Chapter 5
Data Link Layer

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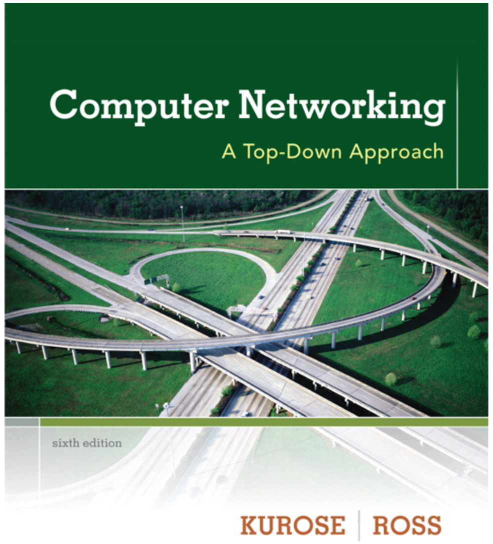
We thank for the support material Prof. Kurose-Ross



Computer Networking: A Top Down Approach
6th edition
Jim Kurose, Keith Ross
Addison-Wesley
March 2012

Chapter 5: The Data Link Layer

Our goals:

- understand principles behind data link layer services:
  - error detection, correction
  - sharing a broadcast channel: multiple access
  - link layer addressing
  - reliable data transfer, flow control: *done!*
- instantiation and implementation of various link layer technologies

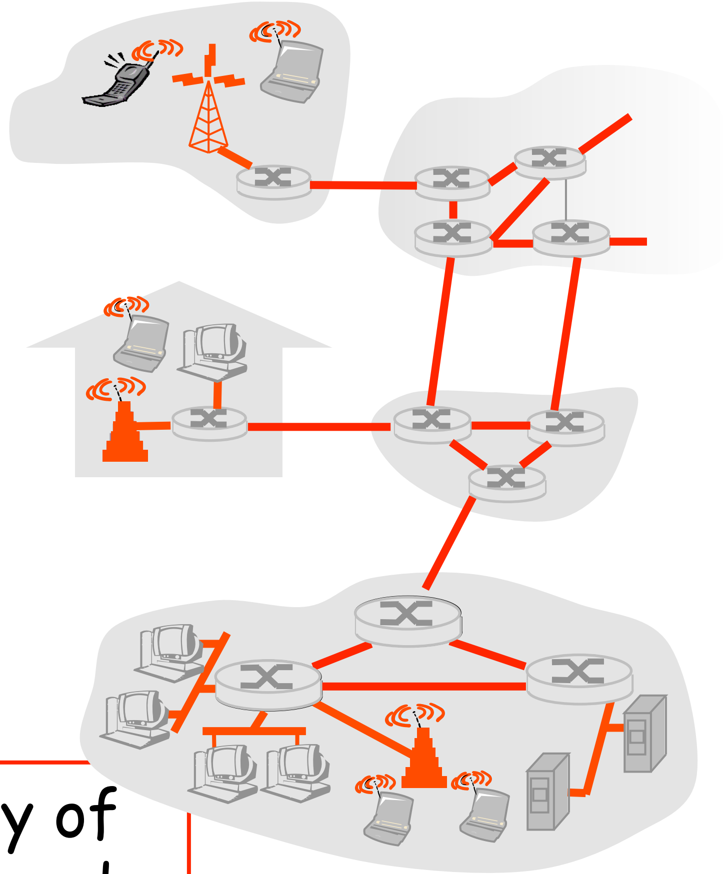
Link Layer

- 5.1 Introduction and services
- 5.2 Error detection and correction
- 5.3Multiple access protocols
- 5.4 Link-layer Addressing
- 5.5 Ethernet
- 5.6 Link-layer switches
- 5.7 PPP
- 5.8 Link virtualization: MPLS
- 5.9 A day in the life of a web request

Link Layer: Introduction

Some terminology:

- hosts and routers are **nodes**
- communication channels that connect adjacent nodes along communication path are **links**
  - wired links
  - wireless links
  - LANs
- layer-2 packet is a **frame**, encapsulates datagram



data-link layer has responsibility of transferring datagram from one node to adjacent node over a link

Link layer: context

- datagram transferred by different link protocols over different links:
  - e.g., Ethernet on first link, frame relay on intermediate links, 802.11 on last link
- each link protocol provides different services
  - e.g., may or may not provide rdt over link

transportation analogy

- trip from Princeton to Lausanne
  - limo: Princeton to JFK
  - plane: JFK to Geneva
  - train: Geneva to Lausanne
- tourist = datagram
- transport segment = communication link
- transportation mode = link layer protocol
- travel agent = routing algorithm

