Computer Network Design

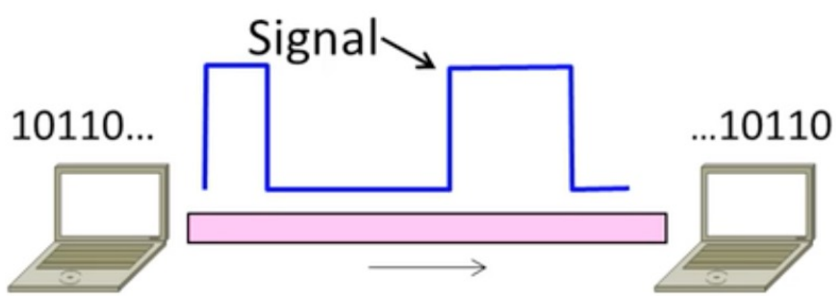
Yalda Edalat – Spring 23

Physical Layer

Modulation

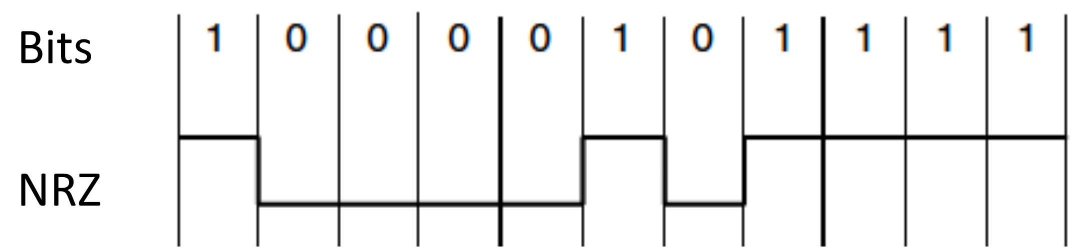
- Wires and wireless channels carry analog signals
- We need to send digital data

- The process of converting between bits and signals that represent them is called **digital modulation**



NRZ (Non-Return-to-Zero)

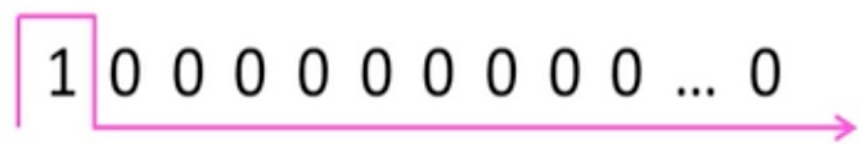
- Most straightforward form of digital modulation
- Uses a positive voltage to represent a 1 and a negative voltage to represent a 0



➢Engineers consideration: clock recovery

Clock Recovery

- A long run of 0s or 1s leaves the signal unchanged
- It is hard to tell the bits apart

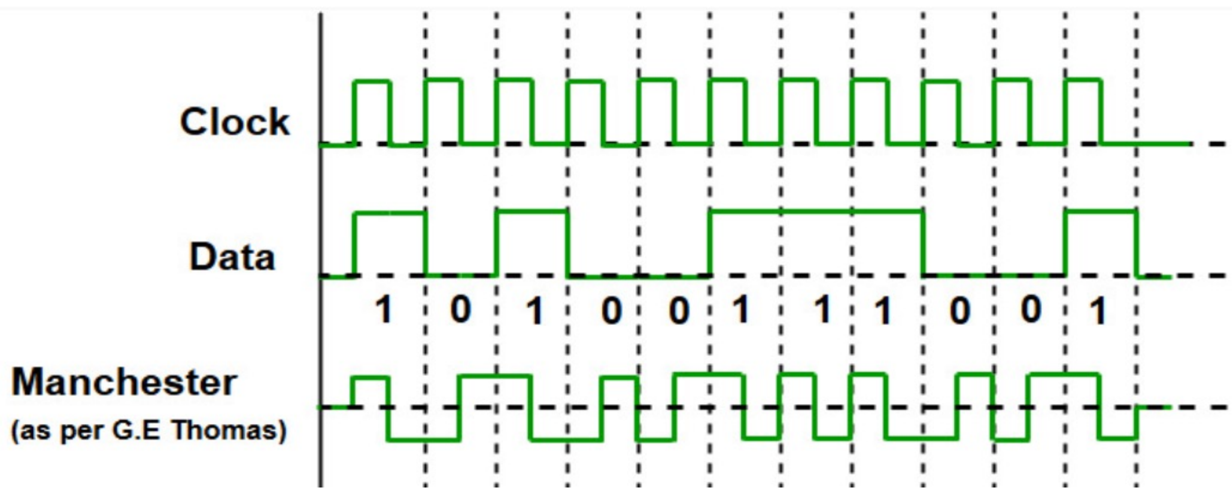


- Accurate clocks would help with this problem
- BUT clock is expensive!

