Medium Access Layer
Ethernet Switches

- layer 2 (frame) forwarding, filtering using LAN addresses
- **Switching**: A-to-B and A’-to-B’ simultaneously, no collisions
- large number of interfaces
- often: individual hosts, star-connected into switch
  - Ethernet, but no collisions
Ethernet Switches

• **cut-through switching:** frame forwarded from input to output port without awaiting for assembly of entire frame
  - slight reduction in latency

• combinations of shared/dedicated, 10/100/1000 Mbps interfaces
Ethernet Switches (more)
IEEE 802.11 Wireless LAN

- wireless LANs: untethered (often mobile) networking
- IEEE 802.11 standard:
  - MAC protocol
  - unlicensed frequency spectrum: 900Mhz, 2.4Ghz

- **Basic Service Set (BSS)** (a.k.a. “cell”) contains:
  - wireless hosts
  - access point (AP): base station

- BSS’s combined to form distribution system (DS)
Ad Hoc Networks

- **Ad hoc network**: IEEE 802.11 stations can dynamically form network *without* AP
- Applications:
  - “laptop” meeting in conference room, car
  - interconnection of “personal” devices
  - battlefield
- IETF MANET
  (Mobile Ad hoc Networks) working group
IEEE 802.11 MAC Protocol: CSMA/CA

802.11 CSMA: sender
- if sense channel idle for DIFS sec.
  then transmit entire frame (no collision detection)
- if sense channel busy
  then binary backoff

802.11 CSMA receiver:
if received OK
  return ACK after SIFS
IEEE 802.11 MAC Protocol

802.11 CSMA Protocol:
- **NAV**: Network Allocation Vector
- 802.11 frame has transmission time field
- others (hearing data) defer access for NAV time units
Hidden Terminal effect

- **hidden terminals**: A, C cannot hear each other
  - obstacles, signal attenuation
  - collisions at B
- **goal**: avoid collisions at B
- **CSMA/CA**: CSMA with Collision Avoidance
Collision Avoidance: RTS-CTS exchange

- CSMA/CA: explicit channel reservation
  - sender: send short RTS: request to send
  - receiver: reply with short CTS: clear to send
- CTS reserves channel for sender, notifying (possibly hidden) stations
- avoid hidden station collisions
Collision Avoidance: RTS-CTS exchange

- RTS and CTS short:
  - collisions less likely, of shorter duration
  - end result similar to collision detection
- IEEE 802.11 allows:
  - CSMA
  - CSMA/CA: reservations
  - polling from AP
Point to Point Data Link Control

- one sender, one receiver, one link: easier than broadcast link:
  - no Media Access Control
  - no need for explicit MAC addressing
  - e.g., dialup link, ISDN line

- popular point-to-point DLC protocols:
  - PPP (point-to-point protocol)
  - HDLC: High level data link control (Data link used to be considered “high layer” in protocol stack!)
PPP Design Requirements [RFC 1557]

- **packet framing**: encapsulation of network-layer datagram in data link frame
  - carry network layer data of any network layer protocol (not just IP) *at same time*
  - ability to demultiplex upwards
- **bit transparency**: must carry any bit pattern in the data field
- **error detection** (no correction)
- **connection liveness**: detect, signal link failure to network layer
- **network layer address negotiation**: endpoint can learn/configure each other’s network address
PPP non-requirements

- no error correction/recovery
- no flow control
- out of order delivery OK
- no need to support multipoint links (e.g., polling)

Error recovery, flow control, data re-ordering all relegated to higher layers!
PPP Data Frame

- **Flag**: delimiter (framing)
- **Address**: does nothing (only one option)
- **Control**: does nothing; in the future possible multiple control fields
- **Protocol**: upper layer protocol to which frame delivered (e.g., PPP-LCP, IP, IPCP, etc)
PPP Data Frame

- **info**: upper layer data being carried
- **check**: cyclic redundancy check for error detection

```
  1  1  1  1 or 2  variable length  2 or 4  1
  01111110  11111111  00000011  protocol  info  check  01111110
  flag      control address  flag
```
Byte Stuffing

- “data transparency” requirement: data field must be allowed to include flag pattern <01111110>
  - **Q**: is received <01111110> data or flag?