Link Layer Services

- PHY layer accepts only a raw bit stream and attempts to deliver to destination

  01100011000011000000001001100000100001

  - Communication is not necessarily error free
  - Multiplexing of different flows of information
    - → Data link layer breaks the bit stream up into discrete frames (FRAMING) and computes the checksum for each frame (ERROR DETECTION)

Link Layer Services

Framing:

- encapsulate datagram into frame, adding header, trailer
- How to delimit frames:
  - We cannot count on some time gap (strong synch requirement and jitter requirement)
  - Character count: A field in the header specifies the number of characters in the frame (OK but loose synch in case of transmission error)
  - Starting and ending characters with character stuffing
    - ES ASCII character sequence DLE STX (Data Link Escape Start of TeXt)…DLE ETX (ETX=End of TeXt)
    - What if binary data are transmitted with sequences corresponding to DLE STX or SLE ETX occurring in the data?
    - Character stuffing: before transmitting add DLE before each of
      - such sequences in the data: DLE STX→DLE DLE STX

Link Layer Services

Framing:

- encapsulate datagram into frame, adding header, trailer
- How to delimit frames:
  - Starting and ending flags with bit stuffing
    - Each frame begins and ends with a special bit pattern, e.g. 01111110 (**flag** sequence)
    - Techniques to avoid problems in case the flag sequence appears in data: whenever data link layer encounters five consecutive ones in the data add a 0 bit in the outgoing bit stream (removed at the other end of the link)→bit stuffing
    - Es.: (a) 01101111111111111111110010
    - (b) 011011111**0**11111**0**11111**0**10010

Stuffed bits

Link Layer Services

Framing:

- encapsulate datagram into frame, adding header, trailer
- How to delimit frames:
  - Physical layer coding variations
    - For instance if Manchester encoding used a High-High or Low-Low sequence
  - A combination of character count and one of the other typically used

Link Layer Services

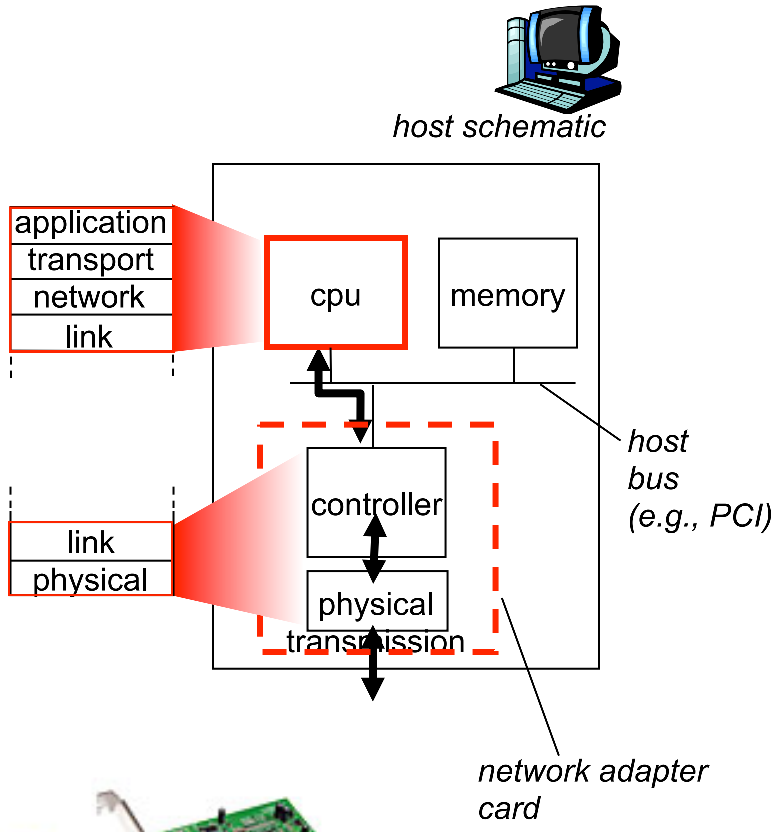
- *link access*
  - **channel access if shared medium**
    - **avoids or limits the effect of collisions over a broadcast channel**
- addressing
  - "MAC" addresses used in frame headers to identify source, dest
    - different from IP address!
- *error detection*:
  - errors caused by signal attenuation, noise.
  - receiver detects presence of errors:
    - signals sender for retransmission or drops frame
- error correction:
  - receiver identifies *and corrects* bit error(s) without resorting to retransmission
- *half-duplex and full-duplex*
  - with half duplex, nodes at both ends of link can transmit, but not at same time