➢ Several possible designs, e.g.: Manchester encoding

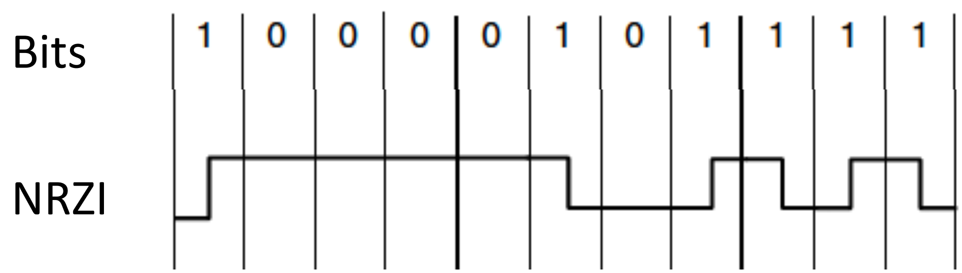
Manchester Encoding

- Mix clock with signal with the data signal by XORing them
- When it is XORed with the 0 level it makes a low-to-high transition
- When it is XORed with the 1 level it makes a high-to-low transition
- Used for classic Ethernet



NRZI (Non-Return-to-Zero Inverted)

- Coding a 1 as a transition and a 0 as no transition, or vice versa
- USB (Universal Serial Bus) standard uses NRZI
- Long runs of 1s do not cause a problem



4B/5B

- Every 4 bits is mapped into a 5-bit pattern
- Patterns do not have more than three consecutive 0s

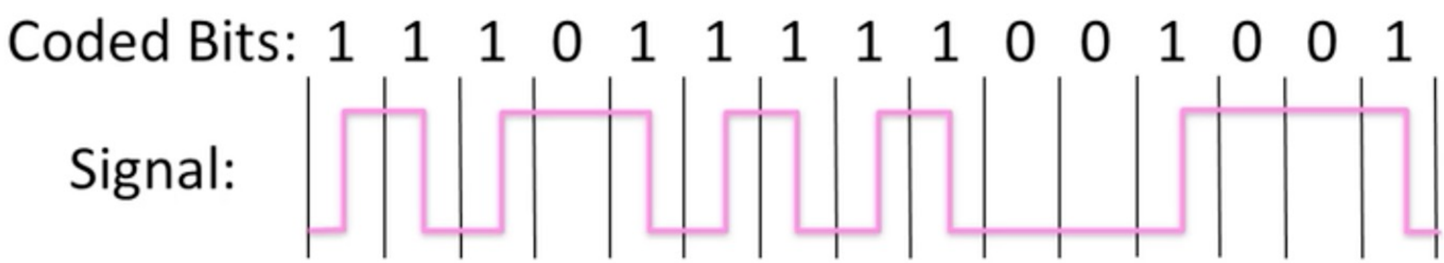
Data (4B)	Codeword (5B)	Data (4B)	Codeword (5B)
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

➢Combine this method with NRZI: Invert signal level on a 1 to break up long runs of 1s

