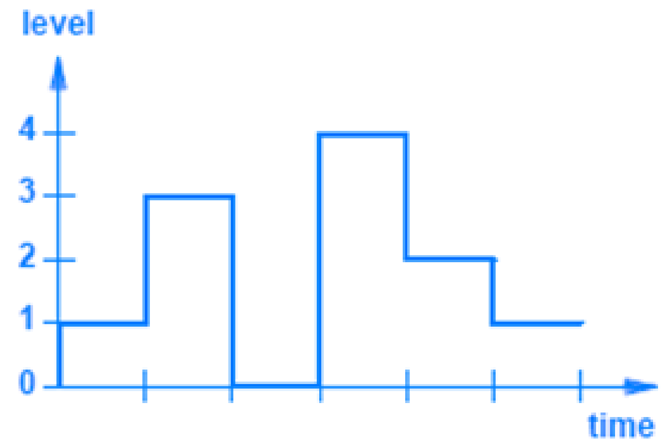
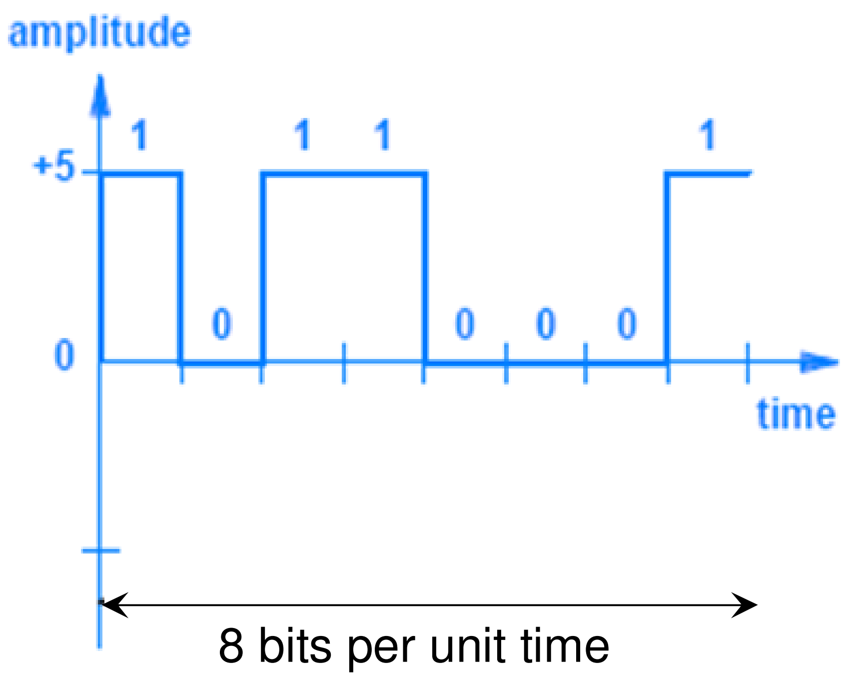
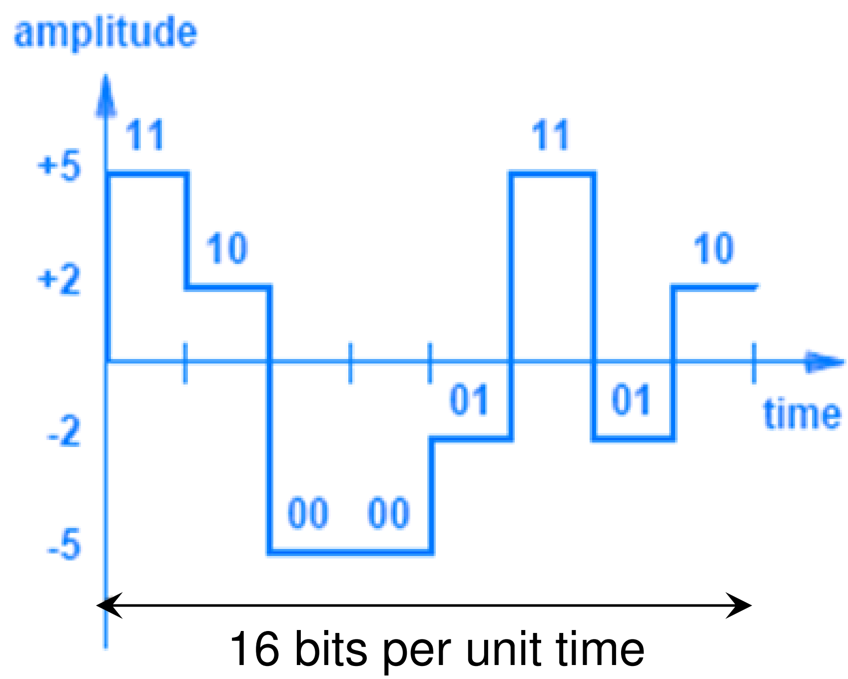


