Computer Networks

What you will learn

• Lots of terminology
• Basics of communications
• Internetworking
• Network hardware
• Protocols and Layering
• Network Addressing
• Routing, Flow, Error and Congestion Control
What you will not learn learn

• Network operating systems
• How to configure/operate equipment in a vendor-specific way
• How to design and implement network software

You will not learn working with networks!
You will learn how to learn working with them
What is a Computer Network?

• A collection of transmission hardware and facilities, terminal equipment, and protocols

• Provides communication that is
  – Reliable
  – Fair
  – Efficient
  – From one application to another

• Automatically detects and corrects
  – Data corruption
  – Data loss
  – Duplication
  – Out-of-order delivery

• Automatically finds optimal path from source to destination
Network examples

• Telephone
• Satellite
• TV programs
• Internet
  – ftp
  – mail
  – Chat
  – …
Uses of Computer Networks

- Business Applications
  - online buying
- Home Applications
  - mail, chat
- Mobile Users
  - wireless: laptops, PDA, mobile, in plane
- Social Issues
**Business Applications of Networks**

- A network with two clients and one server.
  - Check bank account
  - Pay bills
  - Reserve ticket

- The client-server model involves requests and replies.
Home Network Applications

• Access to remote information
  – Leaning online, downloading

• Person-to-person communication
  – chat, phone

• Interactive entertainment
  – games, movies, ...

• Electronic commerce
Home Network Applications

• Peer-to-peer (P2P)
  – Kazaa, Emule,

• E-commerce

<table>
<thead>
<tr>
<th>Full name</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Business-to-consumer</td>
<td>Ordering books on-line</td>
</tr>
<tr>
<td>Business-to-business</td>
<td>Car manufacturer ordering tires from supplier</td>
</tr>
<tr>
<td>Government-to-consumer</td>
<td>Government distributing tax forms electronically</td>
</tr>
<tr>
<td>Consumer-to-consumer</td>
<td>Auctioning second-hand products on-line</td>
</tr>
<tr>
<td>Peer-to-peer</td>
<td>File sharing</td>
</tr>
</tbody>
</table>
## Mobile Network Users

- Combinations of wireless networks and mobile computing.

<table>
<thead>
<tr>
<th>Wireless</th>
<th>Mobile</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>Desktop computers in offices</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>A notebook computer used in a hotel room</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
<td>Networks in older, unwired buildings</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Portable office; PDA for store inventory</td>
</tr>
</tbody>
</table>
Social Issues

• Discussions about
  – politics,
  – religion,
  – ...

• Hack and robbery
What A Network Includes

• Transmission hardware
• Special-purpose hardware devices
  – interconnect transmission media
  – control transmission
  – run protocol software
• Protocol software
  – encodes and formats data
  – detects and corrects problems
Network Hardware

• Transmission technology (2 types)
  – Broadcast links
  – Point-to-point links

• Scale
  – Local Area Networks (LAN)
  – Metropolitan Area Networks (MAN)
  – Wide Area Networks (WAN)
  – Wireless Networks
  – Home Networks
  – Internetworks
Broadcast Networks

- There are **A single communication link** for all systems in network = **Broadcasting**
  - TV programs

- Messages (**Packets**) contain destination address

- **Multicasting**: A subset of systems can get the message

- Usually used in small networks like LANs
**Point-to-point**

- Individual connections between pairs of machines.
- There are many **paths** from one machine to another
  - Need efficient **routing algorithms**

- Usually used in large scale networks like WAN
Therefore...

• Packets
  – Messages - the "chunk" of data transmitted from one machine to the next.

• Addressing
  – One to one: Packet contains specific target address.
  – Broadcasting: All machines on the network receive and process the packet.
  – Multicasting: A subset of machines receive and process the packet.
## Classification by Scale

<table>
<thead>
<tr>
<th>Interprocessor Distance</th>
<th>Processors Located in the Same</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m</td>
<td>Square meter</td>
<td>Personal area network</td>
</tr>
<tr>
<td>10 m</td>
<td>Room</td>
<td>Local area network</td>
</tr>
<tr>
<td>100 m</td>
<td>Building</td>
<td>Metropolitan area network</td>
</tr>
<tr>
<td>1 km</td>
<td>Campus</td>
<td>Wide area network</td>
</tr>
<tr>
<td>10 km</td>
<td>City</td>
<td>The Internet</td>
</tr>
<tr>
<td>100 km</td>
<td>Country</td>
<td></td>
</tr>
<tr>
<td>1000 km</td>
<td>Continent</td>
<td></td>
</tr>
<tr>
<td>10,000 km</td>
<td>Planet</td>
<td></td>
</tr>
</tbody>
</table>
Local Area Networks