4B/5B Example

- Reference:
  0000->11110, 0001->01001, 1110->11100,….1111->11101

- Message bits: 1111 0000 0001



Passband Modulation

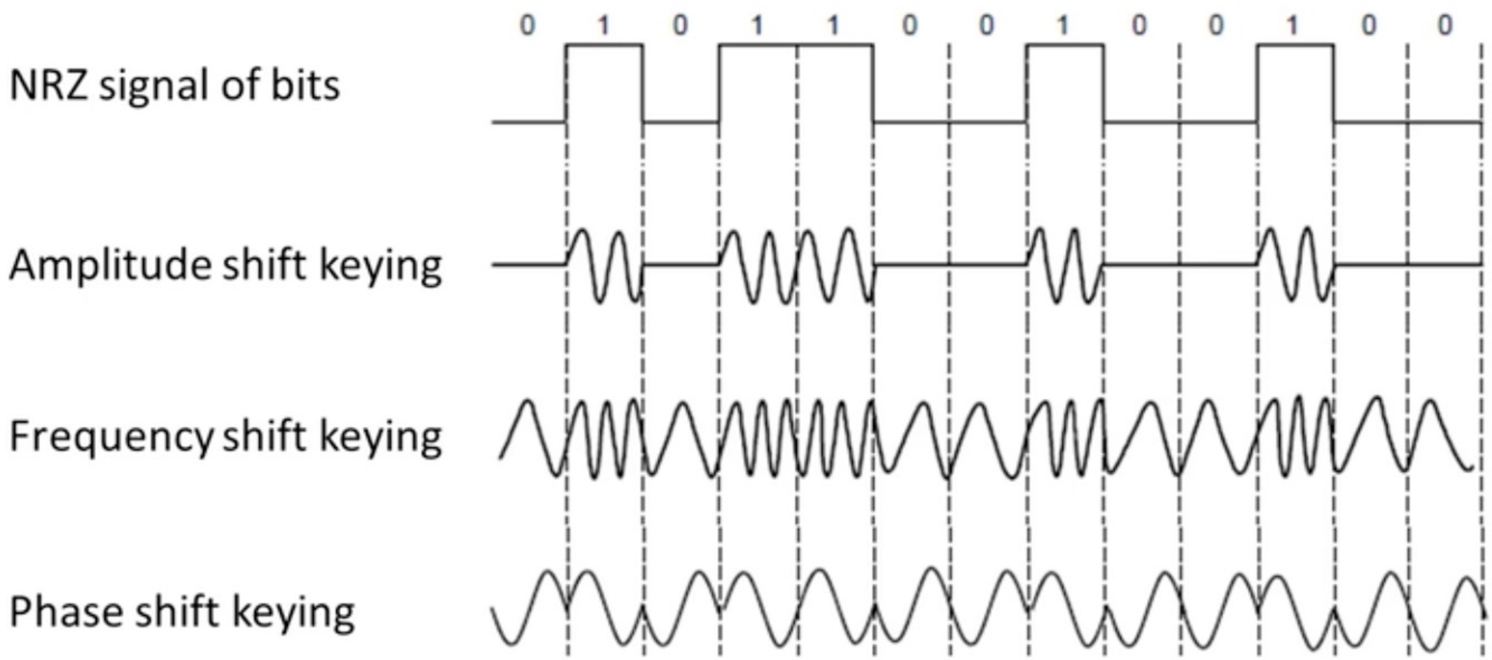
- What we have seen so far is **baseband** modulation for wires
  - Signal is sent directly on a wire
  - Do not propagate well on wireless and fiber
    - Need to send at higher frequency
- How to send information at high frequency?
- **Passband** modulation carries a signal by modulating the carrier

Passband Modulation (2)

- Carrier is simply a signal oscillating at a desired frequency

- We can modulate it by changing:
  - Amplitude
  - Frequency
  - Phase

Passband Modulation Example



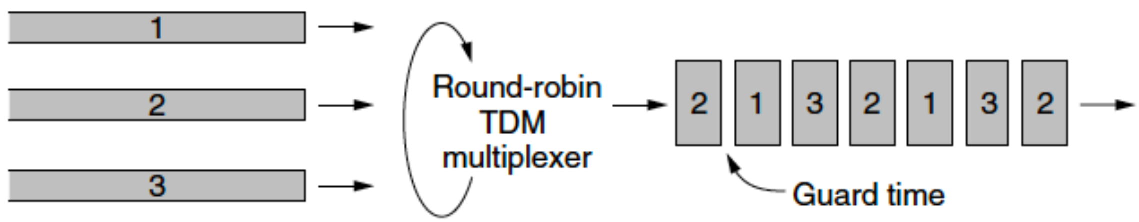
Multiplexing

- Channels are often shared by multiple signals
- This kind of sharing is called multiplexing

- Several methods:
  - FDM
    - OFDM
  - TDM
  - ….

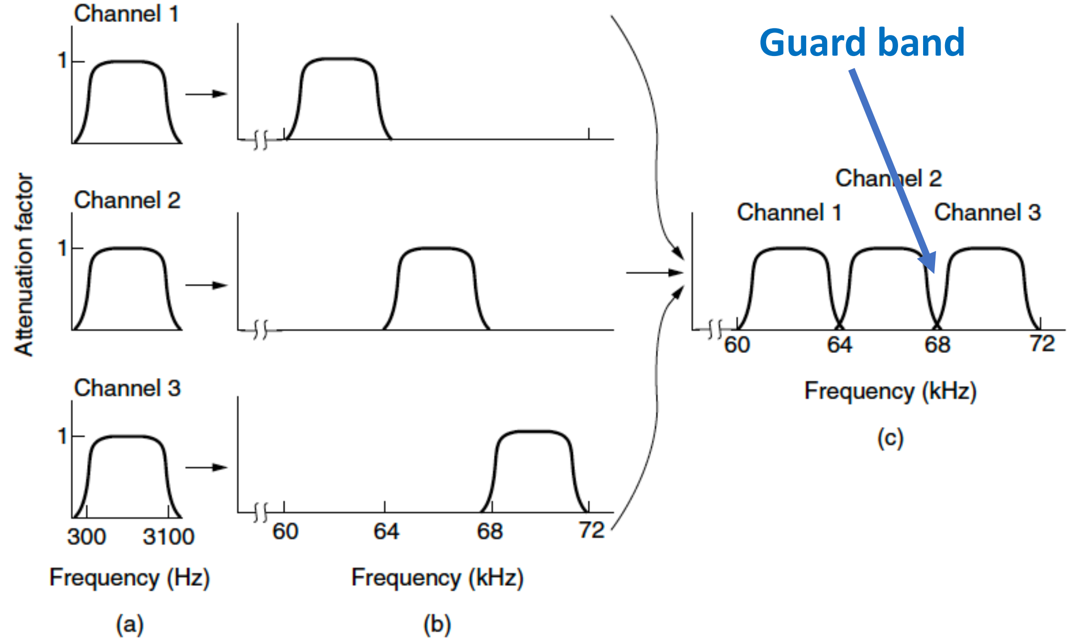
Time Division Multiplexing (TDM)