Link Layer Services (more)

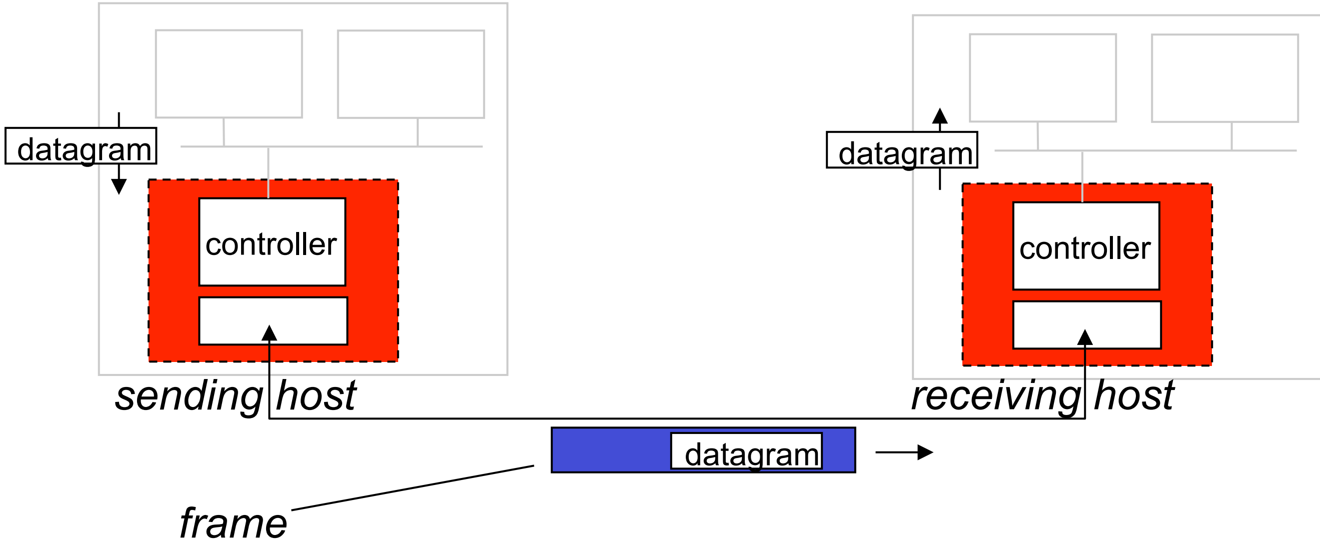
- *reliable delivery between adjacent nodes*
  - we learned how to do this already (chapter 3)!
  - seldom used on low bit-error link (fiber, some twisted pair)
  - wireless links: high error rates
    - Q: why both link-level and end-end reliability?
- *flow control:*
  - pacing between adjacent sending and receiving nodes

Where is the link layer implemented?

- in each and every host
- link layer implemented in "adaptor" (aka *network interface card* NIC)
  - Ethernet card, PCMCI card, 802.11 card
  - implements link, physical layer
- attaches into host's system buses
- combination of hardware, software, firmware



Adaptors Communicating



- sending side:
  - encapsulates datagram in frame
  - adds error checking bits, rdt, flow control, etc.
- receiving side
  - looks for errors, rdt, flow control, etc
  - extracts datagram, passes to upper layer at receiving side

