IN2140:
Introduction to Operating Systems and Data Communication

Routing and Switching

End-to-end delivery on layer 3

in TCP/IP terms

Network Layer

- Primary task from a layer model perspective
  - To provide service to the transport layer
    - *Connectionless* or *connection-oriented* service

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    - Internetworking: provide transitions between networks

[unknown, 1920]

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    - Congestion control

[Giftzwerg 88@wikipedia, CC BY-SA 4.0]

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    - Internetworking: provide transitions between networks
    - Routing
    - Congestion control
    - Quality of Service (QoS)

- Inside the network layer

Layer	Data entity
Transport	…
Network	Packet
Data link	Frame
Physical	Bit/byte (bit stream)

Inside the Network Layer

An L3 packet includes

(2) headers and trailer to specify service requirements
in particular:
- information required by intermediate systems for forwarding

for connection-oriented service:
- route label

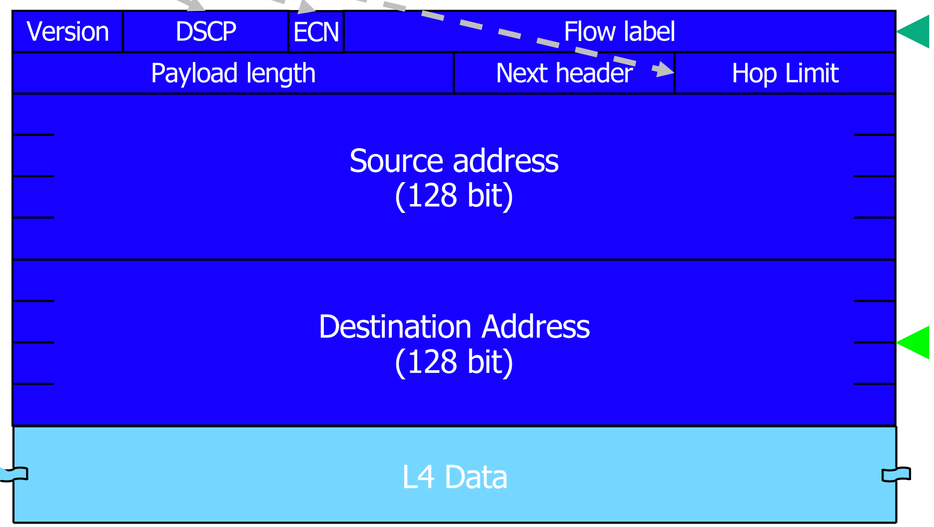
OR

for connectionless service:
- end system address of the destination

QoS requirements

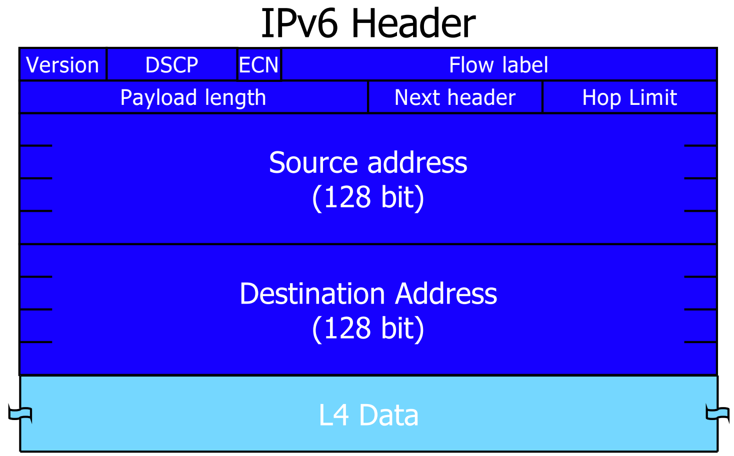
(1) payload from the transport layer

IPv6 Header

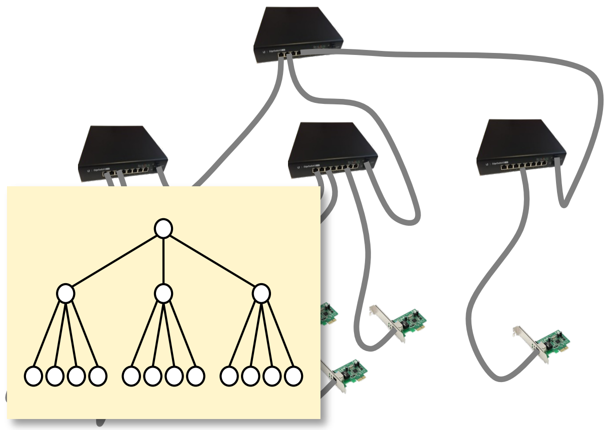


Inside the Network Layer

- An L3 packet includes
  - Payload from the transport layer
  - Headers and trailers
    - End system address or route label
    - QoS requirements



- Knowledge required by intermediate system
  - Subnetwork topology
  - Address / localization of the end system