- Users take turns getting the entire bandwidth for a little burst of time (in a round-robin fashion)
- Used widely as part of the telephone and cellular networks



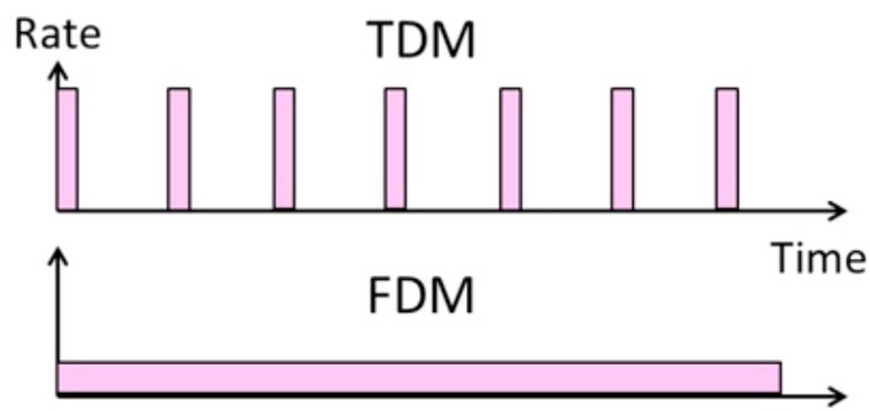
Frequency Division Multiplexing (FDM)

- It divides the spectrum into frequency band
- Each user having exclusive possession of some band
- Used in AM radio and satellite communication



TDM vs. FDM

- In TDM a user sends at a high rate a fraction of the time; in FDM, a user sends at a low rate all the time

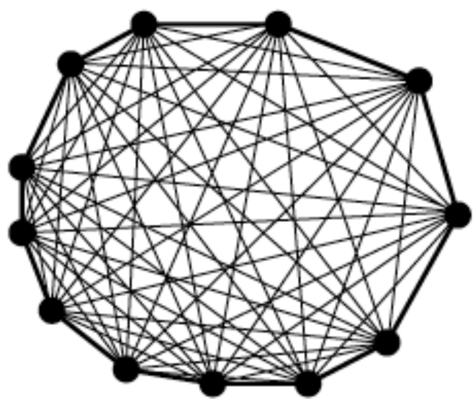


TDM/FDM Usage

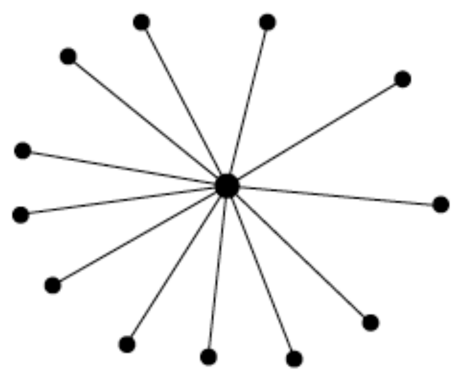
- Statically divide a resource
  - Suited for continuous traffic, fixed number of users

- Widely used in telecommunications
  - TV and radio stations (FDM)
  - GSM (2G cellular) allocates calls using TDM with FDM

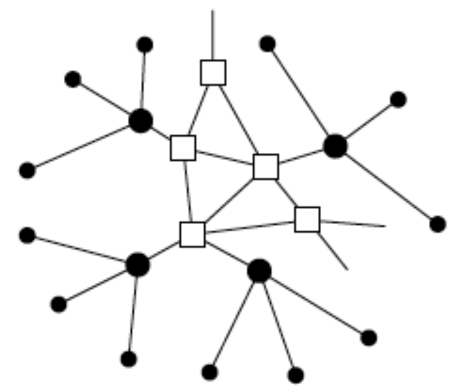
Structure of the Switched Telephone System