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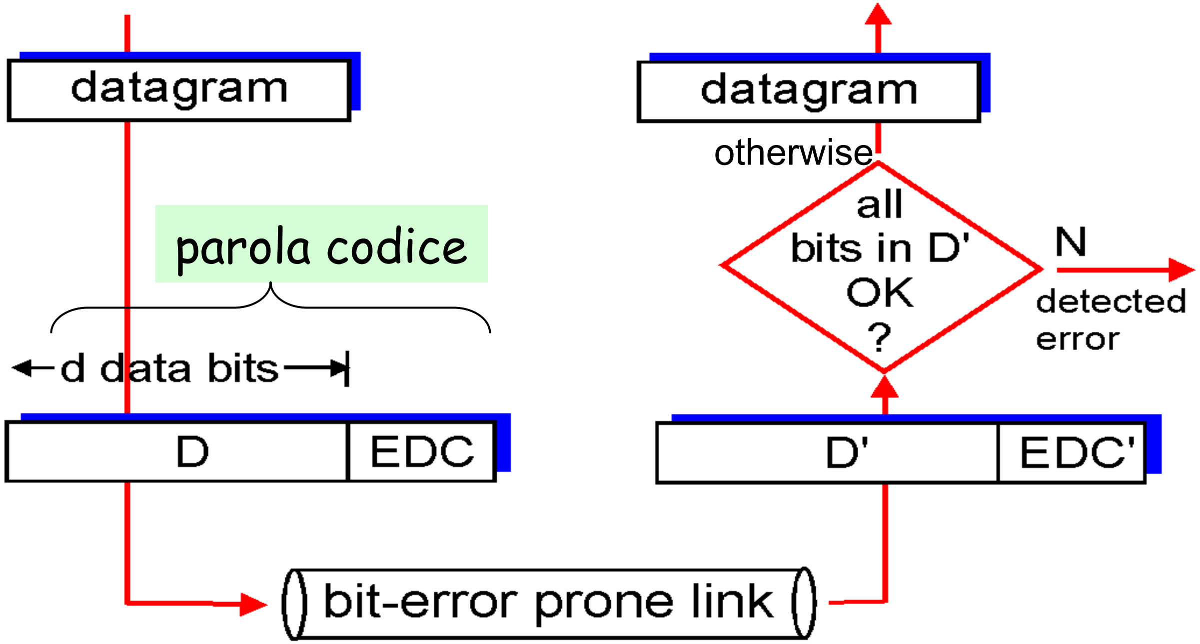
Error Detection

EDC= Error Detection and Correction bits (redundancy)
D = Data protected by error checking, may include header fields

- Error detection not 100% reliable!
  - protocol may miss some errors, but rarely
  - larger EDC field yields better detection and correction



Distanza di Hamming

- Date due parole codice e.g., 10001001 e 10110001 è possibile determinare in quanti bit 'differiscano' (XOR delle due parole e contate il numero di 1 del risultato)
  - Il numero di posizioni nelle quali le due parole di codice differiscono determina la loro distanza di Hamming
  - Se due parole codice hanno una distanza di Hamming d ci vorranno d errori sui singoli bit per tramutare una parola di codice nell'altra
  - Per come sono usati i bit di ridondanza se la lunghezza delle parole di codice è n=m+r sono possibili 2^m messaggi dati ma non tutte le 2^n parole codice
    - la distanza di Hamming di un codice è la minima distanza di Hamming tra due parole codice

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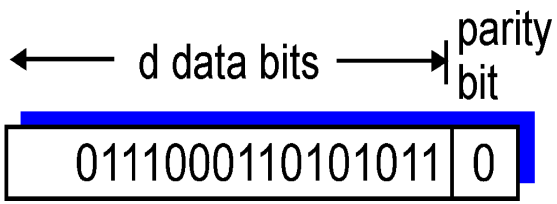
    - la distanza di Hamming di un codice è la minima distanza di Hamming tra due parole codice
  - Per fare il detection di d errori serve un codice con distanza di Hamming d+1
  - Per correggere d errori serve un codice con distanza di Hamming 2d+1

Parity Checking

Single Bit Parity:

