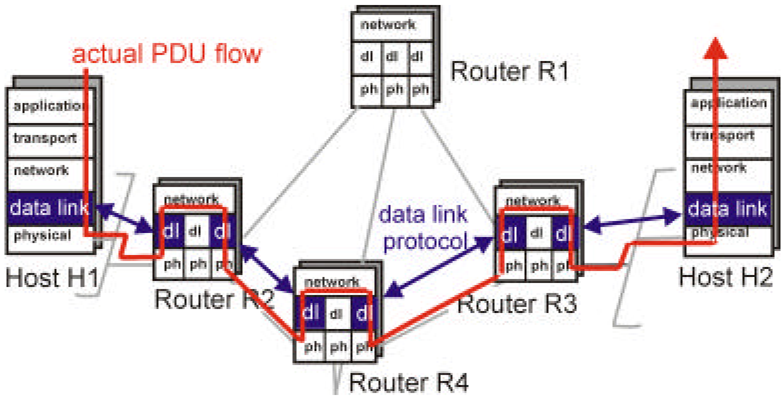
Link Layer Protocols



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Link Layer Services

- **Framing and link access**:
  - encapsulate datagram into frame adding header and trailer,
  - implement channel access if shared medium,
  - *physical addresses* 'are used in frame headers to identify source and destination of frames on broadcast links
- **Reliable Delivery**:
  - seldom used on fiber optic, co-axial cable and some twisted pairs too due to low bit error rate.
  - Used on wireless links, where the goal is to reduce errors thus avoiding end-to-end retransmissions

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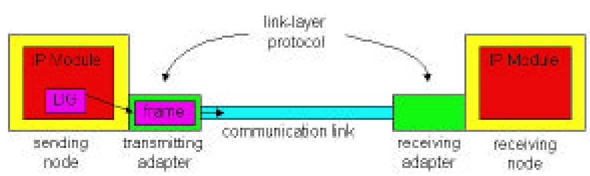
Link Layer Services (more)

- ***Flow Control*:**
  - pacing between senders and receivers
- ***Error Detection*:**
  - errors are caused by signal attenuation and noise.
  - Receiver detects presence of errors:
  - it signals the sender for retransmission or just drops the corrupted frame
- ***Error Correction*:**
  - mechanism for the receiver to locate and correct the error without resorting to retransmission

Link Layer Protocol Implementation

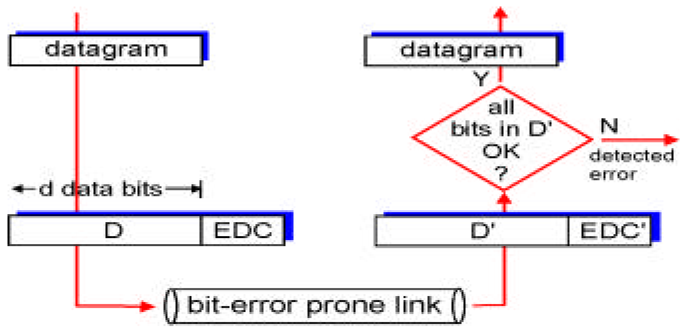
- Link layer protocol entirely implemented in the adapter (eg, NIC/PCMCIA card). Adapter typically includes: RAM, DSP chips, host bus interface, and link interface
- Adapter **send** operations: encapsulates (set sequence numbers, feedback info, etc.), adds error detection bits, implements channel access for shared medium, transmits on link
- Adapter **receive** operations: error checking and correction, interrupts host to send frame up the protocol stack, updates state info regarding feedback to sender, sequence numbers, etc.