• Privately owned. Can be up to several kilometers long; Ex. in a building

• Separated by their:
  1. **Size:** Restricted so worst case transmission time can be contained.
  2. **Transmission technology:** Single channel with multiple machines connected to it. Run at speeds of 10, 100, or more Mbps.
  3. **Topology:** two popular broadcast networks:
     • **Bus**
     • **Ring**

![Bus topography diagram](Image of Bus topography)

![Ring topography diagram](Image of Ring topography)
Local Area Networks

- **Topology ...**
  - **Bus**
    - **Ethernet (IEEE 802.3):**
      - Bus based broadcast network with decentralized control at 10 or 100 Mbps.
  
  - **Ring**
    - **Token Ring (IEEE 802.5):**
      - Ring based broadcast network with token arbitration at 4 or 16 Mbps.

- ✔ Low delay. High reliability.
- ✗ Requires collision arbitration
Metropolitan Area Networks

• Larger version of LAN ("city" wide).
  – Public or private / data or voice.
  – Broadcast - no switches.
  – Can be distinguished from LANs based on wiring mechanism.
    • **DQDB** (Distributed Queue Dual Bus), **IEEE 802.6**

• **Ex.** A metropolitan area network based on cable TV
Wide Area Networks

• Networks spanning large distances.

• **Ex.** Relation between hosts on LANs and the subnet.

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• **Hosts** or End Systems:
  – Machines running user applications.
**Wide Area Networks**

• (Communication) **Subnet:**
  – Connections between hosts - transmission lines + switches.
  – A "locality" understanding each other's addresses.

• **Circuits (Channels, Trunks):**
  – Transmission lines move the bits.

• **Packet switching nodes (Router, Intermediate systems):**
  – Specialized computers moving data between several inputs to several outputs.

• **Point-to-point/Store-and-forward/Packet-switched** -
  – Moving through a series of routers, packets are received at a router, stored there, then forwarded to the next router.
Wide Area Networks

- Ex. A stream of packets from sender to receiver.
Wireless Networks

• Used where computer is mobile or far away from wires.
  – Only 1 - 2 Mbps,
  – higher error rates,
  – interference

• Use
  – Sound
  – Light and mirrors
  – Infrared
  – RF
  – Microwave
Wireless Networks

Bluetooth configuration

Wireless LAN

- Ex. A flying LAN
Network Software

• Primary networks more depend on hardware
• It talks about the philosophy of connecting together two entities.

• “Layering” is the key word
  – Protocol Hierarchies
  – Design Issues for the Layers
  – The Relationship of Services to Protocols
Network Software

• **Layers**:
  – The concept that network software is organized functionally into levels. A level on one host talks to the same level on another host (its peer).

• **Protocol**:
  – The protocol is the convention or standard that a layer uses to talk to the other layer. An agreement or standard on the conversation.
Protocol Hierarchies

- Layers,
  Important that each layer perform specific actions.

- Protocols,

- Interfaces
  Defines the services that one layer offers another (either up or down.)
Network Software

- Ex. Protocol Hierarchies

  information flow supporting virtual communication in layer 5
Network Software

• Physical Medium:
  – Underneath the layers is the wire or fiber or whatever.

• Network architecture:
  – A set of layers and protocols. It contains details on what happens in the layer and what the layers says to its peer.
  – Functional interfaces and implementation details are not part of the spec, since that's not visible outside the machine.

• Protocol stack:
  – A list of protocols used by a system, one protocol per layer.