  - Packet / data stream communication requirements (Quality of Service)
  - Network status (utilization,…)



- Intermediate system can then **route** or **switch** packets

Routing and Switching: Terminology

- The general ideas apply in many fields, including route planning for cars or supplying electricity
- We stick to Internet terminology where that is possible

- **Routing** and **Switching** have one thing in common:
  - a packet arrives at an IS, and the IS (if it is not the target) decides choose the right interface for forwarding it
- In the Internet, there is a strong *historical* association of switching with L2 and routing with L3

- In packet-based networks like the Internet, we call something …
  - … **routing**, when an IS reads a destination address from an arriving packet, computes which of its direct neighbors is best suited for reaching that destination, and sends the packet to the neighbor.
  - … **switching**, when an IS reads an identifier from an arriving packet, looks it up in a pre-filled mapping table that translates the identifier to a direct neighbor, and sends the packet to the neighbor.

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Routing and Switching

End-to-end delivery:

general concepts

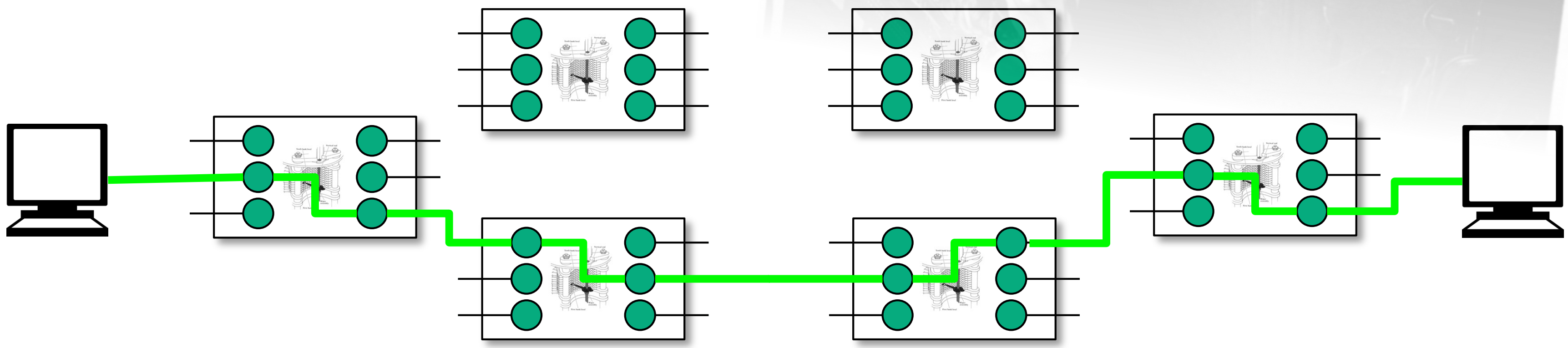
Circuit switching

Principle

- Connection exists physically for the duration of the conversation

- Refers to
  - Switching centers
  - Connections between switching centers
    (frequency spectrum, dedicated ports)
- Implementation examples
  - Historically: on switching boards
  - Mechanical positioning of the dialers

