Communication is central

- process management: messages synchronize, coordinate
- file mgmt: messages access and transmit files and directory information
- device mgmt: messages carry data
- memory mgmt: messages carry data

Network Layer
- facilities to send and receive messages to addressed locations
- routing: messages are forwarded

Communication Networks

Steve Goddard
cse.unl.edu

/~goddard/Courses/CSCE855
Communication Networks

- Open System Interconnect (OSI) 7-layer model
  - Physical
  - Data Link
  - Network
  - Transport
  - Session
  - Presentation
  - Application

OSI 7-layer model

- Physical
  - transmit bits and bytes
  - LANs
- Data Link
  - translate signals (bits/bytes) into frames
  - checksums, source and destination
- Network
  - translate frames into packets
  - packet routing
  - datagrams
OSI 7-layer model

◆ **Transport**
  » reliable end-to-end byte streams
  » packet re-sending, packet ordering
  » virtual circuits

◆ **Session**
  » high-level naming, bi-directional streams
  » managing more than one communication session

◆ **Presentation**
  » translation between protocols
  » heterogeneous systems

◆ **Application**
  » user applications

OSI 7-layer model (cont.)

◆ **Higher-level facilities**
  » Application
  » Presentation
  » Session

◆ **Basic network communication services**
  » transport
  » network

◆ **Physical medium and LANs**
  » data-link
  » physical
OSI 7-layer model (cont.)

◆ General tradeoff
  » quite flexible
    ❖ supports a wide range of applications
    ❖ makes communication as transparent as user needs it (i.e. user can choose level as needed)
  » each layer adds overhead
    ❖ reduce number of layers
    ❖ simplify layers
    ❖ improve implementations

◆ Specific protocols for different problems

Network and Transport Layers

◆ Network layer does not provide reliability
  » packets may be lost
    ❖ no means to detect errors
    ❖ higher levels must provide for detection of errors and re-sending packets
  » packets may be received out-of-order
    ❖ large messages broken down into fixed packet size
    ❖ packets reconstructed to make message at recipient
Network and Transport Layers (cont.)

◆ Transport layer
  » transparent transfer of data
  » reliability provided
    ♦ re-sending lost messages
    ♦ packet ordering

◆ Network layer provides services for transport layer
  » connectionless (IP - datagram service)
  » connection-oriented (X.25 - virtual circuit service)

Connectionless and Connection-Oriented Services

◆ Connectionless services
  » datagrams: single message sent from point-to-point
  » no relationship established between packets
  » advantages:
    ♦ protocol is simple
    ♦ data delivery is fast
  » disadvantages:
    ♦ no error handling, ordering of packets
    ♦ each packet self-identifying; leads to long headers
    ♦ packets may arrive out of order
Connection-oriented service

» virtual circuit: data path between endpoints
» communication can have a state
  ✤ send a reply every 5 messages
» three phases
  ✤ establish connection
  ✤ transfer data
  ✤ release connection
» advantage: reliable communication
» disadvantage:
  ✤ protocol complexity makes communication slower
  ✤ error handling, flow control add overhead

Overhead from “virtual circuits”

» connection establishment, release
» reliability
  ✤ detecting lost messages (time-outs, etc)
  ✤ re-sending lost messages
  ✤ message acknowledgment
  ✤ packet ordering
  ✤ ordering algorithm
  ✤ sending additional order information

Network layer

» virtual circuits do not guarantee reliability
» connectionless services (datagrams) dominate
Connection-Oriented Services (cont.)

- Transport layer
  - virtual circuits guarantee reliability
    - TCP
  - some connectionless services have reliability services
    - IP: guaranteed packet delivery with TCP over IP

Internet Protocols

- Internet Protocol (IP)
  - connection-less
  - network routing
  - datagram construction
Internet Protocols

◆ Transmission Control Protocol (TCP)
  » connection-oriented; establish a (logical) virtual circuit
  » positive acks, time-out
  » sequence numbers
  » connection procedures
  » state information is kept

◆ User Datagram Protocol (UDP)
  » no acks, messages may arrive out-of-order
  » essentially IP with some minor additions

<table>
<thead>
<tr>
<th>Transmission Control Protocol (TCP)</th>
<th>User Datagram Protocol (UDP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internet Protocol (IP)</td>
<td></td>
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</tbody>
</table>

Asynchronous Transfer Mode (ATM)

◆ Connection Oriented

◆ Virtual circuits

◆ Fixed-size blocks (cells)

◆ Connection is established and all cells follow the same route over a switched network
ATM

Rationale

◆ Voice transmissions require steady bandwidth
  » bandwidth needs are low, but need to be consistent
◆ Data (esp. real-time) is bursty
  » high rates needed when transmitting data, no bandwidth otherwise
◆ Want networks to handle both
  » solution: small packets that can be rapidly switched