• Information flow:
  – "Send_to_peer" rather than "call_next_layer_down".
Design Issues for the Layers

<table>
<thead>
<tr>
<th>Connection</th>
<th>Both Directions</th>
<th>Simultaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simplex</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Half duplex</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Full duplex</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- Addressing
- Error control. (garbled or missing.)
- Preservation of message ordering.
- Flow control.
- Breaking up messages into a smaller chunks (and reassembly.)
- Multiplexing messages on same connection.
- Routing - how to get from one host to another.
Connection-Oriented and Connectionless Services

• Connection oriented service:
  – Like the phone system. The system establishes a connection, uses it, and closes it. Acts like a tube. Data comes out the other end in the same order as it goes in.
    » Connection Setup
    » Data Transfer
    » Connection Termination

• Connectionless service:
  – Like the post office. Each message has the entire address on it. Each message may follow a different route to its destination. Ordering not maintained.
    » Data Transfer
Connection-Oriented and Connectionless Services

• Quality of service (QoS):
  – Will the message arrive?
    • A reliable connection-oriented service guarantees success.
      – Message sequence - message boundaries and order are maintained.
      – Byte streams - messages are broken up or combined; flow is bytes. Can pair mechanism with upper-layer requirements.

• Datagram Service:
  – Like junk mail. It's not worth the cost to determine if it actually arrived. Needs a high probability of arrival, but 100% not required. Connectionless, no acknowledgment.

• Acknowledged datagram service:
  – As above, but improved reliability via acknowledgment.

• Request-reply service:
  – Acknowledgment is in the form of a reply.
### Connection-Oriented and Connectionless Services

- Summary of six different types of service.

<table>
<thead>
<tr>
<th>Service</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliable message stream</td>
<td>Sequence of pages</td>
</tr>
<tr>
<td>Reliable byte stream</td>
<td>Remote login</td>
</tr>
<tr>
<td>Unreliable connection</td>
<td>Digitized voice</td>
</tr>
<tr>
<td>Unreliable datagram</td>
<td>Electronic junk mail</td>
</tr>
<tr>
<td>Acknowledged datagram</td>
<td>Registered mail</td>
</tr>
<tr>
<td>Request-reply</td>
<td>Database query</td>
</tr>
</tbody>
</table>
Connection-Oriented and Connectionless Services

Service Primitives for connection-oriented service

<table>
<thead>
<tr>
<th>Primitive</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>LISTEN</td>
<td>Block waiting for an incoming connection</td>
</tr>
<tr>
<td>CONNECT</td>
<td>Establish a connection with a waiting peer</td>
</tr>
<tr>
<td>RECEIVE</td>
<td>Block waiting for an incoming message</td>
</tr>
<tr>
<td>SEND</td>
<td>Send a message to the peer</td>
</tr>
<tr>
<td>DISCONNECT</td>
<td>Terminate a connection</td>
</tr>
</tbody>
</table>

Client machine

- Client process
- Operating system
  - Kernel
  - Protocol stack
  - Drivers

Server machine

- Server process
- Operating system
  - Kernel
  - Protocol stack
  - Drivers

(1) Connect request
(2) ACK
(3) Request for data
(4) Reply
(5) Disconnect
(6) Disconnect
Services to Protocols Relationship

- Services are primitives that a layer provides for the layer above it.

- Protocols are rules governing the meaning of frames/packets/messages exchanged with the peer entity.
What is Layering?

• Modular approach to network functionality
• Example:

```
Application
Application-to-application channels
Host-to-host connectivity
Link hardware
```
Layering

• Module in layered structure
• Set of rules governing communication between network elements (applications, hosts, routers)
• Protocols define:
  – Interface to higher layers (API)
  – Interface to peer
    • Format and order of messages
    • Actions taken on receipt of a message
Layering Characteristics

- Each layer relies on services from layer below and exports services to layer above
- Interface defines interaction
- Hides implementation - layers can change without disturbing other layers (black box)
Reference Models