[Harris & Ewing, 1905]



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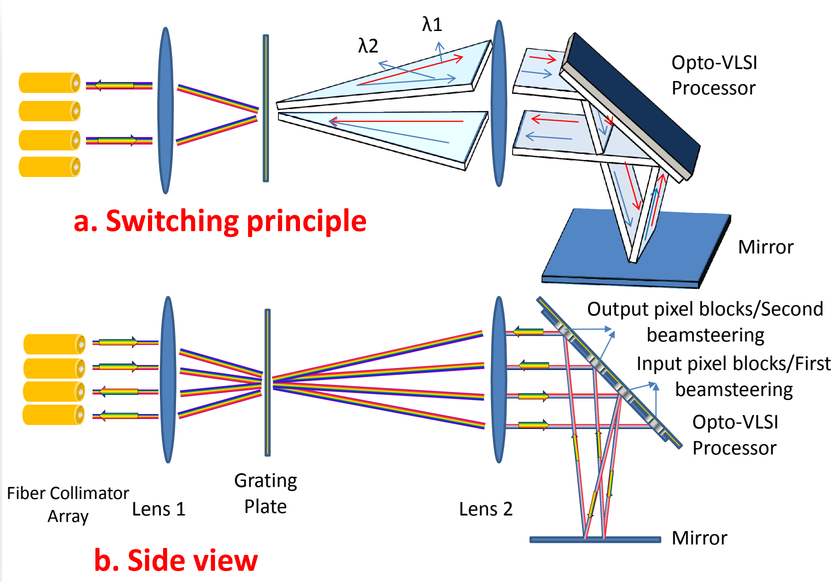
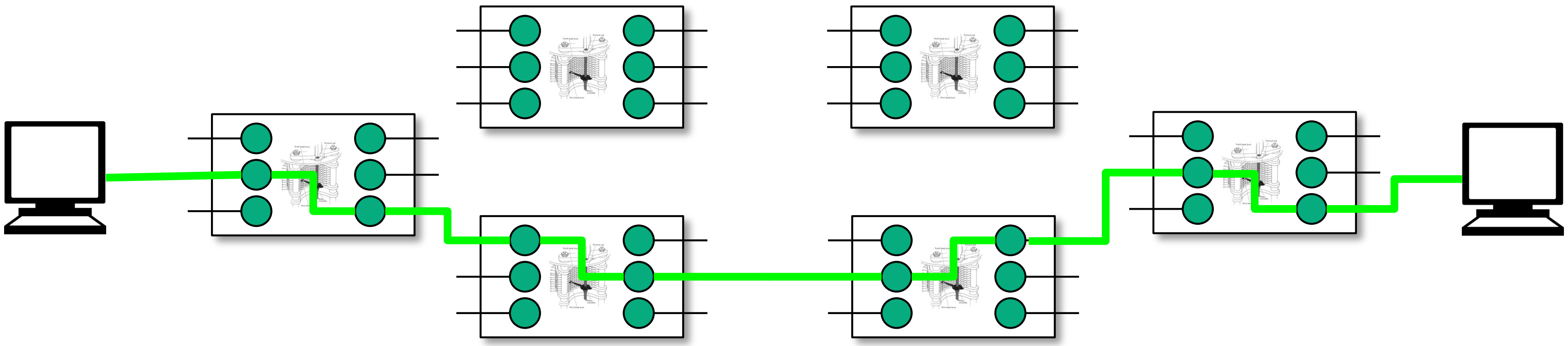
  - Today: optical networks (e.g. WDM)
  - Setting coupling points in circuits



[from "Opto-VLSI-based N × M wavelength selective switch", DOI 10.1364/OE.21.018160]