- **Sender**: adds (“stuffs”) extra < 01111110> byte after each < 01111110> data byte
- **Receiver**:
  - two 01111110 bytes in a row: discard first byte, continue data reception
  - single 01111110: flag byte
Byte Stuffing

flag byte pattern in data to send

flag byte pattern plus stuffed byte in transmitted data
PPP Data Control Protocol

Before exchanging network-layer data, data link peers must

- **configure PPP link** (max. frame length, authentication)
- **learn/configure network layer information**
  - for IP: carry IP Control Protocol (IPCP) msgs (protocol field: 8021) to configure/learn IP address
Asynchronous Transfer Mode: ATM

- **1980s/1990’s standard for high-speed** (155Mbps to 622 Mbps and higher) Broadband Integrated Service Digital Network architecture

- **Goal:** integrated, end-end transport of carry voice, video, data
  - meeting timing/QoS requirements of voice, video (versus Internet best-effort model)
  - “next generation” telephony: technical roots in telephone world
  - packet-switching (fixed length packets, called “cells”) using virtual circuits
ATM architecture

- **adaptation layer**: only at edge of ATM network
  - data segmentation/reassembly
  - roughly analogous to Internet transport layer
- **ATM layer**: “network” layer
  - cell switching, routing
- **physical layer**
ATM: network or link layer?

**Vision:** end-to-end transport: “ATM from desktop to desktop”
- ATM *is* a network technology

**Reality:** used to connect IP backbone routers
- “IP over ATM”
- ATM as switched link layer, connecting IP routers
ATM Adaptation Layer (AAL)

- **ATM Adaptation Layer** (AAL): “adapts” upper layers (IP or native ATM applications) to ATM layer below
- AAL present only in end systems, not in switches
- AAL layer segment (header/trailer fields, data) fragmented across multiple ATM cells
  – analogy: TCP segment in many IP packets
ATM Adaption Layer (AAL) [more]

Different versions of AAL layers, depending on ATM service class:

- **AAL1**: for CBR (Constant Bit Rate) services, e.g. circuit emulation
- **AAL2**: for VBR (Variable Bit Rate) services, e.g., MPEG video
- **AAL5**: for data (eg, IP datagrams)
AAL5 - Simple And Efficient AL (SEAL)

- **AAL5**: low overhead AAL used to carry IP datagrams
  - 4 byte cyclic redundancy check
  - PAD ensures payload multiple of 48 bytes
  - Large AAL5 data unit to be fragmented into 48-byte ATM cells

<table>
<thead>
<tr>
<th>CPCS-PDU payload</th>
<th>PAD</th>
<th>Length</th>
<th>CRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-65535</td>
<td>0-47</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>
## ATM Layer

**Service:** transport cells across ATM network
- analogous to IP network layer
- very different services than IP network layer

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Internet</td>
<td>best effort</td>
<td>none</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>no (inferred via loss)</td>
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<tr>
<td>ATM</td>
<td>CBR</td>
<td>constant rate</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no congestion</td>
</tr>
<tr>
<td>ATM</td>
<td>VBR</td>
<td>guaranteed rate</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no congestion</td>
</tr>
<tr>
<td>ATM</td>
<td>ABR</td>
<td>guaranteed minimum</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td></td>
<td>yes</td>
</tr>
<tr>
<td>ATM</td>
<td>UBR</td>
<td>none</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
</tr>
</tbody>
</table>
ATM Layer: Virtual Circuits

- **VC transport**: cells carried on VC from source to dest
  - call setup, teardown for each call *before* data can flow
  - each packet carries VC identifier (not destination ID)
  - *every* switch on source-dest path maintain “state” for each passing connection
  - link, switch resources (bandwidth, buffers) may be *allocated* to VC: to get circuit-like perf.

- **Permanent VCs (PVCs)**
  - long lasting connections
  - typically: “permanent” route between to IP routers

- **Switched VCs (SVC)**:
  - dynamically set up on per-call basis
ATM VCs

• Advantages of ATM VC approach:
  – QoS performance guarantee for connection mapped to VC (bandwidth, delay, delay jitter)

• Drawbacks of ATM VC approach:
  – Inefficient support of datagram traffic
  – one PVC between each source/dest pair) does not scale (N*2 connections needed)
  – SVC introduces call setup latency, processing overhead for short lived connections
ATM Layer: ATM cell

- 5-byte ATM cell header
- 48-byte payload
  - Why?: small payload -> short cell-creation delay for digitized voice
  - halfway between 32 and 64 (compromise!)
ATM cell header

- **VCI**: virtual channel ID
  - will *change* from link to link thru net
- **PT**: Payload type (e.g. RM cell versus data cell)
- **CLP**: Cell Loss Priority bit
  - CLP = 1 implies low priority cell, can be discarded if congestion
- **HEC**: Header Error Checksum
  - cyclic redundancy check
ATM Physical Layer (more)

Two pieces (sublayers) of physical layer:

- **Transmission Convergence Sublayer (TCS):** adapts ATM layer above to PMD sublayer below
- **Physical Medium Dependent:** depends on physical medium being used

