Switching Networks

- Long distance transmission is typically done over a network of switched nodes
- Nodes not concerned with content of data
- End devices are stations
  — Computer, terminal, phone, etc.
- A collection of nodes and connections is a communications network
- Data is routed by being switched from node to node
Nodes

- Nodes may connect to other nodes only, or to stations and other nodes
- Node to node links usually multiplexed
- Network is usually partially connected
  - Some redundant connections are desirable for reliability
- Two different switching technologies
  - Circuit switching
  - Packet switching
Circuit Switching

- Dedicated communication path between two stations
- Three phases
  - Establish
  - Transfer
  - Disconnect
- Must have switching capacity and channel capacity to establish connection
- Must have intelligence to work out routing

Circuit Switching

- Inefficient
  - Channel capacity dedicated for duration of connection
  - If no data, capacity wasted
- Set up (connection) takes time
- Once connected, transfer is transparent
- Developed for voice traffic (phone)
Public Circuit Switched Network

Telecom Components

- Subscriber
  - Devices attached to network
- Subscriber line
  - Local Loop
  - Subscriber loop
  - Connection to network
  - Few km up to few tens of km
- Exchange
  - Switching centers
  - End office - supports subscribers
- Trunks
  - Branches between exchanges
  - Multiplexed
Circuit Switching Concepts

- **Digital Switch**
  - Provide transparent signal path between devices
- **Network Interface**
- **Control Unit**
  - Establish connections
    - Generally on demand
    - Handle and acknowledge requests
    - Determine if destination is free
    - Construct path
  - Maintain connection
  - Disconnect
**Blocking or Non-blocking**

- **Blocking**
  - A network is unable to connect stations because all paths are in use
  - A blocking network allows this
  - Used on voice systems
    - Short duration calls

- **Non-blocking**
  - Permits all stations to connect (in pairs) at once
  - Used for some data connections
Space Division Switching

- Developed for analog environment
- Separate physical paths
- Crossbar switch
  - Number of cross-points grows in $n^2$
  - Loss of cross-point prevents connection
  - Inefficient use of cross-points
    - All stations connected, only a few cross-points in use
  - Non-blocking
Multistage Switch

- Reduced number of cross-points
- More than one path through network
  - Increased reliability
- More complex control
- May be blocking

Three Stage Space Division Switch
Interconnection Networks

- Omega Network

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Interconnection Networks

- Butterflies
  - isomorphic to Omega (a composition of shuffle-exchange networks with programmable switches) and SW-Banyan switch
  - closely related to hypercube and shuffle-exchange network
  - number of nodes $N = (k + 1)2^k$
    - this means $k + 1$ rows (or ranks) consisting of $n = 2^k$ nodes each
  - Let node($i,j$) refer to the $j$-th node in the $i$-th row, where $i$ is in $[0,k]$
  - Then node($i,j$) in row $i>0$ is connected to two nodes in row $i-1$
    - node($i-1,j$) and node($i-1,m$) where $m$ is the integer found by inverting the $i$th most significant bit in the binary representation of $j$.
  - Note that if node($i,j$) is connected to node($i-1,m$), then node($i,m$) is connected to node($i-1,j$).
  - Benes network is consisting of two butterflies back to back
Interconnection Networks

- Butterflies

Time Division Switching

- Modern digital systems rely on intelligent control of space and time division elements
- Use digital time division techniques to set up and maintain virtual circuits
- Partition low speed bit stream into pieces that share higher speed stream
### Interconnection Networks

#### An Application: ATM switch architecture

- **Two extremes**

  ![Diagram](image)

  - **IC** = Input controller
  - **OC** = Output controller
  - **IC** and **OC** are connected through a time-division bus.
  - Time is distributed over multiple IC and OC interfaces, allowing for efficient data transmission.

  **Hal96 fig.10.8**

#### Interconnection Networks

- **Delta Switch Matrix**
  - Non-blocking/blocking
  - Self routing

  ![Diagram](image)

  - The Delta switch matrix is a key component in ATM switch architecture, facilitating efficient data routing.
  - **Routing addresses** are crucial for directing data packets to their destinations.

