CS3600 — SYSTEMS AND NETWORKS
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Lecture 17: Internet architecture

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A Generic Switch

incoming links  Switch  outgoing links
A Generic Switch

incoming links  Switch  outgoing links

How to Demultiplex?
A Generic Switch

incoming links

Switch

outgoing links

How to Demultiplex?

How to Multiplex?
A Generic Switch

How to Demultiplex?

How to Switch?

How to Multiplex?
Circuit Switching: Multiplexing/Demultiplexing

Frames

Slots = 0 1 2 3 4 5 0 1 2 3 4 5
Circuit Switching: Multiplexing/Demultiplexing

- Time divided in frames and frames divided in slots

![Diagram showing frames and slots](https://example.com/diagram.png)
Circuit Switching: Multiplexing/Demultiplexing

- Time divided in frames and frames divided in slots
- Relative slot position inside a frame determines which conversation the data belongs to
  - E.g., slot 0 belongs to red conversation
- Needs synchronization between sender and receiver
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- In case of non-permanent conversations
  - Needs to dynamic bind a slot to a conversation
  - How to do this?
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  - Needs to dynamic bind a slot to a conversation
  - How to do this?
- If a conversation does not use its circuit the capacity is lost!
Circuit Switching

• Three phases
  1. circuit establishment
  2. data transfer
  3. circuit termination
• If circuit not available: busy
• Examples
  – Telephone networks
  – ISDN (Integrated Services Digital Networks)
Timing in Circuit Switching

- Propagation delay between Host 1 and Switch 1
- Propagation delay between Host 1 and Host 2
- Transmission delay

Information

time
Timing in Circuit Switching

Circuit Establishment

Transmission

Circuit Termination

propagation delay between Host 1 and Switch1
propagation delay between Host 1 and Host 2

Transmission delay

Information

time
Packet Switching: Multiplexing/Demultiplexing
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• How to demultiplex?
Packet Switching: Multiplexing/Demultiplexing

- Data from any conversation can be transmitted at any given time
  - A single conversation can use the entire link capacity if it is alone
- How to demultiplex?
  - Use meta-data (header) to describe data
Packet Switching

• Data are sent as formatted bit-sequences, so-called packets.
• Packets have the following structure:

\[
\begin{array}{c|c|c}
\text{Header} & \text{Data} & \text{Trailer} \\
\end{array}
\]

• Header and Trailer carry control information (e.g., destination address, check sum)
• At each node the entire packet is received, stored briefly, and then forwarded to the next node based on the header information (Store-and-Forward Networks)
• Allows statistical multiplexing
Packet Switch

incoming links    Node    outgoing links

Memory

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Datagram Packet Switching
Datagram Packet Switching

- Each packet is independently switched
Datagram Packet Switching

- Each packet is independently switched
  - Each packet header contains destination address
Timing of Datagram Packet Switching

transmission time of Packet 1 at Host 1

propagation delay between Host 1 and Switch 2

processing delay of Packet 1 at Switch 2

Packet 1
Packet 2
Packet 3
Packet 1
Packet 2
Packet 3
Packet 1
Packet 2
Packet 3

Host 1
Switch 1
Switch 2
Host 2
Packet-Switching vs. Circuit-Switching
Packet-Switching vs. Circuit-Switching

• Most important advantage of packet-switching over circuit switching: ability to exploit statistical multiplexing
  – More efficient bandwidth usage
• However, packet-switching needs to buffer and deal with congestion
  – More complex switches
  – Harder to provide good network services (e.g., delay and bandwidth guarantees)
Organizing Network Functionality

- Many kinds of networking functionality
  - e.g., encoding, framing, routing, addressing, reliability, etc.
- Many different network styles and technologies
  - circuit-switched vs packet-switched, etc.
  - wireless vs wired vs optical, etc.
- Many different applications
  - ftp, email, web, P2P, etc.

- Network architecture
  - How should different pieces be organized?
  - How should different pieces interact?
Problem

Application

SMTP
SSH
FTP

Transmission Media

Coaxial cable
Fiber optic
Problem

Application

SMTP  SSH  FTP  HTTP

Transmission Media

Coaxial cable  Fiber optic
Problem

Application

SMTP
SSH
FTP
HTTP

Transmission Media

Coaxial cable
Fiber optic
Problem

Application
- SMTP
- SSH
- FTP
- HTTP

Transmission Media
- Coaxial cable
- Fiber optic
- Packet radio
Problem

Application
- SMTP
- SSH
- FTP
- HTTP

Transmission Media
- Coaxial cable
- Fiber optic
- Packet radio
Problem

- new application has to interface to all existing media
  - adding new application requires $O(m)$ work, $m =$ number of media
- new media requires all existing applications be modified
  - adding new media requires $O(a)$ work, $a =$ number of applications
Problem

- new application has to interface to all existing media
  - adding new application requires $O(m)$ work, $m = \text{number of media}$
- new media requires all existing applications be modified
  - adding new media requires $O(a)$ work, $a = \text{number of applications}$
- total work in system $O(ma) \rightarrow$ eventually too much work to add apps/media
- Application end points may not be on the same media!
Solution: Indirection

- Solution: introduce an intermediate layer that provides a single abstraction for various network technologies
  - O(1) work to add app/media
  - Indirection is an often used technique in computer science

```
+-----------------+     +-----------------+     +-----------------+
| Application     |     | Intermediate    |     | Transmission   |
|                 |     | layer            |     | Media          |
| SMTP            |     |                 |     | Coaxial cable  |
| SSH             |     |                 |     | Fiber optic    |
| NFS             |     +-----------------+     +-----------------+
```