Digital Signals

- The voltage levels are used to differentiate the values sent



Digital signal using 2-voltage levels



Digital signal using 4-voltage levels

Number of Signal Levels

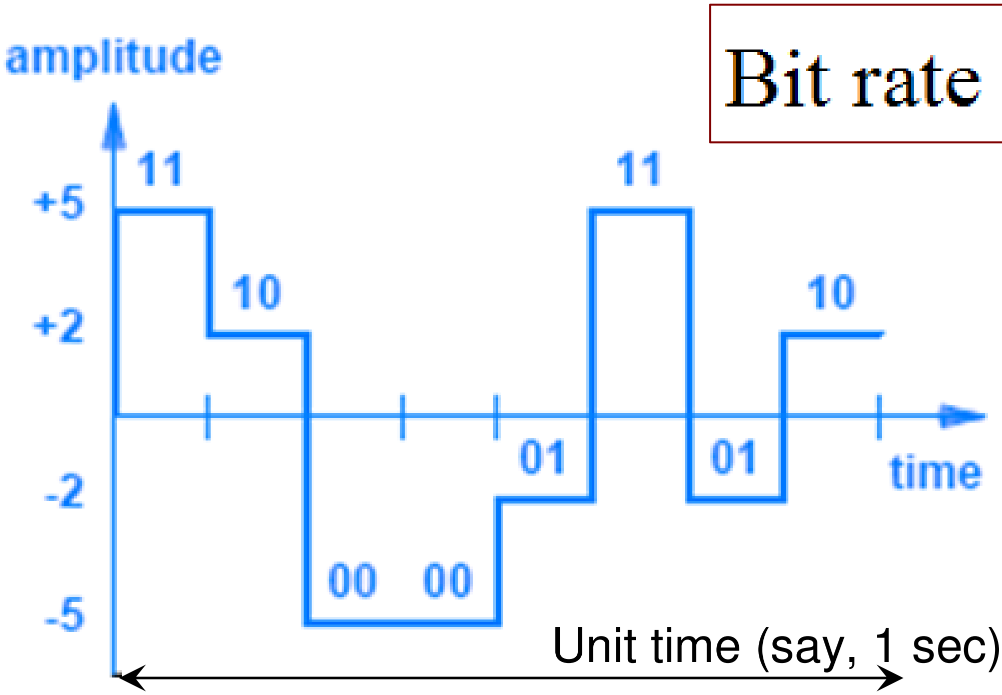
- Increasing the number of signal levels and/or decreasing the duration for which the signal should be held at a particular level would increase the number of bits sent per unit time (referred to as bit rate).

- However, due to signal deterioration during transmission, it might become difficult for the receiver to distinguish between two signal levels (especially, if we use a lot of signal levels).
  - This is the reason we cannot have communication channels with infinite bandwidth.
- Hence, we can use only a limited number of signal levels as well as hold the signal at a particular level for a minimum duration.

Baud rate vs. Bit Rate

- Baud rate:
  - 1 / duration for which a signal needs to be maintained at a particular level
  - Also, quantified as the number of times the signal change its levels in unit time
- Bit rate:
  - The number of bits that can be sent in unit time.