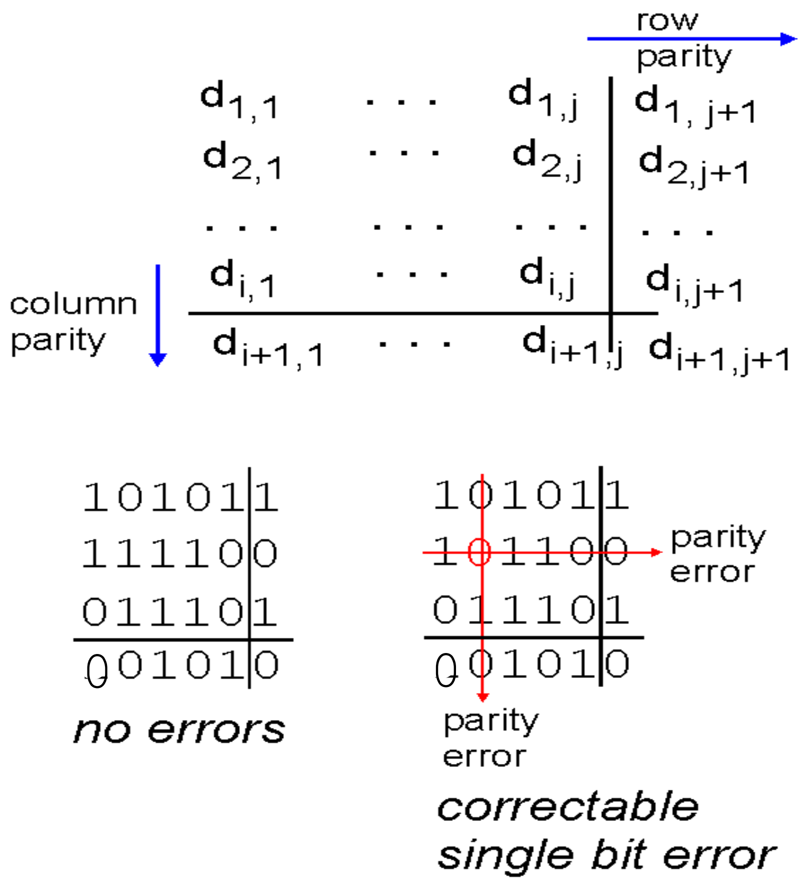
Detect single bit errors



Schema di parità dispari: Il mittente include un bit addizionale e sceglie il suo valore in modo che il numero di uno nei d+1 bit sia dispari

Two Dimensional Bit Parity:

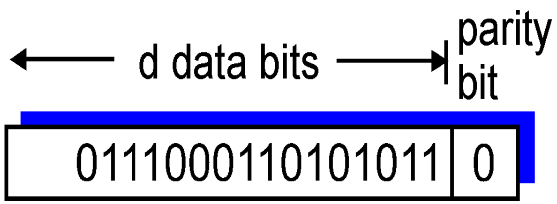
Detect *and correct* single bit errors



Parity Checking

Single Bit Parity:

Detect single bit errors



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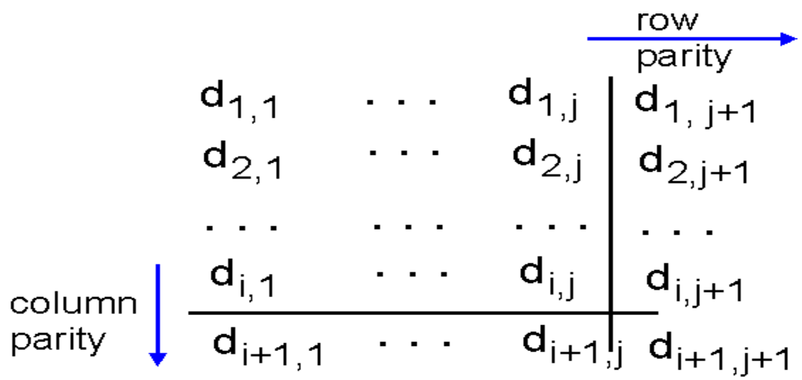
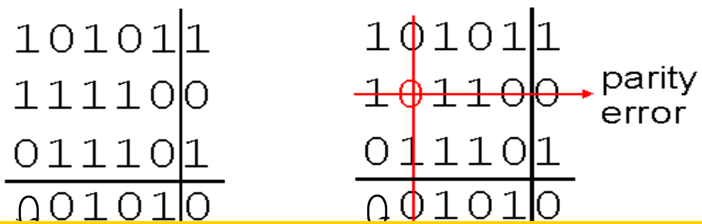




Schemi semplici possono essere sufficienti nel caso di errori casuali
Cosa si può fare nel caso di errori a burst?
- **Maggiore ridondanza**
- **Interleaving**

Internet checksum (review)

Goal: detect "errors" (e.g., flipped bits) in transmitted packet (note: used at transport layer *only*)

Sender:

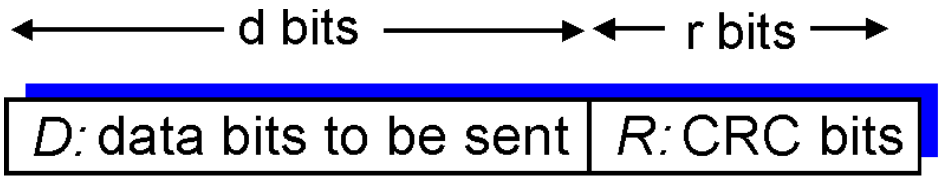
- treat segment contents as sequence of 16-bit integers
- checksum: addition (1's complement sum) of segment contents
- sender puts checksum value into UDP checksum field

Receiver:

- compute checksum of received segment
- check if computed checksum equals checksum field value:
  - NO - error detected
  - YES - no error detected. *But maybe errors nonetheless?*