Error Detection

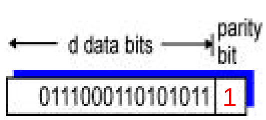
EDC= Error Detection and Correction bits (redundancy)
D = Data protected by error checking, may include some header fields

- Error detection is not 100%;
- protocol may miss some errors, but rarely
- Larger EDC field yields better detection and correction

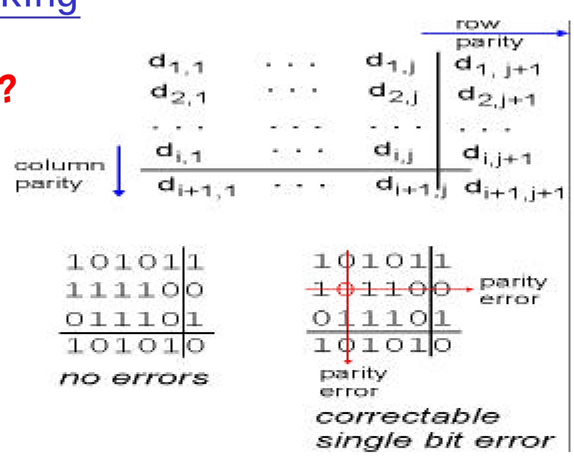


Parity Checking

Is this sufficient?



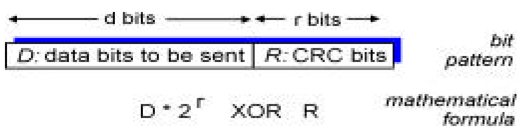
Single Bit Even Parity:
Detect single bit errors



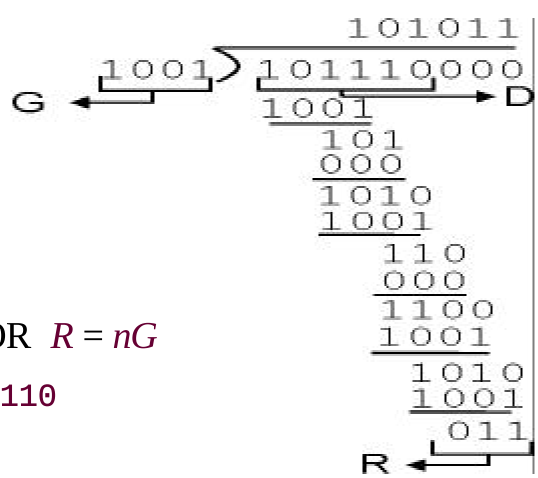
Two Dimensional Bit Parity:
Detect and correct single bit errors

Checksumming Methods

- **Internet Checksum:** View data as made up of 16 bit integers; add all the 16 bit fields (one's complement arithmetic) and append the frame with the resulting sum; the receiver repeats the same operation and matches the checksum sent with the frame
- **Cyclic Redundancy Codes:**
  - Data is viewed as a string of coefficients of a polynomial (D)
  - A *Generator* polynomial is chosen (=> r+1 bits), (G)
  - Divide (modulo 2) the D*2^r polynomial by G. Append the remainder (R) to D. Note that, by construction, the new string <D,R> is now divisible exactly by G



CRC Example



$$D \cdot 2^r \text{ XOR } R = nG$$

D = 101110
r = 3
R = 011
G = 1001

CRC Implementation (cont)

- The sender carries out on-line, in hardware the division of the string D by the polynomial G and appends the remainder R to it
- The receiver divides <D, R> by G; if the remainder is non-zero, the transmission was corrupted
- International standards for G polynomials of degrees 8, 12, 16 and 32 have been defined
  - CRC-12 $X^{12} + X^{11} + X^3 + X^2 + X + 1$
  - CRC-16 $X^{16} + X^{15} + X^2 + 1$
  - CRC-CCITT $X^{16} + X^{12} + X^5 + 1$
  - CRC-32 $X^{32} + X^{26} + X^{23} + X^{22} + X^{16} + X^{12} + X^{11} + X^{10} + X^8 + X^7 + X^5 + X^4 + X^2 + X + 1$
- ARPANET was using a 24 bit CRC for the alternating bit link protocol
- ATM is using a 32 bit CRC in ALL 5 (CRC-32)
- HDLC uses a 16 bit CRC (CRC-16)

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Multiple Access Links and Protocols

Three types of links:

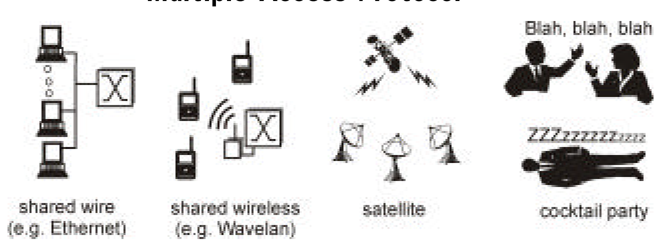
(a) Point-to-point (single wire)

(b) Broadcast (shared wire or medium; eg, E-net, wireless, etc.)