Fully interconnected network



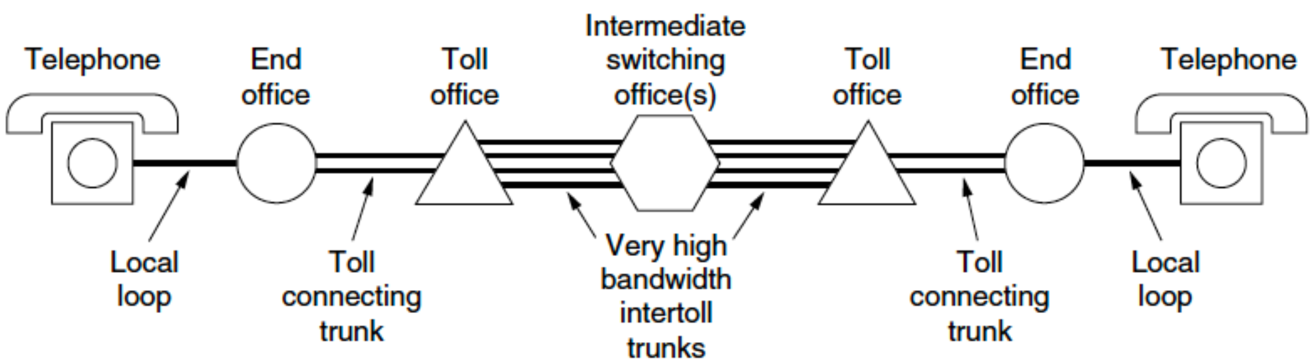
Centralized switch



Two-level hierarchy

Structure of the Telephone System (2)

- In summary, the telephone system consists of three major components:
    1. Local loops (analog twisted pairs going to houses and businesses)
    2. Trunks (digital fiber optic links connecting the switching offices)
    3. Switching offices (where calls are moved from one trunk to another)



Local Loop

- The two-wire connections between each subscriber's telephone and the end office (1 to 10km)
- Modems used to convert digital to analog and vise versa
- Modems were displaced by broadband technologies such as Digital Subscriber Lines (DSL)
- Limitations of old local loops:
  - Relatively narrow bandwidth
  - Attenuation and distortion of signals
  - Susceptibility to electrical noise such as crosstalk

➢ Local loop has been modernized by installing optical fiber

Trunks

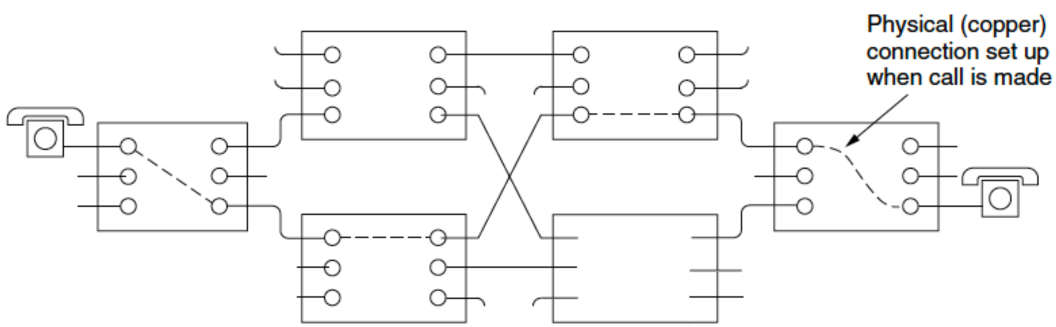
- Much faster than local loops
- They carry digital information not analog
- Carry thousands, even millions, of calls simultaneously using FDM and TDM multiplexing

Switching

- Two types of switching:
  - Circuit switching -> traditional telephone system
  - Packet switching -> voice over IP

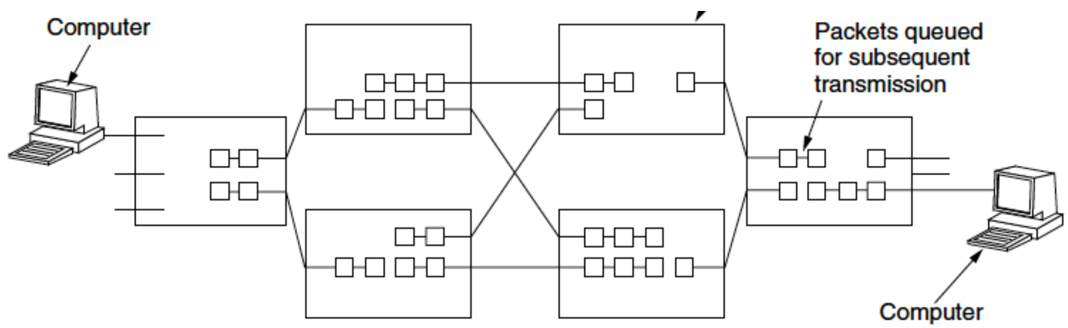
Circuit Switching

- Need to set up an end-to-end path before any data can be sent
- Once a call has been set up, a dedicated path between both ends exists and will continue to exist until the call is finished
  - The only delay for data is the propagation time for the electromagnetic signal
  - There is no danger of congestion (may be at the setup time)



Packet Switching

- Packets are sent as soon as they are available
- No need to set up a dedicated path in advance -> queueing delay and congestion
- Different packets can follow different paths -> may arrive out of order
- Not wasting resources