$$\text{Bit rate} = \text{Baud rate} * \lfloor \log_2^{levels} \rfloor$$



Baud rate = 8
 # Levels = 4

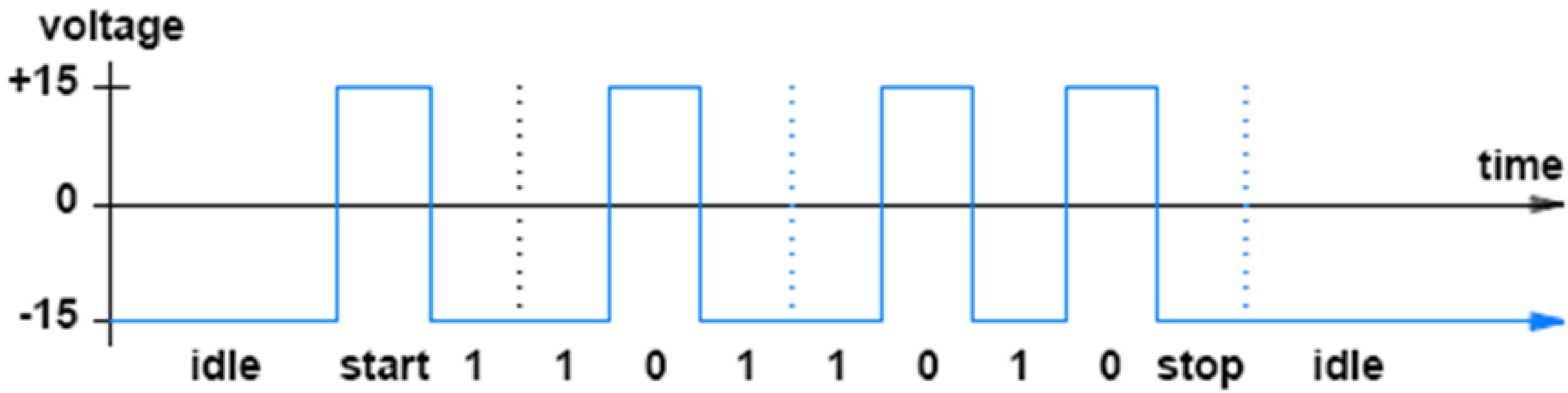
Bit rate = 8 * log2(4)
= 8 * 2
= 16 bits/sec

3.2 Asynchronous Transmission

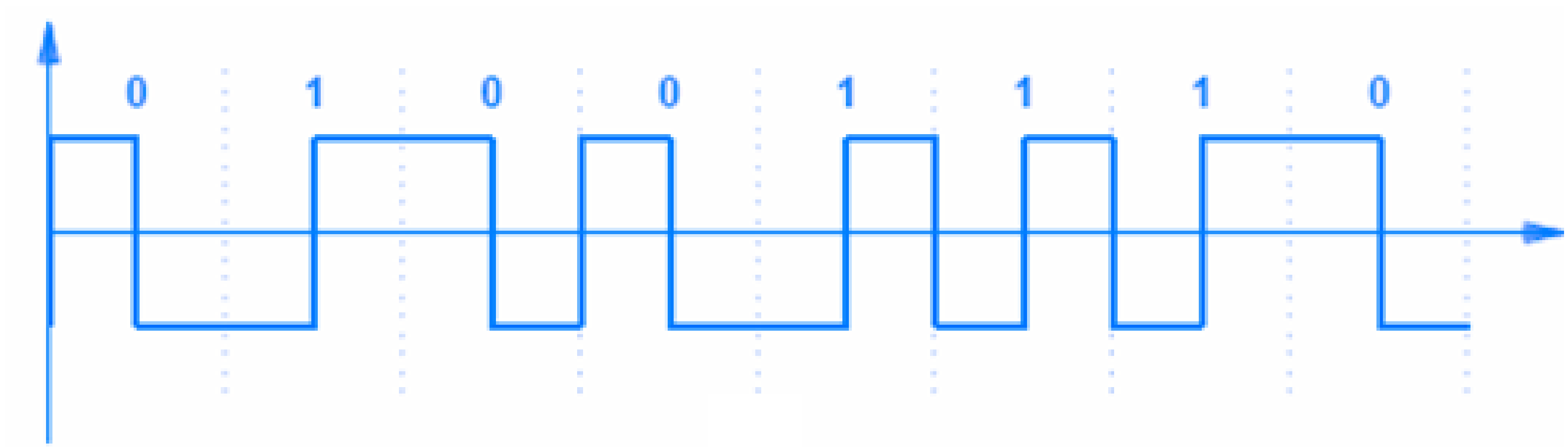
- Asynchronous transmission is the typical form of transmission wherein the receiver is not synchronized with the sender (i.e., the receiver does not know how long the medium will be idle before it receives data).
- The sender has to include some *extra* bits (called preamble) to indicate the beginning and end of the transmission.