Circuit switching

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  - Today: optical networks (e.g. WDM)
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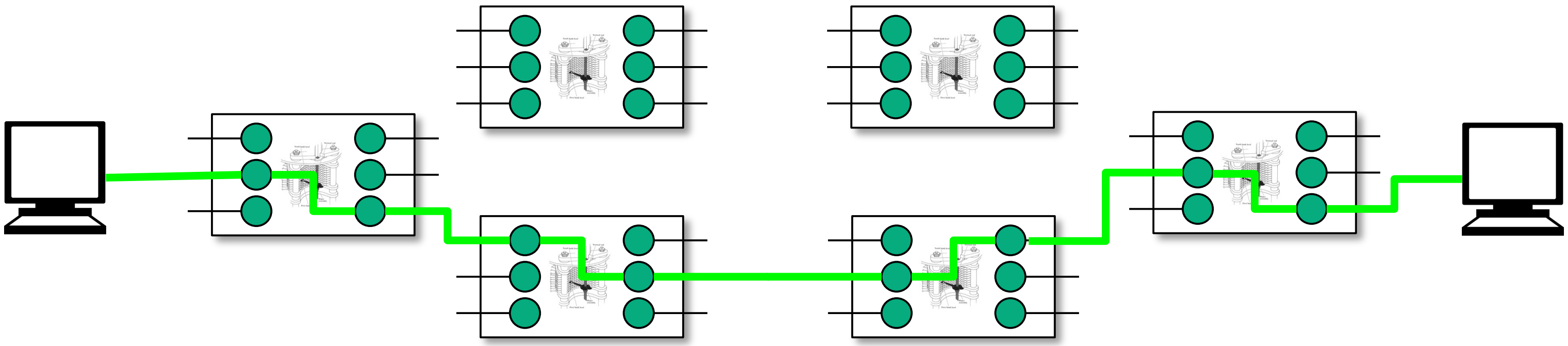
    (frequency spectrum, dedicated ports)
- Implementation examples
  - Historically: on switching boards
  - Mechanical positioning of the dialers
- Properties
  - Connection has to occur before transmission
  - Establishing a connection takes time
  - Resource allocation is rigid (possibly waste of resources)
  - Once connection is established it cannot be blocked anymore

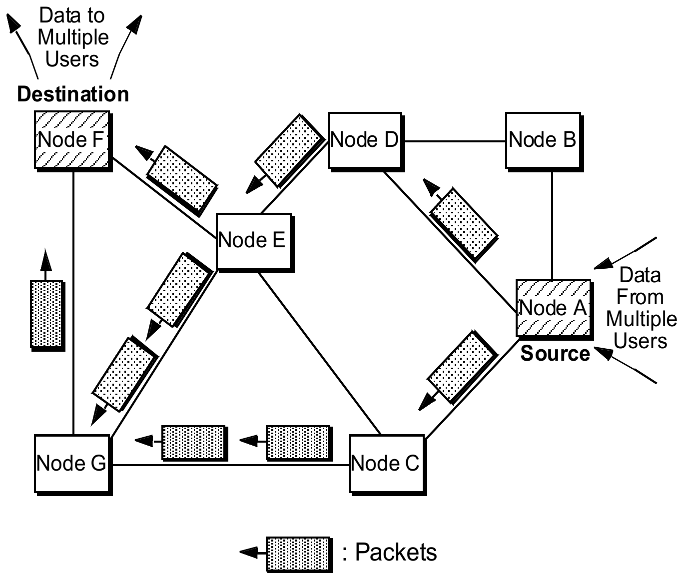


Packet Switching

Principle

- Packets of limited size
- Dynamic route search (no connect phase)
- No dedicated path from source to destination

Example: Internet



- Properties
  - Possibly only reservation of average bandwidth (static reservation)
  - Possibility of congestion
  - High utilization of resources

Comparison: Circuit and Packet Switching

- Circuit switching
  - Connection establishment can take a long time
  - Bandwidth is reserved
    - No danger of congestion
    - Possibly poor bandwidth utilization (burst traffic)
  - constant transmission time
  - all data is transmitted over the same path

- Packet switching
  - No connect phase
  - No allocation of bandwidth
    - Danger of congestion
    - Potentially 100% bandwidth utilization
  - varying transmission time
  - packets between same end systems may use different paths