Circuit Switching vs. Packet Switching

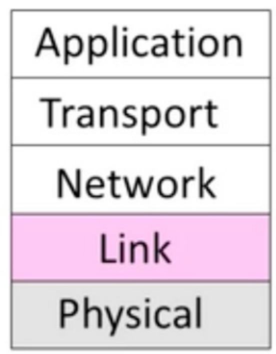
Item	Circuit switched	Packet switched
Call setup	Required	Not needed
Dedicated physical path	Yes	No
Each packet follows the same route	Yes	No
Packets arrive in order	Yes	No
Is a switch crash fatal	Yes	No
Bandwidth available	Fixed	Dynamic
Time of possible congestion	At setup time	On every packet
Potentially wasted bandwidth	Yes	No
Store-and-forward transmission	No	Yes
Charging	Per minute	Per packet

- The trade-off is between guaranteed service and wasting resources versus not guaranteeing service and not wasting resources

Data Link Layer

Where We Are In The Course?

- Moving to the link layer



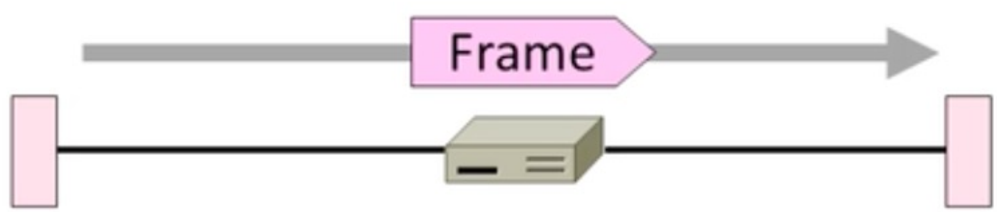
Limitations of Links

- Communication channels:
  - Make errors occasionally
  - They have only a finite data rate
  - There is a nonzero propagation delay between the time a bit is sent and the time it is received

➢ There is a need to have protocols to handle these limitations

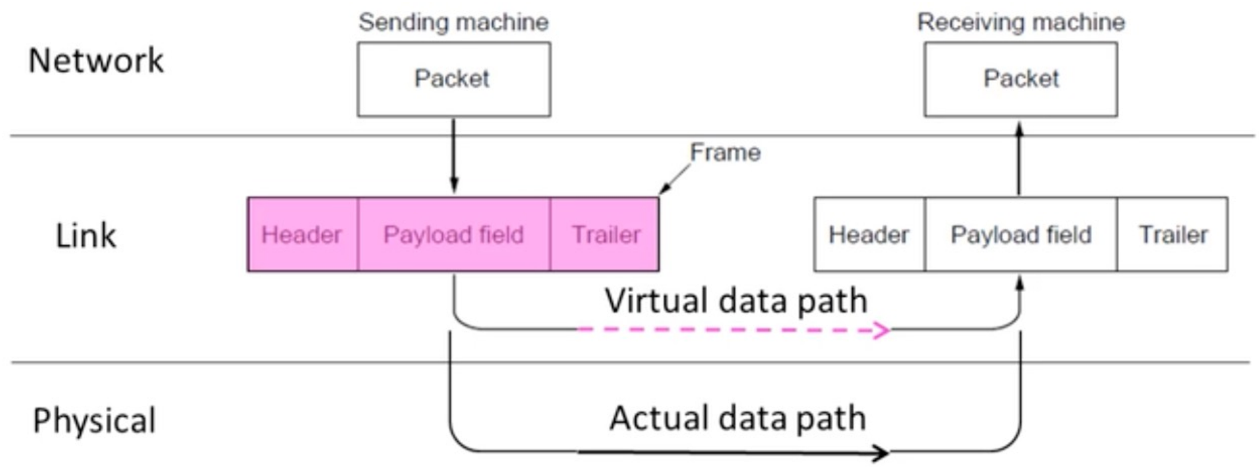
Data Link Layer

- Deals with algorithms for achieving **reliable**, **efficient communication** of whole units of information called frames between two **adjacent** machines



Link Layer Functions

1. Providing a well-defined service interface to the network layer
2. Framing
3. Dealing with transmission errors
4. Regulating the flow of data so that slow receivers are not swamped by fast senders

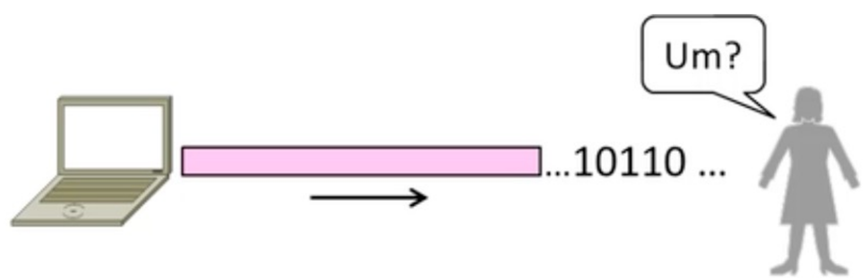


Services to Network Layer

- Transferring data from the network layer on the source machine to the network layer on the destination machine
- Services depends on protocols
  1. Unacknowledged connectionless service (Ethernet)
  2. Acknowledged connectionless service (802.11)
  3. Acknowledged connection-oriented service
     - Connection establishment
     - Data transfer
     - Connection released