- Two commonly used encoding standards
  - RS-232 Standard (Ex. the communication between the CPU and a keyboard)
    - Uses the actual voltage levels as the basis
  - Manchester Standard (Ex. Ethernet)
    - Uses the transition from voltage level to another as the basis

RS-232 Standard



Manchester Standard



uses a 64-bit preamble (alternating 0s and 1s)

Delays

- In network communication, the delay incurred to send data from a source to destination is a combination of the following components:
  - Transmission Delay
  - Propagation Delay
  - Queuing Delay (including the Switching Delay)
- Transmission Delay – the delay incurred to insert the bits of a packet onto a channel of a given bandwidth

$$\text{Transmission Delay} = \frac{\text{Packet Size (bits)}}{\text{Channel Bandwidth (bits/sec)}}$$

- Propagation Delay – the delay incurred for a packet to propagate (for the signal to move) on a channel of a particular length

$$\text{Propagation Delay} = \frac{\text{Channel Length (m)}}{\text{Speed of the Signal (m/s)}}$$

Question: RS-232 Std. & Delay

- Determine the transmission delay, propagation delay and the total delay incurred to transmit data of size 2000 characters using the RS-232 standard. Assume the channel bandwidth is 40000 bits/sec and length is $2*10^6$m. Assume the speed of the signal on the channel is 60% of the speed of light.

- <u>Solution:</u>
  - To transmit a character according to the RS-232 standard, 10 bits (8 data bits plus 1 start and 1 stop bits) are needed. Hence, to transmit 2000 characters, we need 2000 * 10 = 20,000 bits
  - Transmission Delay = Data Size/ Channel Bandwidth

    = (20,000 bits)/ (40,000 bits/sec) = 0.50 sec
  - Propagation Delay = Channel length/ speed of the signal on the channel

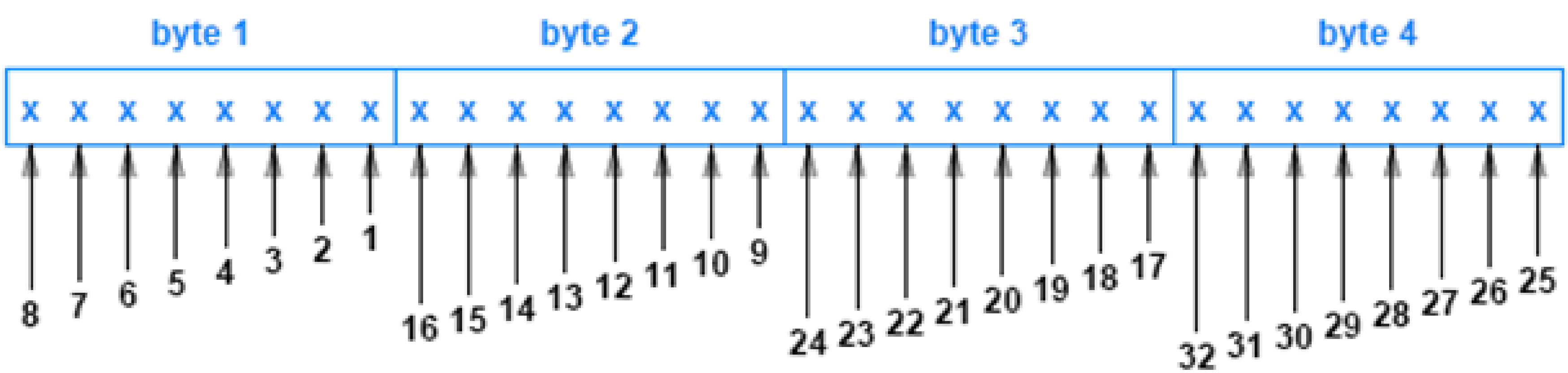
    = $(2 * 10^6$ m$)/ (0.6 * 3 * 10^8$ m/s$) = 0.011$ sec
  - Total Delay = Transmission Delay + Propagation Delay = 0.511 sec

Transmission Order: Bits and Bytes

- In serial mode, when sending bits, which bit should be sent across the medium first?
- Consider an integer: Should a sender transmit
  - the Most Significant Bit (MSB)
  - or the Least Significant Bit (LSB) first?
- We use the term little-endian to describe a system that sends the LSB first
- We use the term big-endian to describe a system that sends the MSB first
- Either form can be used, but the sender and receiver must agree