(c) Switched (eg, switched Ethernet, ATM, etc.)

We start with **Broadcast** links. Main challenge:

Multiple Access Protocol



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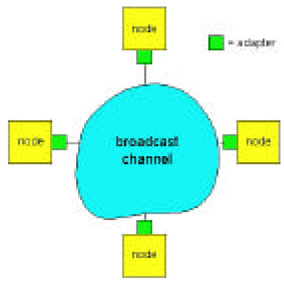
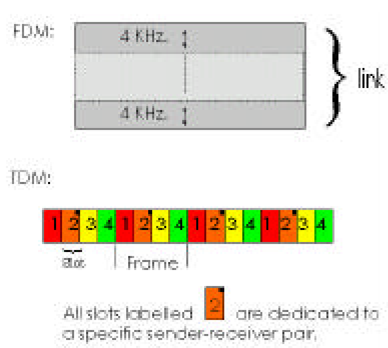
Multiple Access Control (MAC) Protocols

- MAC protocol: coordinates transmissions from different stations in order to minimize/avoid collisions
- (a) **Channel Partitioning** MAC protocols
- (b) **Random Access** MAC protocols
- (c) “**Taking turns**” MAC protocols
- Goal: **efficient, fair, simple, decentralized**



Channel Partitioning MAC protocols

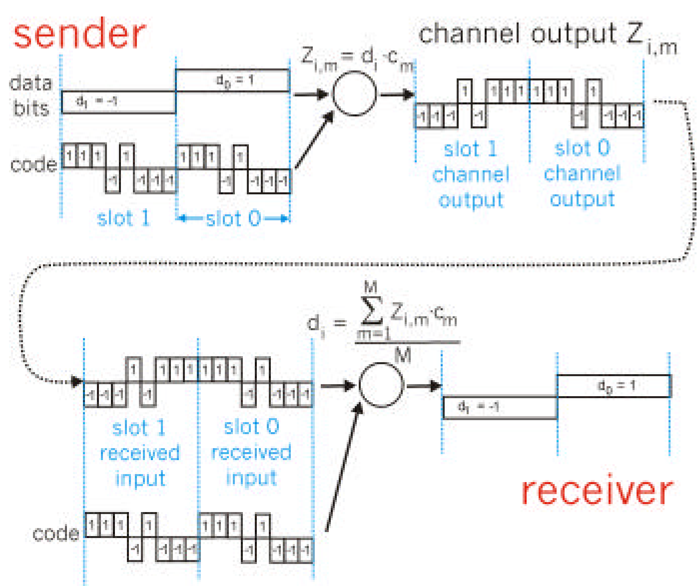


- TDM (Time Division Multiplexing): channel divided into N time slots, one per user; inefficient with low duty cycle users and at light load.
- FDM (Frequency Division Multiplexing): frequency subdivided.

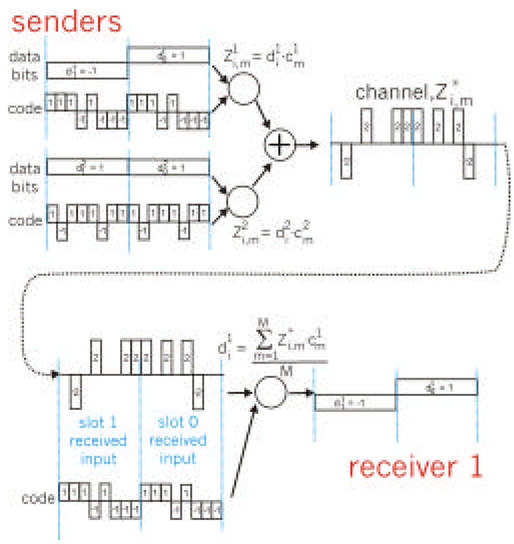
Channel Partitioning (CDMA)