Framing

- Physical layer accepts a raw bit stream and attempt to deliver it to the destination
- Data link layer breaks up the bit stream into discrete frames
- Framing has to be:
  - Easy for a receiver to find the start of new frames
  - Using little of the channel bandwidth



Framing Methods

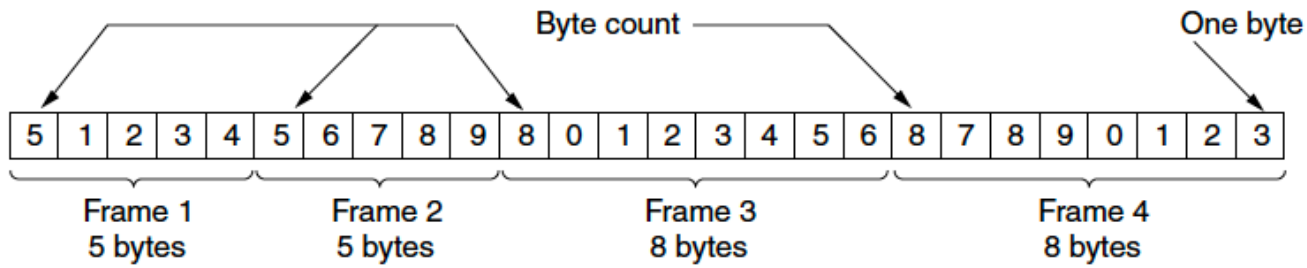
1. Byte count
2. Flag bytes with byte stuffing
3. Flag bits with bit stuffing

Byte Count

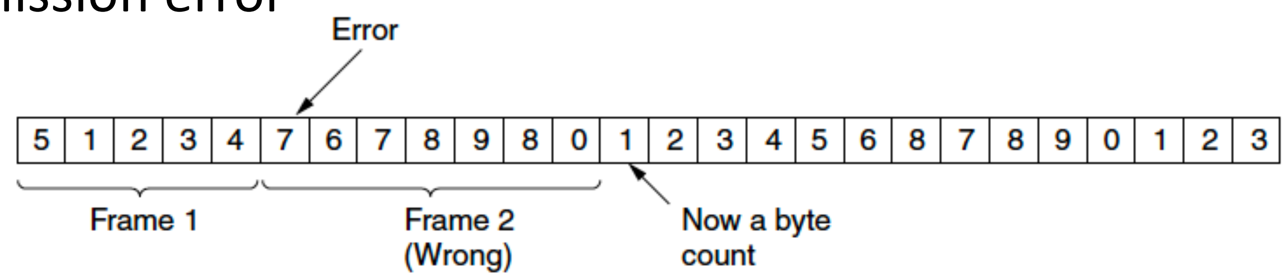
- Starts each frame with a length field!
- At sender: uses a field in the header to specify the number of bytes in the frame
- At receiver: sees the byte count, it knows how many bytes follow and hence where the end of the frame is

- It is simple but does it work?!

Byte Count Example



- Problem: The byte count itself can be changed due to the transmission error



Flag Bytes With Byte Stuffing

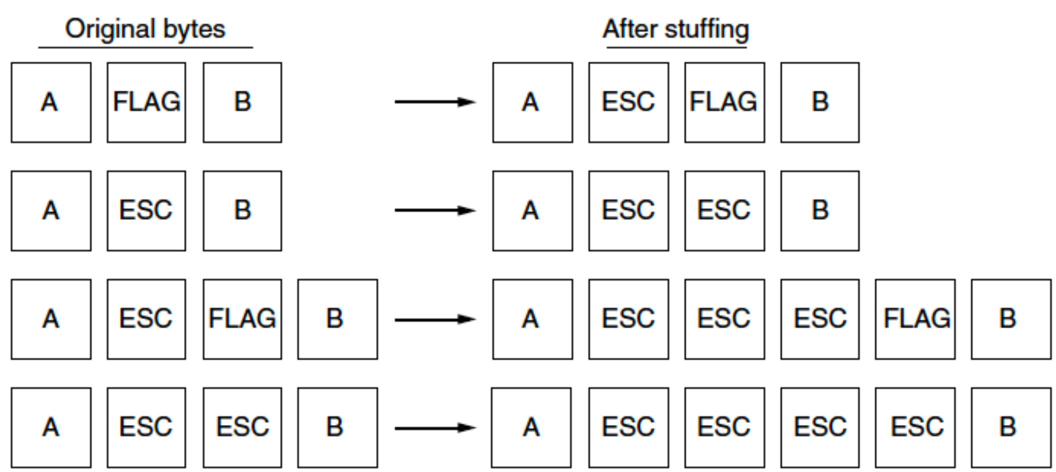
- Each frame starts and ends with special bytes called **flag byte**
- Two consecutive flag bytes indicate the end of one frame and the start of the next

FLAG	Header	Payload field	Trailer	FLAG

- Problem: May have that flag byte in the data!
- Solution: Sender's data link layer insert (**stuff**) a special escape byte (ESC) just before each ''accidental'' flag byte in the data
- Complication: Have to escape the escape code too!