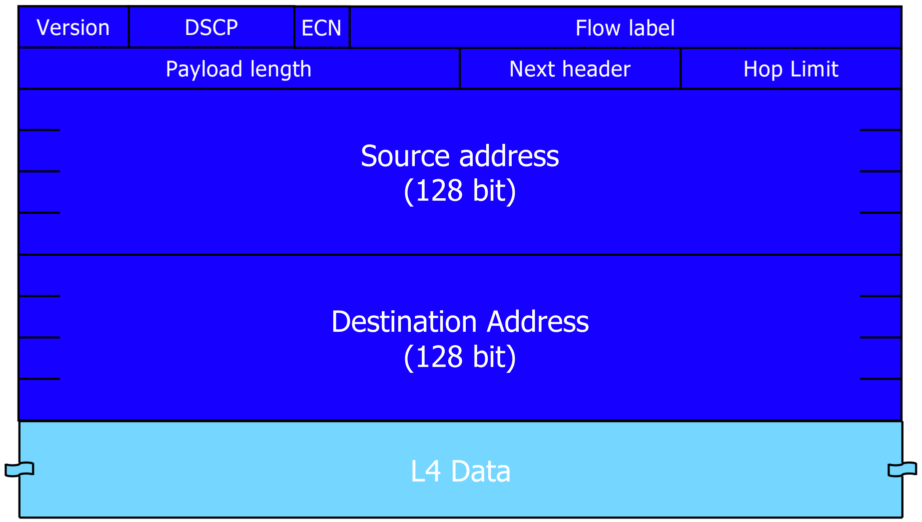
Virtual Circuit Switching

Principle

- Setup path from source to destination for entire duration of call
  - Using state information in nodes but no physical connection
  - Connection setup: defines data path
  - Messages: as in packet switching, but:
    - No routing decision per packet
    - Simpler addressing: associate with virtual circuit instead of destination

- Properties
  - Possible to ensure Quality of Service
  - Possible to maintain order of packets

IPv6 Header



Flow label for virtual circuit identification:

- shorter than destination address
- received earlier than destination address

Comparison: Virtual Circuit and Packet Switching

- Virtual circuit switching
  - Connection establishment can take a long time
  - Bandwidth can be reserved
    - Provider can guarantee loss probability of package losses and probability of waiting times
    - Better bandwidth utilization than circuit switching
  - varying transmission time
  - all data is transmitted over the same path

- Packet switching
  - No connect phase
  - No allocation of bandwidth
    - Danger of congestion
    - Potentially 100% bandwidth utilization
  - varying transmission time
  - packets between same end systems may use different paths

Message Switching

very rare at L3 today:
just for completeness

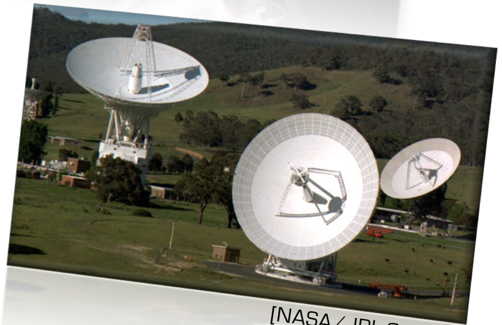
some applications on L5
operate like this

Principle

- All data to be sent are treated as a "message"
- “Store and forward" network:
  in each node the message is handled as follows:
  1. Accepted (L2 frames are collected until L3 message is complete)
  2. Treatment of possible errors
  3. Stored
  4. Forwarded (divide into several L2 frames for sending to the next node)

[secretlondon123@flickr, CC BY SA 2.0]

- Ancient history
  - dial-up networks
  - and its protocol UUCP – Unix to Unix Copy
- Recent research
  - delay-tolerant networks, e.g. NASA Deep Space Network



[NASA/JPL-Caltech]