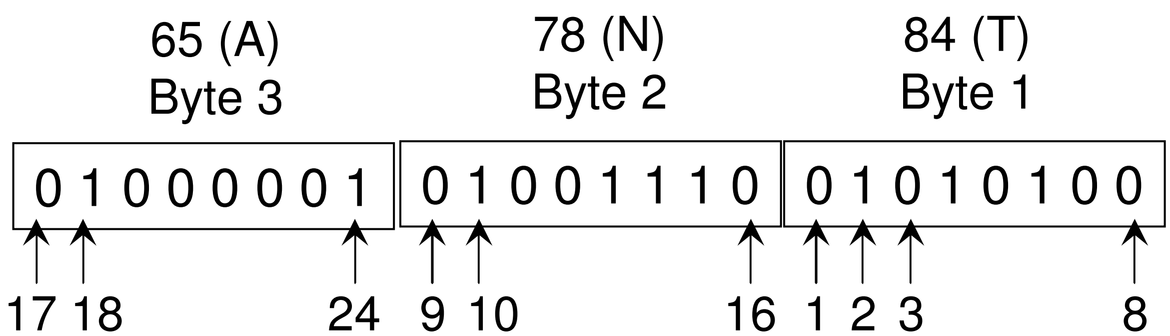
Transmission Order: Bits and Bytes

- It is possible to choose a byte order and a bit order independently
  - For example, Ethernet technology specifies that data is sent byte big-endian and bit little-endian, as shown below for a 32-bit data

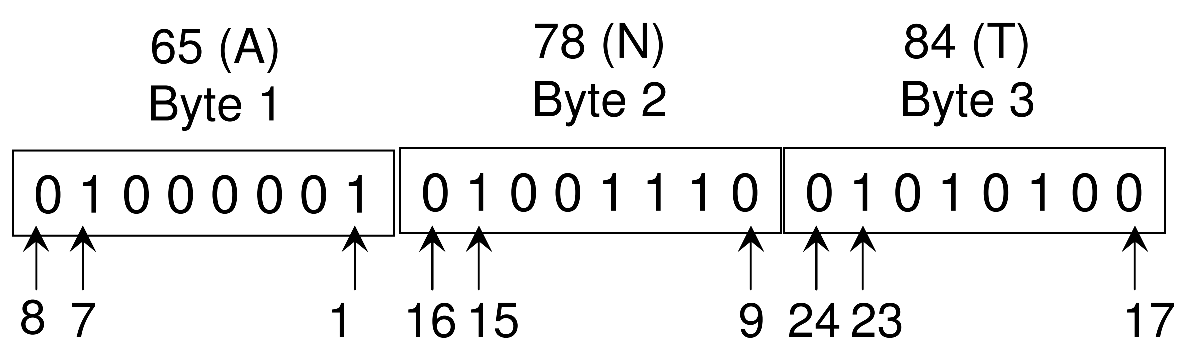


Sample Question: Transmission Order of Bits and Bytes

- Consider the word 'ANT' with the ASCII values of 'A', 'N' and 'T' being 65, 78 and 84 respectively. How would this word be transmitted if the transmission order is:
  - Byte little-endian and bit big-endian?