**TCS Functions:**
- Header **checksum** generation: 8 bits CRC
- Cell **delineation**
- With “unstructured” PMD sublayer, transmission of **idle cells** when no data cells to send
ATM Physical Layer

Physical Medium Dependent (PMD) sublayer

- **SONET/SDH**: transmission frame structure (like a container carrying bits);
  - bit synchronization;
  - bandwidth partitions (TDM);
  - several speeds: OC1 = 51.84 Mbps; OC3 = 155.52 Mbps; OC12 = 622.08 Mbps

- **TI/T3**: transmission frame structure (old telephone hierarchy): 1.5 Mbps/ 45 Mbps

- **unstructured**: just cells (busy/idle)
IP-Over-ATM

Classic IP only
- 3 “networks” (e.g., LAN segments)
- MAC (802.3) and IP addresses

IP over ATM
- replace “network” (e.g., LAN segment) with ATM network
- ATM addresses, IP addresses
IP-Over-ATM

Issues:

- IP datagrams into ATM AAL5 PDUs
- from IP addresses to ATM addresses
  - just like IP addresses to 802.3 MAC addresses!
Datagram Journey in IP-over-ATM Network

• at Source Host:
  – IP layer finds mapping between IP, ATM dest address (using ARP)
  – passes datagram to AAL5
  – AAL5 encapsulates data, segments to cells, passes to ATM layer

• ATM network: moves cell along VC to destination

• at Destination Host:
  – AAL5 reassembles cells into original datagram
  – if CRC OK, datgram is passed to IP
ARP in ATM Nets

- ATM network needs destination ATM address
  - just like Ethernet needs destination Ethernet address
- IP/ATM address translation done by ATM ARP (Address Resolution Protocol)
  - ARP server in ATM network performs broadcast of ATM ARP translation request to all connected ATM devices
  - hosts can register their ATM addresses with server to avoid lookup
X.25 and Frame Relay

Like ATM:

- wide area network technologies
- virtual circuit oriented
- origins in telephony world
- can be used to carry IP datagrams
  - can thus be viewed as Link Layers by IP protocol
X.25

- X.25 builds VC between source and destination for each user connection
- **Per-hop control along path**
  - error control (with retransmissions) on each hop using LAP-B
    - variant of the HDLC protocol
  - per-hop flow control using credits
    - congestion arising at intermediate node propagates to previous node on path
    - back to source via back pressure
IP versus X.25

- X.25: reliable in-sequence end-end delivery from end-to-end
  - “intelligence in the network”
- IP: unreliable, out-of-sequence end-end delivery
  - “intelligence in the endpoints”
- gigabit routers: limited processing possible
- 2000: IP wins
Frame Relay

- Designed in late ‘80s, widely deployed in the ‘90s
- Frame relay service:
  - no error control
  - end-to-end congestion control
Frame Relay (more)

- Designed to **interconnect** corporate customer LANs
  - typically permanent VC’s: **“pipe”** carrying aggregate traffic between two routers
  - switched VC’s: as in ATM
- corporate customer **leases** FR service from public Frame Relay network (eg, Sprint, ATT)
Frame Relay (more)

- Flag bits, 01111110, delimit frame
- address:
  - 10 bit VC ID field
  - 3 congestion control bits
    - FECN: forward explicit congestion notification (frame experienced congestion on path)
    - BECN: congestion on reverse path
    - DE: discard eligibility
Frame Relay -VC Rate Control

- Committed Information Rate (CIR)
  - defined, “guaranteed” for each VC
  - negotiated at VC set up time
  - customer pays based on CIR

- DE bit: Discard Eligibility bit
  - Edge FR switch measures traffic rate for each VC; marks DE bit
  - DE = 0: high priority, rate compliant frame; deliver at “all costs”
  - DE = 1: low priority, eligible for discard when congestion
Frame Relay - CIR & Frame Marking

- **Access Rate**: rate $R$ of the access link between the source router (customer) and the edge FR switch (provider); $64\text{Kbps} < R < 1,544\text{Kbps}$

- Typically, **many VCs** (one per destination router) multiplexed on the same access trunk; each VC has its own **CIR**

- Edge FR switch **measures** traffic rate for each VC; it **marks**

- (ie $\text{DE} \leq 1$) frames which **exceed** CIR (these may be later dropped)
Summary

• principles behind data link layer services:
  – error detection, correction
  – sharing a broadcast channel: multiple access
  – link layer addressing, ARP

• various link layer technologies
  – Ethernet
  – hubs, bridges, switches
  – IEEE 802.11 LANs
  – PPP
  – ATM
  – X.25, Frame Relay