• Headers, Data, and Trailers

| flags | source | destination | priority | next protocol | data | CRC |

• Encapsulation

```
Layer x-2
  | Header | data | Trailer |
Layer x-1
  | Header | data | Trailer |
Layer x
  v
  Application
```

```
Reference Models

- There are two competing models for how the software is layered. These are the OSI and the TCP models.

- **OSI (Open Systems Interconnection)**
  - Developed by ISO (International Standards Organization)
  - 7 layers

- **TCP (Transfer Control Protocol)**
  - Used in the Arpanet and in the Internet. Common mechanism that is surpassing the OSI Model.
  - 5 layers
Reference Models

OSI

<table>
<thead>
<tr>
<th>Layer</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Application</td>
</tr>
<tr>
<td>6</td>
<td>Presentation</td>
</tr>
<tr>
<td>5</td>
<td>Session</td>
</tr>
<tr>
<td>4</td>
<td>Transport</td>
</tr>
<tr>
<td>3</td>
<td>Network</td>
</tr>
<tr>
<td>2</td>
<td>Data link</td>
</tr>
<tr>
<td>1</td>
<td>Physical</td>
</tr>
</tbody>
</table>

TCP/IP

<table>
<thead>
<tr>
<th>Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
</tr>
<tr>
<td>Transport</td>
</tr>
<tr>
<td>Internet</td>
</tr>
<tr>
<td>Host-to-network</td>
</tr>
</tbody>
</table>

Not present in the model
Principles used to develop OSI Layering:

1. Need a layer for each different level of abstraction.
2. Each layer performs a well defined function.
3. Each layer should be standardizable.
4. Layer boundaries should minimize data flow across those boundaries.
5. The right number of layers - don't put too many functions together, but not too many layers either.
Reference Models

Layer 7: Application
- Application protocol
- Name of unit exchanged: APDU

Layer 6: Presentation
- Presentation protocol
- Name of unit exchanged: PPDU

Layer 5: Session
- Session protocol
- Name of unit exchanged: SPDУ

Layer 4: Transport
- Transport protocol
- Communication subnet boundary
- Name of unit exchanged: TPDУ

Layer 3: Network
- Internal subnet protocol
- Name of unit exchanged: Packet

Layer 2: Data link
- Name of unit exchanged: Frame

Layer 1: Physical
- Name of unit exchanged: Bit

Host A
- Network layer host-router protocol
- Data link layer host-router protocol
- Physical layer host-router protocol

Host B
OSI Reference Model

1 Physical Layer:
   - Purpose: Transmits raw bits across a medium.
   - Electrical: Concerns are voltage, timing, duplexing, connectors, etc.

2 Data Link Layer:
   - Framing: Breaks apart messages into frames. Reassembles frames into messages.
   - Error handling: solves damaged, lost, and duplicate frames.
   - Flow control: keeps a fast transmitter from flooding a slow receiver.
   - Gaining Access: if many hosts have usage of the medium, how is access arbitrated.
Network Layer:

- **Routing**: What path is followed by packets from source to destination. Can be based on a static table, when the connection is created, or when each packet is sent.

- **Congestion**: Controls the number packets in the subnet.

- **Accounting**: Counts packets/bytes for billing purposes.
Transport Layer:
- **Reliability**: Ensures that packets arrive at their destination. Reassembles out of order messages.
- **Hides network**: Allows details of the network to be hidden from higher level layers.
- **Service Decisions**: What type of service to provide; error-free point to point, datagram, etc.
- **Mapping**: Determines which messages belong to which connections.
- **Naming**: "Send to node ZZZ" must be translated into an internal address and route.
- **Flow control**: keeps a fast transmitter from flooding a slow receiver.
OSI Reference Model

5 Session Layer:
   – **Sessions**: Provides services that span a particular message. For instance, a login session could be logged.
   – **Synchronization**: Provide way to subdivide a long mechanism for reliability.

6 Presentation Layer:
   – **Prettiness**: Syntax and semantics of information transmitted. Understands the nature of the data being transmitted. Converts ASCII/EBCDIC, big endian/little endian

7 Application Layer:
   – **Interfacing**: Terminal type translation.
   – **File transfer**: Programs able to understand directory structures and naming conventions and map them onto various systems.
OSI Reference Model

Data Transmission in the OSI Model
**TCP/IP Reference Model**

### Internet Layer
- **Connector**: Provides packet switched connectionless service.
- **Routing**: The IP (Internet Protocol) does delivery and congestion control.

### Transport Layer
- **TCP (Transmission Control Protocol)**: provides a reliable connection oriented protocol that delivers a byte stream from one node to another. Guarantees delivery and provides flow control.
- **UDP (User Datagram Protocol)** provides an unreliable connectionless protocol for applications that provide their own.
TCP/IP Reference Model

4 Application Layer

– Terminal       Telnet
– File transfer   FTP
– The Web         HTTP
– Mail            SMTP
Network Security