- **CDMA (Code Division Multiple Access)**: exploits **spread spectrum** (DS or FH) encoding scheme
- unique "code" assigned to each user; ie, **code set** partitioning
- Used mostly in **wireless** broadcast channels (cellular, satellite,etc)
- All users share the **same frequency**, but each user has **own "chipping" sequence** (ie, code)
- Chipping sequence like a **mask**: used to **encode** the signal
- **encoded signal** = (original signal) X (chipping sequence)
- **decoding**: innerproduct of encoded signal and chipping sequence (note, the innerproduct is the sum of the component-by-component products)
- To make CDMA work, chipping sequences must be chosen orthogonal to each other (i.e., innerproduct = 0)

CDMA Encode/Decode



CDMA: two-sender interference



CDMA (cont'd)

CDMA Properties:

- protects users from interference and jamming (used in WW II)
- protects users from radio multipath fading
- allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")

Random Access protocols

- A node transmits **at random** (ie, no a priory coordination among nodes) at **full** channel data rate R.
- If two or more nodes "**collide**", they retransmit at random times
- The **random access MAC** protocol specifies how to detect collisions and how to recover from them (via delayed retransmissions, for example)
- Examples of random access MAC protocols:

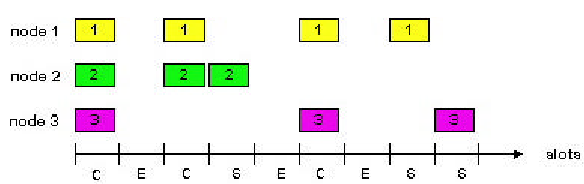
(a) SLOTTED ALOHA

(b) ALOHA

(c) CSMA and CSMA/CD

Slotted Aloha

- Time is divided into equal size slots (= full packet size)
- a newly arriving station transmits a the beginning of the next slot
- if collision occurs (assume channel feedback, eg the receiver informs the source of a collision), the source retransmits the packet at each slot with probability P, until successful.
- Success (S), Collision (C), Empty (E) slots
- S-ALOHA is channel utilization efficient; it is fully decentralized.



Slotted Aloha efficiency

If N stations have packets to send, and each transmits in each slot with probability *p*, the probability of successful transmission *S* is:

For a particular node, S= $p\,(1-p)^{(N-1)}$

For an arbitrary node of the N,

S = Prob (only one transmits) = $N\,p\,(1-p)^{(N-1)}$

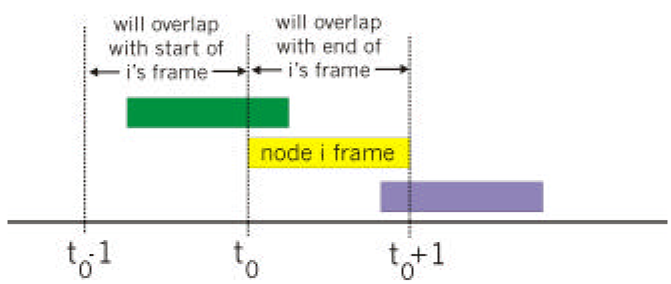
Optimal value of P: P = 1/N

For example, if N=2, S= .5

For N very large one finds S= 1/e (approximately, .37)

