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

• instantiation and implementation of various link layer technologies
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 Services

- **framing, link access:**
  - encapsulate datagram into frame, adding header, trailer
  - channel access if shared medium
  - “MAC” addresses used in frame headers to identify source, dest
    - different from IP address!

- **reliable delivery between adjacent nodes**
  - seldom used on low bit-error link (fiber, some twisted pair)
  - wireless links: high error rates
Link Layer Services (more)

• **flow control:**
  – pacing between adjacent sending and receiving nodes

• **error detection:**
  – errors caused by signal attenuation, noise.
  – receiver detects presence of errors:

• **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
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
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
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
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
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