Checksumming: Cyclic Redundancy Check

- view data bits, D, as a binary number
- choose r+1 bit pattern (generator), G
- goal: choose r CRC bits, R, such that
  - <D,R> exactly divisible by G (modulo 2)
  - receiver knows G, divides <D',R'> by G. If non-zero remainder: error detected!
  - can detect all burst errors less than r+1 bits
- widely used in practice (Ethernet, 802.11 WiFi, ATM)



bit pattern

$D * 2^r$ XOR R

mathematical formula

CRC

- r è l'ordine del polinomio generatore G(x)
- Appendi r bit zero al messaggio M(x) che ora corrisponde a x^r M(x)
- dividi x^rM(x) per G(x) modulo 2
- Sottrai (modulo 2) il resto della divisione da x^rM(x)→ si ottiene T(x), il risultato da trasmettere

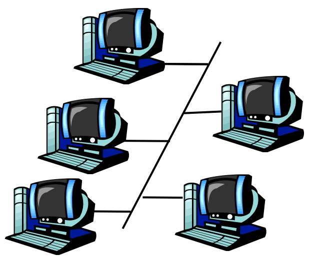
- In ricezione controlla che il resto della divisione per G(x) sia 0
- Estrai la parte di messaggio M(x)

Link Layer

Multiple Access Links and Protocols

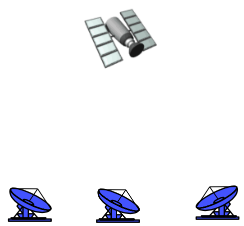
Two types of "links":

- point-to-point
  - PPP for dial-up access
  - point-to-point link between Ethernet switch and host
- broadcast (shared wire or medium)
  - old-fashioned Ethernet
  - upstream HFC
  - 802.11 wireless LAN



shared wire (e.g., cabled Ethernet)

shared RF (e.g., 802.11 WiFi)



shared RF (satellite)

humans at a cocktail party (shared air, acoustical)

Multiple Access protocols

- single shared broadcast channel
- two or more simultaneous transmissions by nodes: interference
  - collision if node receives two or more signals at the same time

multiple access protocol

- distributed algorithm that determines how nodes share channel, i.e., determine when node can transmit
- communication about channel sharing must use channel itself!
  - no out-of-band channel for coordination

Ideal Multiple Access Protocol

Broadcast channel of rate R bps

1. when one node wants to transmit, it can send at rate R.
2. when M nodes want to transmit, each can send at average rate R/M
3. fully decentralized:
   - no special node to coordinate transmissions
   - no synchronization of clocks, slots
4. simple

MAC Protocols: a taxonomy

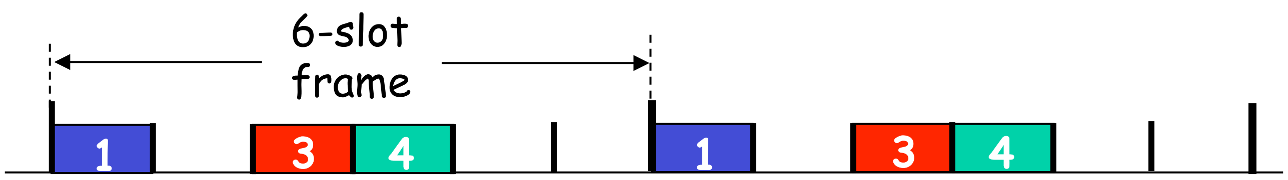
Three broad classes:

- Channel Partitioning
  - divide channel into smaller "pieces" (time slots, frequency, code)
  - allocate piece to node for exclusive use
- Random Access
  - channel not divided, allow collisions
  - "recover" from collisions
- "Taking turns"
  - nodes take turns, but nodes with more to send can take longer turns