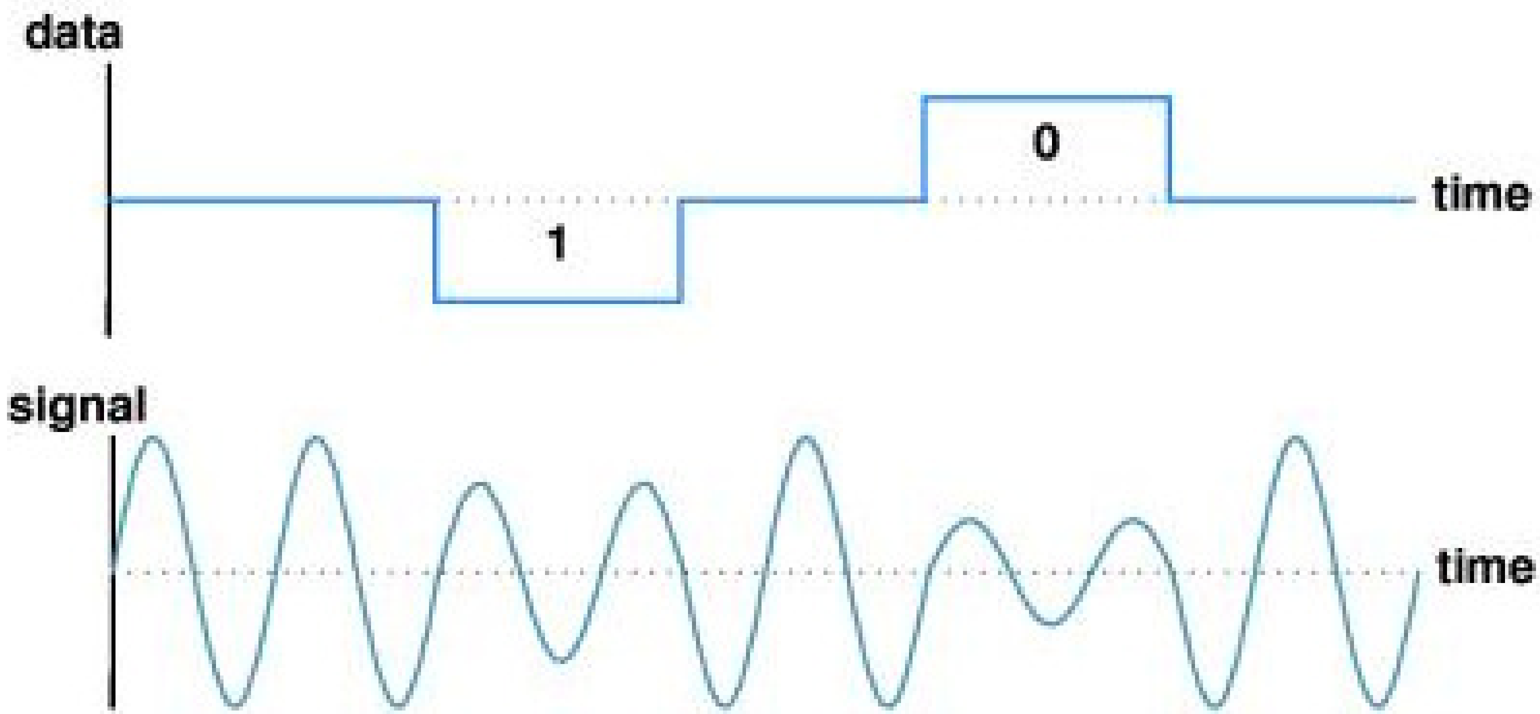


  - Byte big-endian and bit little-endian?



