Cyclic Redundancy Check (CRC)

- view data bits, $d_1 d_2 \ldots d_n$, as a polynomial:

$$A(x) = \sum_{i=0}^{n-1} d_i x^i.$$

- choose r+1 bit pattern (generator), G (leftmost and rightmost bits are both 1), viewed again as polynomial

$$G(x) = \sum_{i=0}^{r} g_i x^i.$$

- choose r CRC bits, R, such that

$$A(x)x^r + R(x) = G(x)H(x)$$

for some polynomial H(x). Here, addition of the polynomial coefficients is modulo 2 arithmetic.

- In other words, the polynomial represented by the concatenation of the data bits and the CRC bits is divisible by G(x)

CRC (continued)

- Note that, since in modulo 2 arithmetic, R(x) = -R(x), one can also interpret R(x) as the remainder when $A(x)x^r$ is divided by G(x).
- Error detection: divide the received string by G(x), and if the remainder is non-zero, announce an error.
- Claim: this CRC can detect burst of errors as long as the burst is of length r or shorter.

CRC Example

Addition of 2 polynomials is the same as mod 2 addition of the components of the two vectors of 0,1's (i.e. without carryover)

$$R = \text{remainder}\left[\frac{D \cdot 2^r}{G}\right]$$

```
               101011
G <- 1001 ) 101110000 -> D
            1001
             101
             000
             1010
             1001
              110
              000
              1100
              1001
               1010
               1001
                011 -> R
```

No carryover!

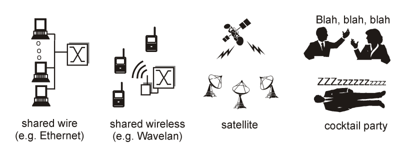
Link Layer

- Introduction and services
- Error detection and correction
- Multiple access protocols
- Link-Layer Addressing
- Ethernet

Multiple Access Links and Protocols

Two types of "links":

- point-to-point
  - point-to-point link between Ethernet switch and host
- shared wire or medium
  - traditional Ethernet
  - 802.11 wireless LAN



Multiple Access protocols

- single shared 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

Ideal Multiple Access Protocol

Shared 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

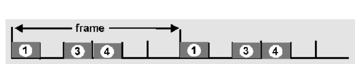
Three broad classes:

- 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" (Centralized polling or token-based)
  - Nodes take turns, but nodes with more to send can take longer turns

Channel Partitioning MAC protocols: TDMA

TDMA: time division multiple access

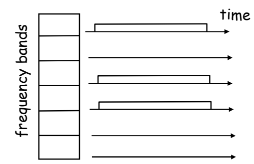
- access to channel in "rounds"
- each node gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-node LAN, 1,3,4 have pkt, slots 2,5,6 idle



Channel Partitioning MAC protocols: FDMA

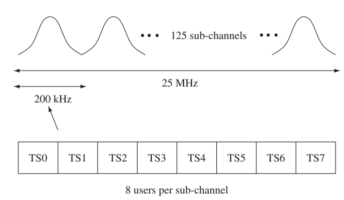
FDMA: frequency division multiple access

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



Example: GSM

- Global System for Mobile (GSM): digital cellular standard developed in Europe.
- 25MHz band divided in 200 kHz sub-channels, further divided into time-slots.



Channel Partitioning:Pros and Cons

- Pro: no conflict between different nodes.
- Con: serious waste of resource when a node has nothing to transmit.
- Good for continuous traffic like voice
- Not very efficient for bursty traffic.

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

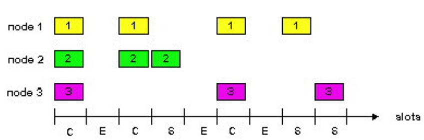
Assumptions

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

Operation

- when node obtains fresh frame, it transmits in next slot
- 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

Slotted Aloha efficiency

Efficiency is the long-run fraction of successful slots when there are many nodes, each with many frames to send

- N nodes with many frames to send, each transmits in slot with probability p (new arrival or re-Tx)
- prob that node 1 has success in a slot $= p(1-p)^{N-1}$
- prob that any node has a success $= Np(1-p)^{N-1}$
- For max efficiency with N nodes, 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 1/e = .37

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