- Properties
  - High memory requirements at the node (switching centers)
    - message size is unlimited
    - usually stored on secondary repository (harddisk)
  - Node may be used to its full capacity over a longer period of time by one message

Switching

more on

Virtual Circuit Switching

Virtual Circuits

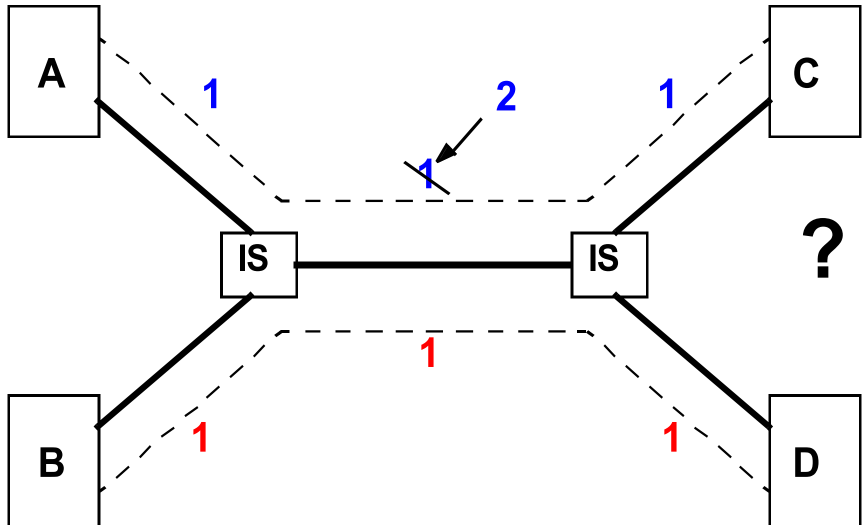
- Connection set-up phase
  - select a path
  - assign a VC identifier (VC number)
  - IS stores path information
  - network reserves all resources required for the connection

- Data transfer phase: all packets follow the selected path
  - every packet contains VC number
    - identification of connection, no address information
  - IS uses stored path information to determine next node
  - maybe update VC number in packet