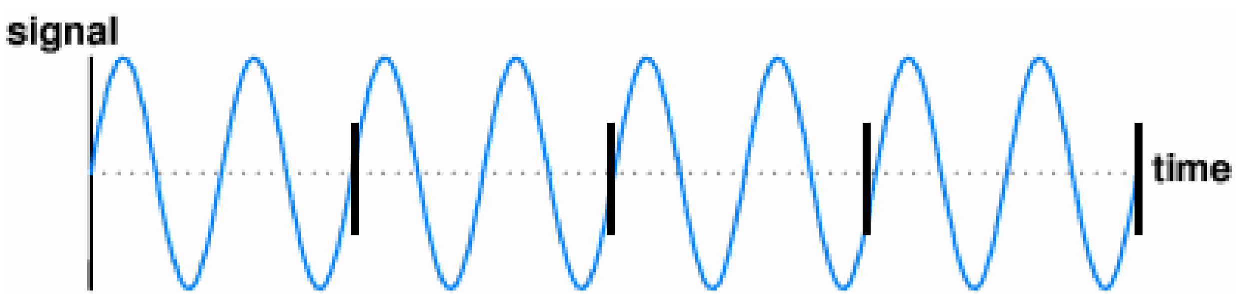
3.4 Modulation Techniques

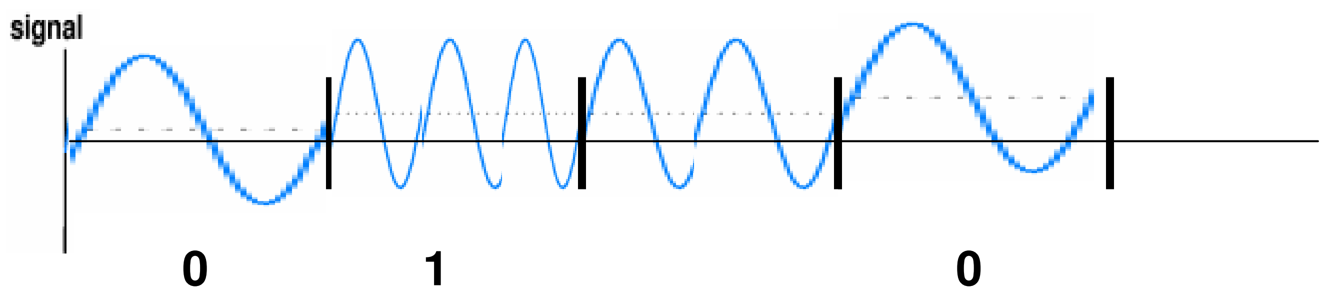
- **Amplitude Modulation**
  - The amplitude of the carrier (a regular sine wave) is modulated to encode data
  - The strength of the carrier signal in (b) is reduced to 2/3rd of its Amplitude to encode a 1 bit and to 1/3rd of the Amplitude to encode 0 bit



3.4 Modulation Techniques

- **<u>Frequency Modulation</u>**
  The two binary digits are represented by two different frequencies that are offset from the carrier frequency by equal but opposite amount.
- Example:
  - Assume the bits are encoded for every two cycles (i.e., two cycles per unit time). Then, to encode data, we could change the frequency to one cycle (for bit 0) and three cycles (for bit 1)per unit time respectively.
  - Assume the sequence of bits to be transmitted is: 0 1 _ 0, where _ indicates the channel is idle.





3.5 Multiplexing Techniques

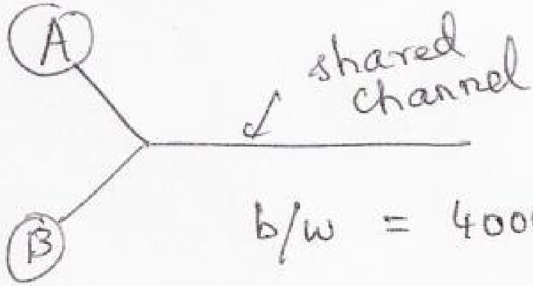
- Broadband: Multiple signals simultaneously propagate through the channel at non-overlapping frequencies: enabling support for a larger bandwidth (bits/sec)
  - Example: Frequency division multiplexing (FDM)
    - Multiple stations can simultaneously transmit on a channel, each different non-overlapping frequency.

- Baseband: Only one signal can propagate through the channel at any time: characteristic of lower bandwidth (like Internet through a dialup connection)
  - Example: Time Division Multiplexing (TDM)
    - All channels can transmit at the same frequency; but in different time slots (round-robin).

Sample Question: TDM

- Assume two computers using time division multiplexing to take turns in sending 512 byte packets over a shared channel that operates at 40000 bits/second. If the hardware takes 10 msec after one computer stops sending before the other can begin, how long it will take for each of the two computers to send 1 MB of a file?

TDM Solution



$$b/w = 40000 \frac{\text{bits}}{\text{second}}$$

Packet size = 512 bytes.

$$\text{Transmission delay per packet} = \frac{\text{packet size}}{b/w} = \frac{512 \text{ bytes}}{40000 \frac{\text{bits}}{\text{sec}}}$$

$$= \frac{512 \times 8}{40000} = \underline{\underline{0.1024 \text{ sec}}}$$

Hardware switching delay = 10 msec $= \underline{\underline{0.01 \text{ sec}}}$

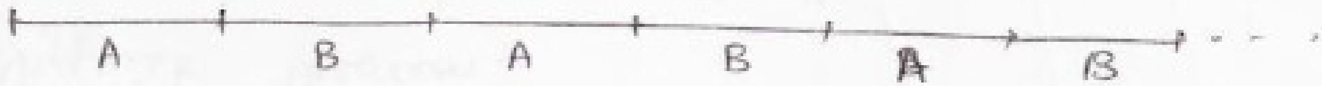
Transfer ~~Total~~ delay per packet per node = Transmission delay per packet + Hardware switching delay

$$= 0.1024 + 0.01$$

$$= \underline{0.1124 \text{ sec}}$$

TDM Solution (continued…)

Timeline



Node A spends 0.1124 sec in transmitting a packet and another 0.1124 sec in waiting for the next turn.