- SMTP
- SSH
- NFS
- Coaxial cable
- Fiber optic
Solution: Indirection

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  - O(1) work to add app/media
  - Indirection is an often used technique in computer science
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![Diagram showing application, intermediate layer, and transmission media with SMTP, SSH, NFS, HTTP, Coaxial cable, and Fiber optic connections.]
Solution: Indirection

- Solution: introduce an intermediate layer that provides a single abstraction for various network technologies
  - $O(1)$ work to add app/media
  - Indirection is an often used technique in computer science

Diagram:

- **Application**:
  - SMTP
  - SSH
  - NFS
  - HTTP

- **Intermediate layer**

- **Transmission Media**:
  - Coaxial cable
  - Fiber optic
  - 802.11 LAN
Solution: Indirection

• Solution: introduce an intermediate layer that provides a single abstraction for various network technologies
  – O(1) work to add app/media
  – Indirection is an often used technique in computer science

![Diagram showing the layers of network technologies: Application layer with SMTP, SSH, NFS, HTTP; Intermediate layer; Transmission Media with Coaxial cable, Fiber optic, 802.11 LAN.]
Network Architecture

• Architecture is **not** the implementation itself

• Architecture is how to “organize” implementations
  – what interfaces are supported
  – where functionality is implemented

• Architecture is the modular design of the network
**Software Modularity**

Break system into modules:

- Well-defined interfaces gives flexibility
  - can change implementation of modules
  - can extend functionality of system by adding new modules

- Interfaces hide information
  - allows for flexibility
  - but can hurt performance
Network Modularity

Like software modularity, but with a twist:

• Implementation distributed across routers and hosts

• Must decide both:
  – how to break system into modules
  – where modules are implemented
Layering

• Layering is a particular form of modularization

• The system is broken into a *vertical hierarchy* of logically distinct entities (layers)

• The service provided by one layer is based *solely* on the service provided by layer below

• Rigid structure: easy reuse, performance suffers
ISO OSI Reference Model

- Seven layers
  - Lower two layers are peer-to-peer
  - Network layer involves multiple switches
  - Next four layers are end-to-end
Key Concepts
Key Concepts

- Service – says **what** a layer does
  - Ethernet: unreliable subnet unicast/multicast/broadcast datagram service
  - IP: unreliable end-to-end unicast datagram service
  - TCP: reliable end-to-end bi-directional byte stream service
  - Guaranteed bandwidth/latency unicast service

- Service Interface – says **how** to access the service
  - E.g. UNIX socket interface

- Protocol – says **how** is the service implemented
  - a set of rules and formats that govern the communication between two peers
Physical Layer (1)

- **Service**: move information between two systems connected by a physical link

- **Interface**: specifies how to send a bit

- **Protocol**: coding scheme used to represent a bit, voltage levels, duration of a bit

- Examples: coaxial cable, optical fiber links; transmitters, receivers
Datalink Layer (2)

• **Service:**
  – framing (attach frame separators)
  – send data frames between peers
  – others:
    • arbitrate the access to common physical media
    • per-hop reliable transmission
    • per-hop flow control

• **Interface:** send a data unit (packet) to a machine connected to the same physical media

• **Protocol:** layer addresses, implement Medium Access Control (MAC) (e.g., CSMA/CD)…
Network Layer (3)

• **Service:**
  – deliver a packet to specified network destination
  – perform segmentation/reassemble
  – others:
    • packet scheduling
    • buffer management

• **Interface:** send a packet to a specified destination

• **Protocol:** define global unique addresses; construct routing tables
Transport Layer (4)

• **Service:**
  – Multiplexing/demultiplexing
  – optional: error-free and flow-controlled delivery

• **Interface:** send message to specific destination

• **Protocol:** implements reliability and flow control

• **Examples:** TCP and UDP
Session Layer (5)

• **Service:**
  – full-duplex
  – access management (e.g., token control)
  – synchronization (e.g., provide check points for long transfers)

• **Interface:** depends on service

• **Protocol:** token management; insert checkpoints, implement roll-back functions
Presentation Layer (6)

- **Service**: convert data between various representations

- **Interface**: depends on service

- **Protocol**: define data formats, and rules to convert from one format to another
Application Layer (7)

• **Service**: any service provided to the end user

• **Interface**: depends on the application

• **Protocol**: depends on the application

• **Examples**: FTP, Telnet, WWW browser
Physical Communication

• Communication goes down to physical network, then to peer, then up to relevant layer
Encapsulation

- A layer can use **only** the service provided by the layer immediate below it
- Each layer may change and add a header to data packet
Encapsulation

- As data is moving down the protocol stack, each protocol is adding layer-specific control information.
Example: Postal System

Standard process (historical):
• Write letter
• Drop an addressed letter off in your local mailbox
• Postal service delivers to address
• Addressee reads letter (and perhaps responds)
Postal Service as Layered System

Layers:
• Letter writing/reading
• Delivery

Information Hiding:
• Network need not know letter contents
• Customer need not know how the postal network works

Encapsulation:
• Envelope
Hourglass

Note: Additional protocols like routing protocols (RIP, OSPF) needed to make IP work.
Implications of Hourglass

A single Internet layer module:

• Allows all networks to interoperate
  – all networks technologies that support IP can exchange packets

• Allows all applications to function on all networks
  – all applications that can run on IP can use any network

• Simultaneous developments above and below IP