  **Hal96 fig.10.9**
Control Signaling Functions

- Audible communication with subscriber
- Transmission of dialed number
- “Call cannot be completed” indication
- “Call ended” indication
- Signal to ring phone
- Billing info
- Equipment and trunk status info
- Diagnostic info
- Control of specialist equipment

Control Signal Sequence

- Both phones on hook
- Subscriber lifts receiver (off hook)
- End office switch signaled
- Switch responds with dial tone
- Caller dials number
- If target not busy, send ringer signal to target subscriber
- Feedback to caller
  - Ringing tone, engaged (busy) tone, unobtainable
- Target accepts call by lifting receiver
- Switch terminates ringing signal and ringing tone
- Switch establishes connection
- Connection release when Source subscriber hangs up
Switch to Switch Signaling

- Subscribers connected to different switches
- Originating switch seizes inter-switch trunk
- Send “off hook” signal on trunk, requesting digit register at target switch (for address)
- Terminating switch sends “off hook” followed by “on hook” (wink) to show register ready
- Originating switch sends address

Location of Signaling

- Subscriber to network
  - Depends on subscriber device and switch
- Within network
  - Management of subscriber calls and network
  - More complex
In Channel Signaling

- Use same channel for signaling and call
  - Requires no additional transmission facilities
- Inband
  - Uses same frequencies as voice signal
  - Can go anywhere a voice signal can
  - Impossible to set up a call on a faulty speech path
- Out of band
  - Voice signals do not use full 4kHz bandwidth
  - Narrow signal band within 4kHz used for control
  - Can be sent whether or not voice signals are present
  - Need extra electronics
  - Slower signal rate (narrow bandwidth)

Drawbacks of In Channel Signaling

- Limited transfer rate
- Delay between entering address (dialing) and connection
- Overcome by use of common channel signaling
**Common Channel Signaling**

- Control signals carried over paths independent of voice channel
  - One control signal channel can carry signals for multiple subscriber channels
    - Common control channel for these subscriber lines
  - Associated Mode
    - Common channel closely tracks inter-switch trunks
  - Disassociated Mode
    - Additional nodes (signal transfer points)
    - Effectively two separate networks

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**Common v. In Channel Signaling**

(a) Inchannel

(b) Common channel

CCIS SIG: Common channel interoffice signaling equipment
SIG: Per-trunk signaling equipment
Common Channel Signaling Modes

Signaling System Number 7
- SS7 is an open-ended common channel signaling standard
- Common channel signaling scheme
  - Especially designed to be used in ISDN (Integrated Services Digital Network)
  - Optimized for 64kbps digital channel network
  - Call control, remote control, management and maintenance
  - Reliable means of transfer of info in sequence
  - Will operate over analog and below 64kbps
  - Point to point terrestrial and satellite links
SS7
Signaling Network Elements

- Signaling point (SP)
  - Any point in the network capable of handling SS7 control message

- Signal transfer point (STP)
  - A signaling point capable of routing control messages

- Control plane
  - Responsible for establishing and managing connections

- Information plane
  - Once a connection is set up, info is transferred in the information plane

Transfer Points

STP = Signaling transfer point
SP = Signaling point
TC = Transit center
LE = Local Exchange
Signaling Network Structures

- STP capacities determine
  - Number of signaling links that can be handled
  - Message transfer time
  - Throughput capacity
- Network performance affected by
  - Number of SPs
  - Signaling delays
- Availability and reliability
  - Ability of network to provide services in the face of STP failures

Softswitch Architecture

- General purpose computer running software to make it a smart phone switch
- Lower costs
- Greater functionality
  - Packetizing of digitized voice data
  - Allowing voice over IP
- Most complex part of telephone network switch is software controlling call process
  - Call routing
  - Call processing logic
  - Typically running on proprietary processor
- Separate call processing from hardware function of switch
- Physical switching done by media gateway
- Call processing done by media gateway controller
Traditional Circuit Switching

(a) Traditional circuit switching

Softswitch

(b) Softswitch architecture
Packet Switching Principles

- Circuit switching designed for voice
  - Resources dedicated to a particular call
  - Much of the time a data connection is idle
  - Data rate is fixed
    - Both ends must operate at the same rate

Packet Switching: Basic Operation

- Data transmitted in small packets
  - Typically 1000 octets
  - Longer messages split into series of packets
  - Each packet contains a portion of user data plus some control info

- Control info
  - Routing (addressing) info

- Packets are received, stored briefly (buffered) and past on to the next node
  - Store and forward
Use of Packets

Advantages

- Line efficiency
  - Single node to node link can be shared by many packets over time
  - Packets queued and transmitted as fast as possible
- Data rate conversion
  - Each station connects to the local node at its own speed
  - Nodes buffer data if required to equalize rates
- Packets are accepted even when network is busy
  - Delivery may slow down
- Priorities can be used
Switching Technique