Byte Stuffing Example

- Rules:
  - Replace each FLAG in data with ESC FLAG
  - Replace each ESC in data with ESC ESC



Flag Bits With Bit Stuffing

- Framing can be also be done at the bit level
- Each frame begins and ends with a special bit pattern, 01111110 or 0x7E in hexadecimal
- Sender’s data link layer stuffs a 0 after five consecutive 1s in the data
- Receiver’s data link layer destuffs (i.e., deletes) the 0 after five consecutive 1s

- Used in USB

Bit stuffing Example

0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0

0 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 0 0 1 0

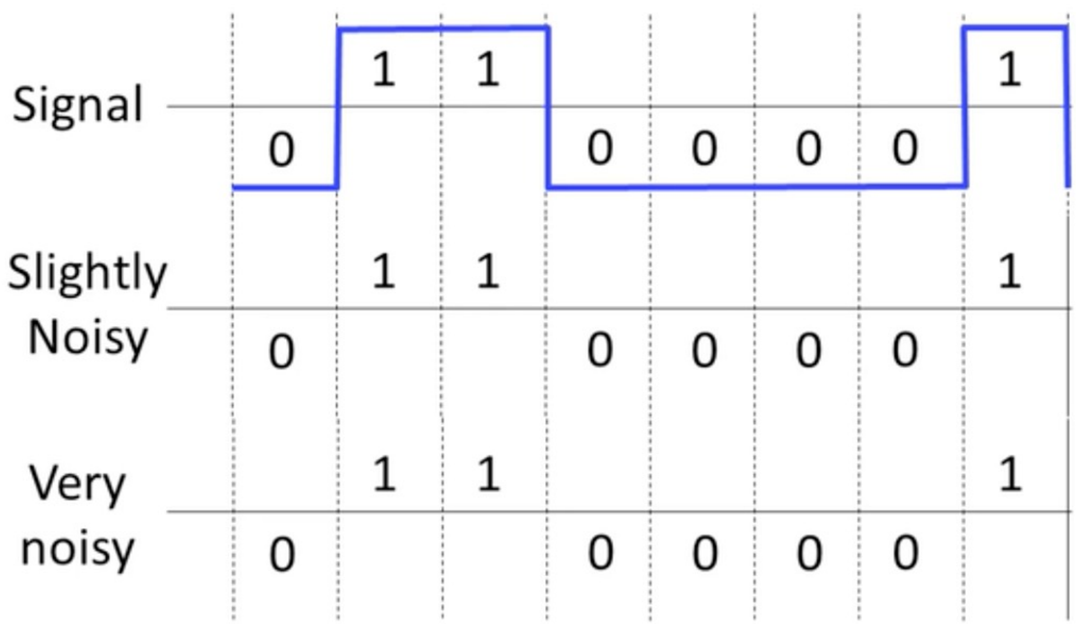
Stuffed bits

Which Framing Method is Used?

- Data link protocols use a combination of these methods
- Ethernet and 802.11 begin a frame with well-defined pattern called a preamble
  - Quite long (72 bits is typical for 802.11)
  - Preamble is followed by a length (i.e., count) field in the header that is used to locate the end of the frame

Noise Over The Links

- Transmission error are here! Some bits will be received in error
  - Reliability cuts across the layers



Error Detection And Correction

- Two strategies:
  - **Error detection code**: Add check bits to the message bits to let some errors be detected
  - **Error correction code**: Add more check bits to let some errors be corrected

- Reliability is an overall concern -> These codes are used in all layers
  - Error-correcting codes are also seen in the physical layer (for noisy channels), and in higher layers (for real time apps)
  - Error-detecting codes are used in link, network, and transport layers

➢ When should we use error detecting code?

Error Detecting Codes

- Three different error detecting codes:
  1. Parity
  2. Checksums
  3. Cyclic Redundancy Checks (CRCs)

- Detection let us fix the error, for example, by retransmission (later)

Parity

- Single parity bit is appended to the data
  - Even parity bit: the parity bit make the whole codeword even
  - Odd parity bit: the parity bit make the whole codeword odd

- Example (If using even parity bit):

  Data: 1001011

  Whole code word: 10010110
- Example (If using odd parity bit):

  Data: 1001011

  Whole code word: 10010111

To-do

- Quiz next week
- Submit your research topic by Feb 9th