Pure (unslotted) ALOHA

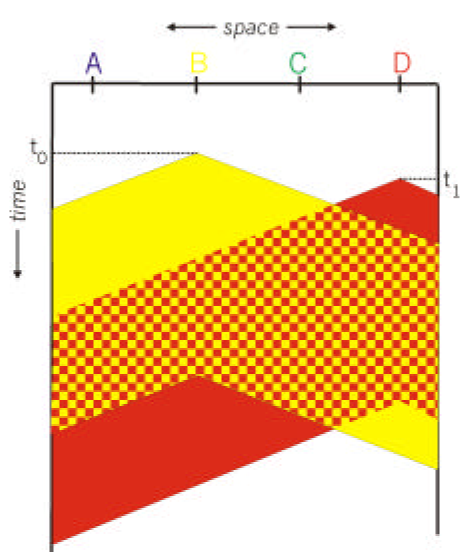
- Slotted ALOHA requires slot synchronization
- A simpler version, pure ALOHA, does not require slots
- A node transmits without awaiting for the beginning of a slot
- Collision probability increases (packet can collide with other packets which are transmitted within a window twice as large as in S-Aloha)
- Throughput is reduced by one half, ie S= 1/(2e)



CSMA (Carrier Sense Multiple Access)

- **CSMA**: listen before transmit. If channel is sensed busy, defer transmission
- **Persistent** CSMA: retry immediately when channel becomes idle (this may cause instability)
- **Non persistent CSMA**: retry after random interval
- Note: collisions may still exist, since two stations may sense the channel idle at the same time (or better, within a "vulnerable" window = round trip delay)
- In case of collision, the entire pkt transmission time is wasted

CSMA collisions



CSMA/CD (Collision Detection)

- **CSMA/CD**: carrier sensing and deferral like in CSMA. But, collisions are detected within a few bit times.
- Transmission is then aborted, reducing the channel wastage considerably.
- Typically, **persistent** retransmission is implemented
- Collision detection is **easy in wired LANs** (eg, E-net): can measure signal strength on the line, or code violations, or compare tx and receive signals
- Collision detection **cannot be done in wireless LANs** (the receiver is shut off while transmitting, to avoid damaging it with excess power)
- CSMA/CD can approach channel utilization =1 in LANs (low ratio of propagation over packet transmission time)

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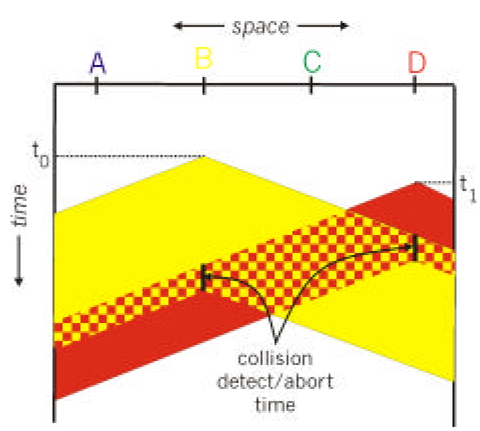
CSMA/CD collision detection



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“Taking Turns” MAC protocols

- So far we have seen that **channel partitioning** MAC protocols (TDM, FDM and CDMA) can share the channel fairly; but a single station cannot use it all
- **Random access** MAC protocols allow a single user full channel rate; but cannot share the channel fairly (in fact, **capture** is often observed)
- Also there are “taking turns” protocols...

“Taking Turns” MAC protocols

- **Taking Turns** MAC protocols achieve both fairness and full rate, at the expense of some extra control overhead

(a) Polling: a Master station on a LAN in turn “invites” the slave stations to transmit their packets (up to a Max). Problems: Request to Send/Clear to Send overhead, latency, single point of failure (Master)

(b) Token passing: the control **token** is passed from one node to the next sequentially. Can alleviate the latency and improve fault tolerance (in a token bus configuration). Still, elaborate procedures to recover from **lost token,** etc.

LAN technologies

- MAC protocols used in LANs, to control access to the channel
- **Token Rings**: IEEE 802.5 (IBM token ring), for computer room, or Department connectivity, up to 16Mbps; FDDI (Fiber Distributed Data Interface), for Campus and Metro connectivity, up to 200 stations, at 100Mbps.
- **Ethernets**: employ the CSMA/CD protocol; 10Mbps (IEEE 802.3), Fast E-net (100Mbps), Giga E-net (1,000 Mbps); by far the most popular LAN technology