ATM

Characteristics

◆ Fixed size blocks sent over virtual circuits
  » routing info stored in switches
◆ A packet-switching network
  » meaning packet transmissions can be interleaved
◆ Packets broken into very small cells
◆ Allowed to drop cells
  » usually results in re-transmission of entire packet
ATM (lowest three) Layers

- Physical
  » same functionality as OSI Layer 1

- ATM
  » OSI Layer 2 and part of OSI Layer 3

- Adaptation
  » OSI Layer 4 but without reliable end-to-end service

ATM Physical Layer

- Designed to use optical technology
- Essentially digital switch technology
  » star topology with switch as central node
  » each machine has dedicated connection to switch
  » multiple communication paths can be open simultaneously
- Switching networks...
  » allow scaling to large networks
ATM
ATM Layer

◆ Connection-oriented cell routing
  » connection set up only if sufficient resources are available

◆ Cell structure
  » 48 bytes of data
  » 5 header fields (53 bytes total)
  » Virtual Path Identifier (VPI)
  » Virtual Circuit Identifier (VCI)

ATM
ATM Layer (cont.)

◆ Virtual channel (VC)
  » unidirectional association between source and destination
  » refers to specific channels inside the virtual path
  » allocated dynamically at connection setup

◆ Virtual paths (VP)
  » collection of VCs
  » (semi-)permanent connection between pairs of endpoints
ATM

Adaptation Layer

- Essentially chops packets into cells ... then re-assembles them
- Cells can be dropped
  » adaptation layer not reliable
- Need higher layers for transport connections
  » use ATM cells to carry TCP/IP packets
  » TCP/IP will take care of reliability
  » means entire packet will need to be re-sent

ATM Switching

- VC and VP together provide routing information
  » VPI: refers to virtual path on the physical link
  » VCI: refers to specific VC inside VP
- General routing strategy
  » VPI field used by routing tables to determine next destination
  » VPI field modified at each hop
  » if virtual path used by more than one cell
    - use VCI field to determine destination
    - VCI field also changed at each hop
ATM Switching (cont.)

◆ Cells needing the same output line
  » must choose whether to buffer or not
    ❖ standard allows to just drop a cell
    ❖ don’t want to do that often
  » buffering at the input port
    ❖ pick one cell to forward, hold others
    ❖ long input queues may result
    ❖ this blocks cells wanting to go to other output ports
    ❖ ...known as head-of-line blocking
  » buffering at the output port
    ❖ queue located at output port
    ❖ removes head-of-line blocking
    ❖ can also have a pool of input and output buffers

Local Area Networks

◆ Three dominant topologies
  » star (digital switch, ATM)
  » ring
  » bus

◆ Ethernet
  » multi-access bus technology
  » messages broadcast to all nodes
  » all nodes listen to bus
    ❖ receives only messages addressed to the node
  » bus contention: single communication line
Ethernet

- Implements physical and data link layers
  - multi-access bus
  - transmits data link frames
- Access Method:Carrier sense multiple access with collision detection (CSMA/CD)
  - CSMA to reduce the chance of collisions
  - CD to detect collisions (and retransmit with back off)

## Ethernet

### CSMA/CD

- Carrier Sense Multiple Access (CSMA)
  - carrier sense: listen for clear bus
    - if busy, wait for clear carrier
    - if clear, send message (transmit a packet)
  - listen to bus while transmitting for CD
- Collision Detection (CD)
  - sender compares outgoing message to received message
    - if mismatch occurs, assume collision has occurred
  - if collision has occurred
    - each sender waits a period of time (back off)
    - then re-send packet
**Ethernet**

**Collision Detection**

- Assume a collision occurs
  - all nodes back off 2 sec and re-transmits
  - what will happen?
- Back off intervals
  - nodes detection collision back off a random time interval
  - what if another collision occurs
    - may want to back off a longer time period
  - binary exponential backoff
    - $i^{th}$ collision back off between 0 and $2^{i-1}$ interval

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**Ethernet vs. ATM**

- **Ethernet**
  - keep traffic fairly sparse to avoid collisions
    - gateways to divide network into smaller units
  - limit transmission time
    - keep packet size small
    - keep length of network small
    - increase transmission speed
- **ATM**
  - packets can be transmitted in parallel
  - “collisions” handled by ATM buffers
    - buffers are a finite size
    - cells can be dropped - re-transmit packet
  - scaling to larger networks
    - use larger switches
    - switching networks
    - network speed a factor, but importance reduced by parallel transfer in ATM
    - busy machine can be a bottleneck