• Station breaks long message into packets
• Packets sent one at a time to the network
• Packets handled in two ways
  — Datagram
  — Virtual circuit

Datagram

• Each packet treated independently
• Packets can take any practical route
• Packets may arrive out of order
• Packets may go missing
• Up to receiver to re-order packets and recover from missing packets
Virtual Circuit

- Preplanned route established before any packets sent
- Call request and call accept packets establish connection (handshake)
- Each packet contains a virtual circuit identifier instead of destination address
- No routing decisions required for each packet
- Clear request to drop circuit
- Not a dedicated path
Virtual Circuits vs. Datagram

- Virtual circuits
  - Network can provide sequencing and error control
  - Packets are forwarded more quickly
    - No routing decisions to make
  - Less reliable
    - Loss of a node looses all circuits through that node

- Datagram
  - No call setup phase
    - Better if few packets
  - More flexible
    - Routing can be used to avoid congested parts of the network
Packet Size

Circuit vs Packet Switching

- Performance
  - Propagation delay
  - Transmission time
  - Node delay
**Event Timing**

(a) Circuit switching  
(b) Virtual circuit packet switching  
(c) Datagram packet switching

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**X.25**

- We will only briefly cover this as an overview
**X.25**

- 1976
- Interface between host and packet switched network
- Almost universal on packet switched networks and packet switching in ISDN
- Defines three layers
  - Physical
  - Link
  - Packet

**X.25 - Physical**

- Interface between attached station and link to node
- Data terminal equipment DTE (user equipment)
- Data circuit terminating equipment DCE (node)
- Uses physical layer specification X.21
- Reliable transfer across physical link
- Sequence of frames
X.25 - Link

- Link Access Protocol Balanced (LAPB)
  - Subset of HDLC
  - see chapter 7

X.25 - Packet

- External virtual circuits
- Logical connections (virtual circuits) between subscribers
**Virtual Circuit Service**

- Logical connection between two stations
  - External virtual circuit
- Specific preplanned route through network
  - Internal virtual circuit
- Typically one to one relationship between external and internal virtual circuits
- Can employ X.25 with datagram style network
- External virtual circuits require logical channel
  - All data considered part of stream
X.25 Levels

- User data passes to X.25 level 3
- X.25 appends control information
  - Header
  - Identifies virtual circuit
  - Provides sequence numbers for flow and error control
- X.25 packet passed down to LAPB entity
  - recall LAPB = Link Access Procedure Balanced
- LAPB appends further control information

User Data and X.25 Protocol Control Information

Diagram showing:
- User data
- X.25 packet
- Layer 3 header
- LAPB header
- LAPB trailer
- LAPB frame
Frame Relay

- Designed to be more efficient than X.25
- Developed before ATM
- Larger installed base than ATM
- ATM now of more interest on high speed networks

Frame Relay Background - X.25

- Call control packets, in band signaling
- Multiplexing of virtual circuits at layer 3
- Layer 2 and 3 include flow and error control
- Considerable overhead
- Not appropriate for modern digital systems with high reliability
Frame Relay - Differences

- Call control carried in separate logical connection
- Multiplexing and switching at layer 2
  —Eliminates one layer of processing
- No hop by hop error or flow control
- End to end flow and error control (if used) are done by higher layer
- Single user data frame sent from source to destination and ACK (from higher layer) sent back

Advantages and Disadvantages

- Lost link by link error and flow control
  —Increased reliability makes this less of a problem
- Streamlined communications process
  —Lower delay
  —Higher throughput
- ITU-T recommend frame relay above 2Mbps
Control Plane

- Between subscriber and network
- Separate logical channel used
  - Similar to common channel signaling for circuit switching services
- Data link layer
  - LAPD (Q.921)
  - Reliable data link control
  - Error and flow control
  - Between user (TE) and network (NT)
  - Used for exchange of Q.933 control signal messages
User Plane

- End to end functionality
- Transfer of info between ends
- LAPF (Link Access Procedure for Frame Mode Bearer Services) Q.922
  - Frame delimiting, alignment and transparency
  - Frame mux and demux using addressing field
  - Ensure frame is integral number of octets (zero bit insertion/extraction)
  - Ensure frame is neither too long nor short
  - Detection of transmission errors
  - Congestion control functions

User Data Transfer

- One frame type
  - User data
  - No control frame
- No inband signaling
- No sequence numbers
  - No flow nor error control
Summary

• circuit verses packet switching network approaches
• X.25
• frame relay