- Disconnect phase:
  - IS releases reserved resources
  - IS forgets the VC

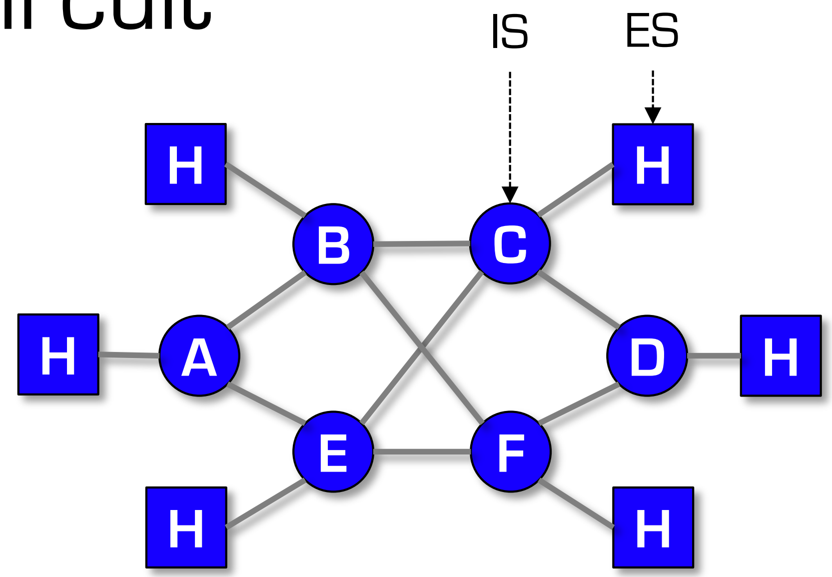
Implementation Virtual Circuit

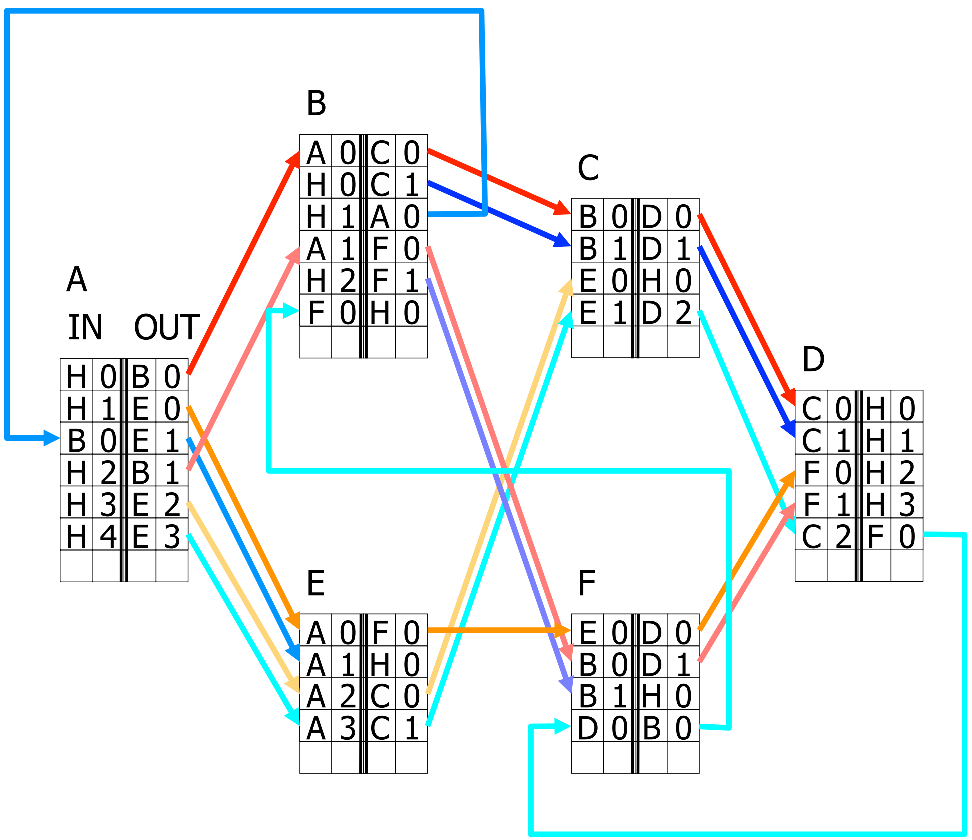
- ES allocates VC number independently (no negotiation)
- Problem: the same VC identifiers may be allocated to different paths



- Solution: allocate VC numbers for virtual circuit *segments*
  - IS differentiates between incoming and outgoing VC-number
    - IS receives incoming VC number in CONNECT message from previous node
    - IS creates outgoing VC number (unique between IS and successor (IS))
    - IS sends outgoing VC number in CONNECT message to next node

Implementation Virtual Circuit





8 Simplex virtual circuits

Originating at A	Originating at B
0 - ABCD	0 - BCD
1 - AEFD	1 - BAE
2 - ABFD	2 - BF
3 - AEC	
4 - AECDFB	

Implementation Packet Switching

- Packet passes through the network as an isolated unit
  - has complete source and destination addresses
  - individual route selection for each packet
  - generally no resource reservation
  - correct sequence not guaranteed

Packet Switching vs. Virtual Circuit

- Packet Switching: IS routing table specifies possible path(s)
  - No connection setup delay
  - Less sensible to IS and link failures
  - Route selection for each packet: quick reaction to failures
- but
  - Each packet contains the full destination and source address
  - Route selection for each packet: overhead
  - QoS guarantees hardly possible

- Virtual Circuit: destination address defined by connection
  - Packets contain short VC-number only
  - Low overhead during transfer phase
  - “Perfect" channel throughout the net
  - Resource reservation: "Quality of Service" guarantees possible
- but
  - Overhead for connection setup
  - Memory for VC tables and state information needed in every IS
  - Sensible to IS and link failures
  - Resource reservation: potentially poor utilization