Hence, total delay per packet per node

= Transfer delay per packet + waiting time for another turn

= 0.1124 + 0.1124 = 0.2248 sec

No. of packets to be sent per node $= \frac{\text{File size}}{\text{Packet size}}$

$= \frac{1024 \times 1024 \text{ bytes}}{512 \text{ bytes/packet}}$

= 2048 packets

∴ Delay to transfer the whole file per node

= 2048 × 0.2248 = 460 sec

Code Division Multiplexing (CDM)

- CDM encodes the data transmitted by a sender with a unique code (called the chip sequence) and is decoded at the receiver using the same code.
- CDM facilitates more than one sender (each with a unique chip sequence) to transmit at the same time.

- At any point in time, each sender has a value to transmit, V_i
  - The senders each multiply C_i x V_i and transmit the results
- The senders transmit at the same time
  - and the values are added together
- To extract value V_i, a receiver multiplies the sum by C_i

CDM Example - Question

- Sample Question: Use Code Division Multiplexing to transmit the data values 0 1 1 0 and 1 0 1 0 from two senders S1 and S2 respectively. The 2-bit Chip Sequence of S1 and S2 are 0 1 and 1 1 respectively.
  - Show the resulting signal values when the two above two data signals are transmitted simultaneously
  - Show how the receiver for the data signals sent by S1 and S2 are able to decode the data?

CDM Example - Solution

- Let the Senders be represented as S1 and S2.
- Data D1 = [0 1 1 0] and D2 = [1 0 1 0]
- Chip Sequence C1 = [0 1] and C2 = [1 1]
- In all our computations, we will replace '0' with '-1' and then revert back to 0 at the end of the computation.
- Accordingly, D1 = [-1 1 1 -1]; D2 = [1 -1 1 -1]; C1 = [-1 1]; C2 = [1 1]

- <u>Initial Step:</u> To check if the chip sequences are orthogonal
- C1*C2 = [-1 1] * [1 1] = (-1)(1) + (1)(1) = -1 + 1 = 0
- Since the product is 0, we say C1 and C2 are orthogonal.
- <u>Encoding at S1:</u> The signal transmitted by the sender S1 is
- $S1 = C1^T * D1$

$$\begin{bmatrix} -1 \\ 1 \end{bmatrix}_{2x1} * [-1\ \ 1\ \ 1\ \ -1]_{1x4} = \begin{bmatrix} 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & -1 \end{bmatrix}_{2x4}$$

CDM Example – Solution (contd..)

- Encoding at S2: The signal transmitted by the sender S2 is
- S2 = $C2^T$ * D2

$$\begin{bmatrix} 1 \\ 1 \end{bmatrix}_{2x1} * [1\ \ -1\ \ 1\ \ -1]_{1x4} = \begin{bmatrix} 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 \end{bmatrix}_{2x4}$$

- Composite Signal Received at each Destination, S = S1 + S2

$$S = \begin{bmatrix} 1 & -1 & -1 & 1 \\ -1 & 1 & 1 & -1 \end{bmatrix}_{2x4} + \begin{bmatrix} 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 \end{bmatrix} = \begin{bmatrix} 2 & -2 & 0 & 0 \\ 0 & 0 & 2 & -2 \end{bmatrix}_{2x4}$$

- Retrieving the Data at the Receiver for S1: = C1 * S

$$= [-1\ \ 1]_{1x2} * \begin{bmatrix} 2 & -2 & 0 & 0 \\ 0 & 0 & 2 & -2 \end{bmatrix}_{2x4} = [-2\ \ 2\ \ 2\ \ -2]_{1x4}$$

Dividing by 2, the data received from S1 = [-1 1 1 -1] ➔ [0 1 1 0]

CDM Example – Solution (contd..)

- Retrieving the Data at the Receiver for S2: = C2 * S

$$= [1 \quad 1]_{1x2} \quad * \quad \begin{bmatrix} 2 & -2 & 0 & 0 \\ 0 & 0 & 2 & -2 \end{bmatrix}_{2x4} \quad = \quad [2 \quad -2 \quad 2 \quad -2]_{1x4}$$

Dividing by 2, the data received from S1 = [1 -1 1 -1] ➔ [1 0 1 0]