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

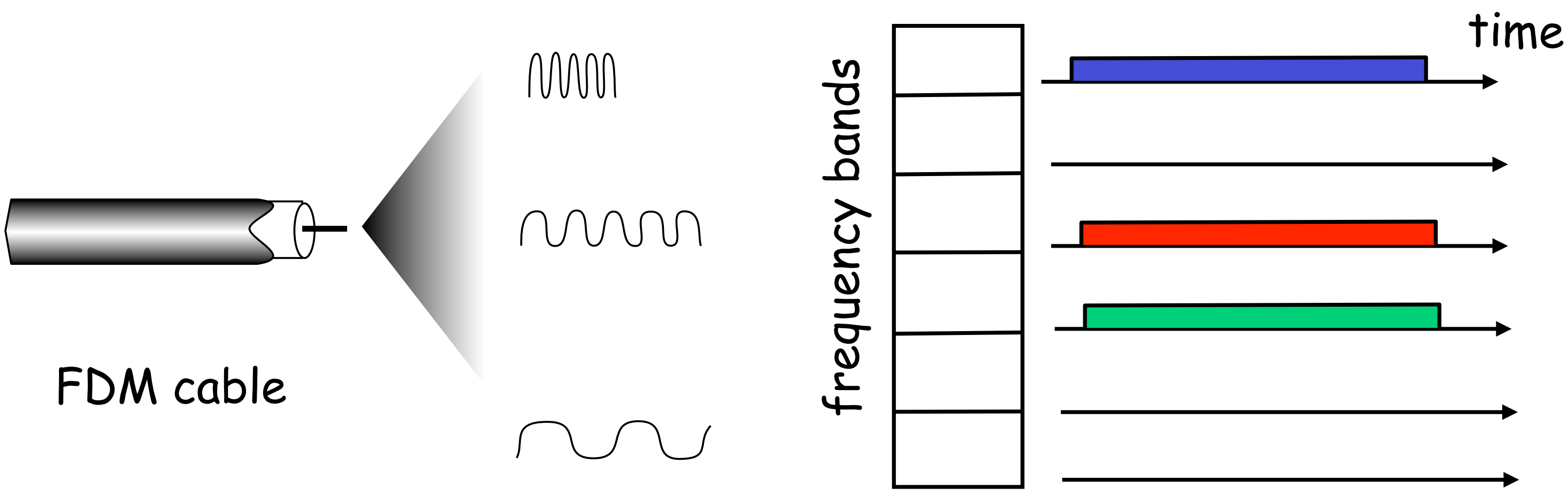
- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle



Channel Partitioning MAC protocols: FDMA

FDMA: frequency division multiple access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle



TDMA/FDMA Vs. Ideal Multiple Access Protocol

Broadcast channel of rate R bps

1. when one node wants to transmit, it can send at rate R. → NOT MET BY TDMA/FDMA
2. when M nodes want to transmit, each can send at average rate R/M → MET BY TDMA/FDMA IN CASE M=N
3. fully decentralized:
   - **no special node to coordinate transmissions**
   - **no synchronization of clocks, slots**
4. simple

Random Access Protocols

- When node has packet to send
  - transmit at full channel data rate R.
  - no *a priori* coordination among nodes
- two or more transmitting nodes ➜ "collision",
- random access MAC protocol specifies:
  - how to detect collisions
  - how to recover from collisions (e.g., via delayed retransmissions)
- Examples of random access MAC protocols:
  - slotted ALOHA
  - ALOHA
  - CSMA, CSMA/CD, CSMA/CA

Slotted ALOHA

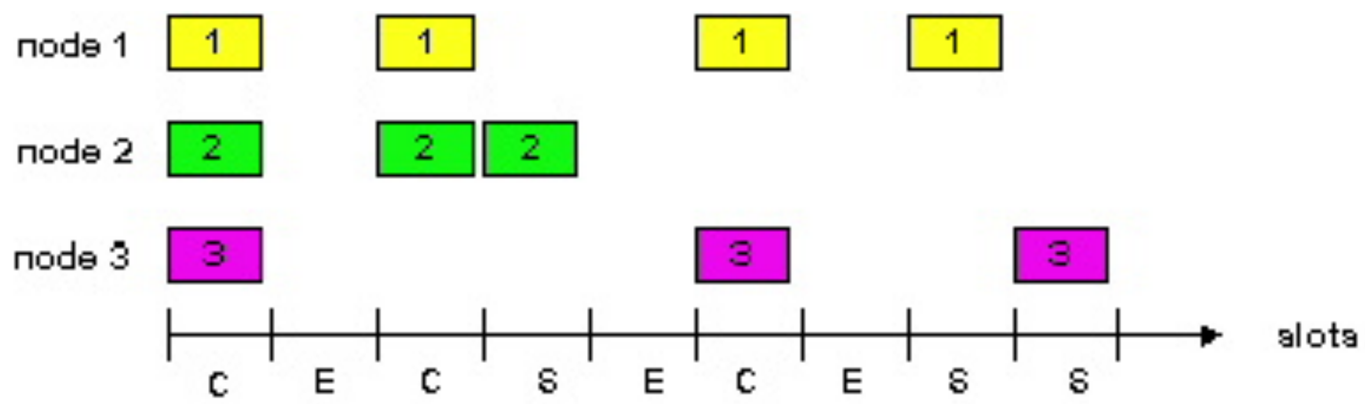
Assumptions:

- all frames same size
- time divided into equal size slots (time to transmit 1 frame)
- nodes start to transmit only slot beginning
- nodes are synchronized
- if 2 or more nodes transmit in slot, all nodes detect collision

Operation:

- when node obtains fresh frame, transmits in next slot
  - *if no collision:* node can send new frame in next slot
  - *if collision:* node retransmits frame in each subsequent slot with prob. p until success

Slotted ALOHA



Pros

- single active node can continuously transmit at full rate of channel
- highly decentralized: only slots in nodes need to be in sync
- simple

Cons

- collisions, wasting slots
- idle slots
- nodes may be able to detect collision in less than time to transmit packet
- clock synchronization

Slotted Aloha efficiency

Efficiency : long-run fraction of successful slots (many nodes, all with many frames to send)

- *suppose:* N nodes with many frames to send, each transmits in slot with probability *p*
- prob that given node has success in a slot = $p(1-p)^{N-1}$
- prob that *any* node has a success = $Np(1-p)^{N-1}$

- max efficiency: find p* that maximizes $Np(1-p)^{N-1}$
- for many nodes, take limit of $Np^*(1-p^*)^{N-1}$ as N goes to infinity, gives:

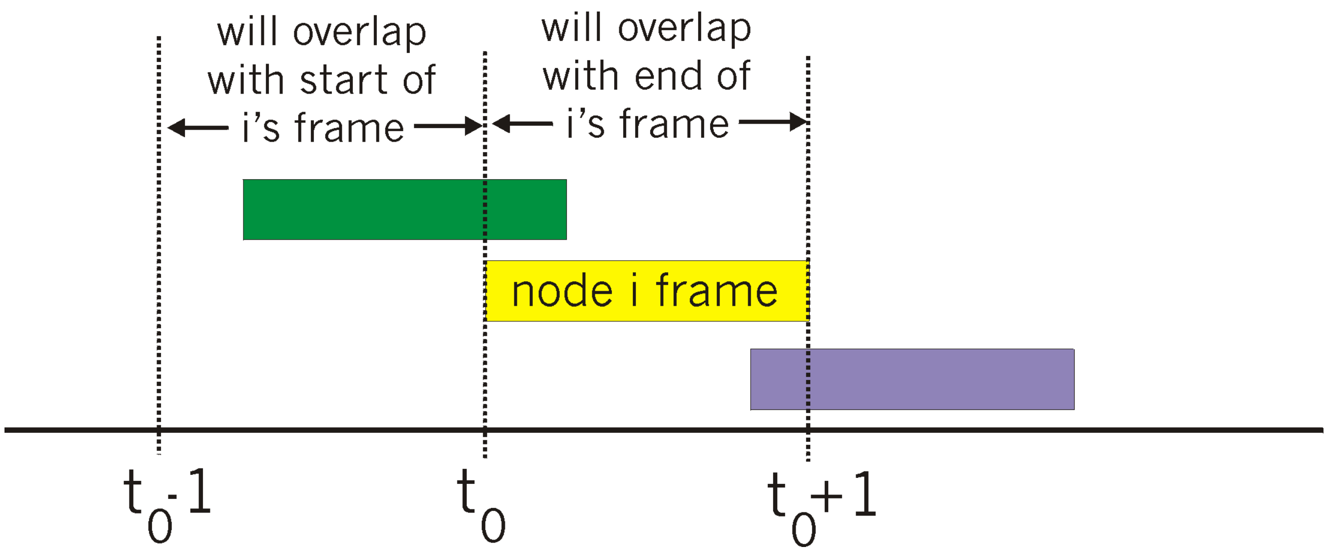
Max efficiency = 1/e = .37

At best: channel used for useful transmissions 37% of time!

!

Pure (unslotted) ALOHA

- unslotted Aloha: simpler, no synchronization
- when frame first arrives
  - transmit immediately
- collision probability increases:
  - frame sent at t_0 collides with other frames sent in $[t_0-1, t_0+1]$



Pure Aloha efficiency

P(success by given node) = P(node transmits) $\cdot$

P(no other node transmits in $[p_0-1, p_0]$ $\cdot$

P(no other node transmits in $[p_0-1, p_0]$

$= p \cdot (1-p)^{N-1} \cdot (1-p)^{N-1}$

$= p \cdot (1-p)^{2(N-1)}$

... choosing optimum p and then letting n -> infty ...

= 1/(2e) = .18

even *worse* than slotted Aloha!