15-441 Computer Networks

Lecture 3

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Review of Lecture 1

- **How long does it take to move 1GB data from campus to your home?**
  - 56Kbps modem
  - 2Mbps DSL
- **Other possibilities?**

Time Travel: Let's Build a Network

- **1870**
  - Alexander Bell
- **1970**
  - Dave Boggs, Bob Metcalfe
- **1970**
  - Larry Roberts, Bob Kahn, Vint Cerf
- **1995**
  - Network architect of UUNET
  - Director of Campus Computing, CMU
- **2004**
  - Network architecture of Reliance
  - Network architecture of General Motor

Early Communication over Long Distance

- **Between human beings**
- **Letter and messenger**
  - Information carried by physical objects
  - Speed limited by transportation means: horse, bird, train, car
  - Bandwidth? distance? security?
- **Fire**
  - Early optical communication
  - Speed of light
  - Bandwidth? distance? security?

Telegraph: Communication Using Electrons

- **Between human beings**
- **Major milestones:**
  - 1827: Ohm's Law
  - 1837: "workable" telegraph invented by Samuel Morse
  - 1838: demonstration over 10 miles at 10 w.p.m
  - 1844: Capitol Hill to Baltimore
  - 1851: Western Union founded
  - 1868: transatlantic cable laid
  - 1985: last telegraph circuit closed down
- **Other important dates**
  - 1869: transcontinental railway
  - 1876: Alexander Bell invented telephone

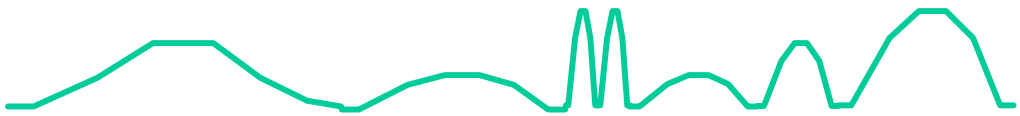
Telegraph Engineering

- **Technical issues**
  - How to encode information?
  - How to feed/input information to the system?
  - How to output information?
  - How to improve the distance?
  - How to improve the speed?
- **Common issues faced by all telecommunication systems**

Telephony

- **Interactive telecommunication between people**
- **Analog voice vs. digital information**
  - Transmitter/receiver continuously contact with electronic circuit
  - Electric current varies with acoustic pressure

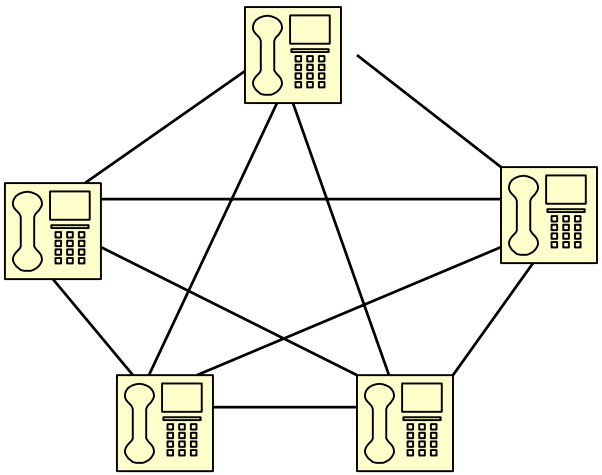
Analog/Continuous Signal



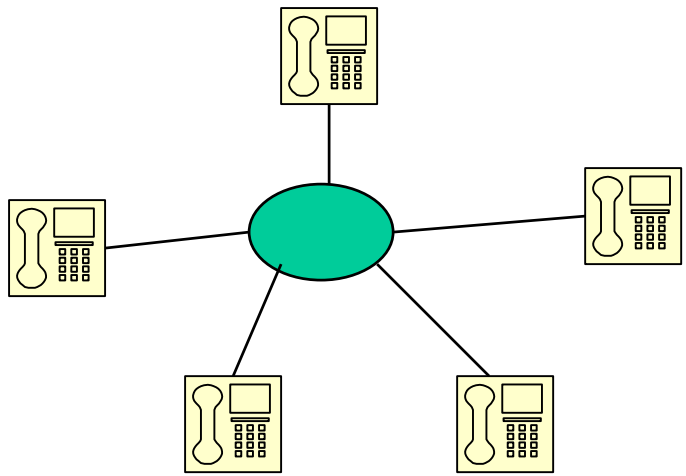
Digital/Discrete Signal

Telephony Milestones

- **1876: Alaxendar Bell invented telephone**
- **1878: Public switches installed at New Haven and San Francisco, public switched telephone network is born**
  - People can talk without being on the same wire !



Without Switch



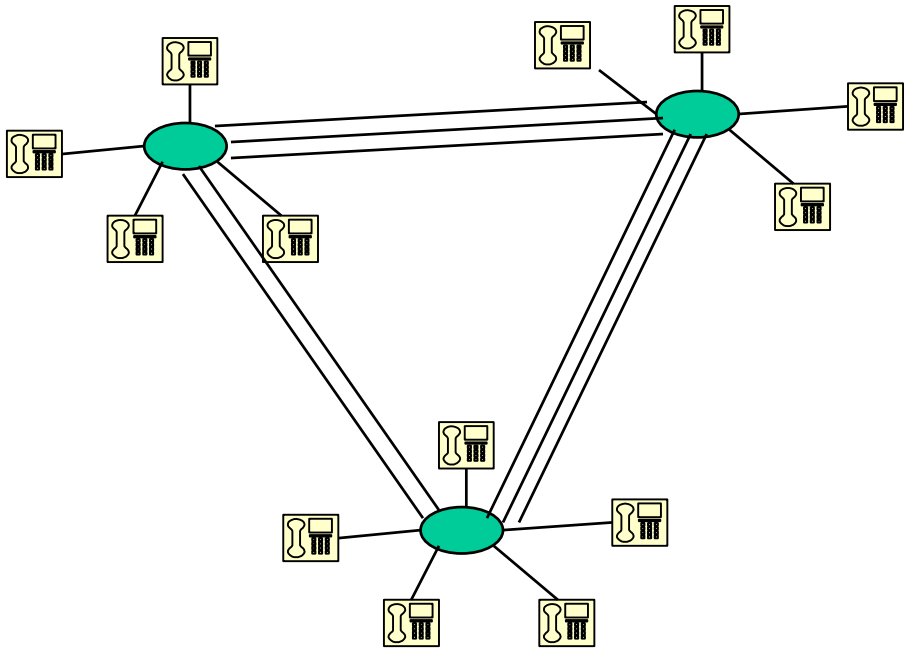
With Switch

Telephony Milestones

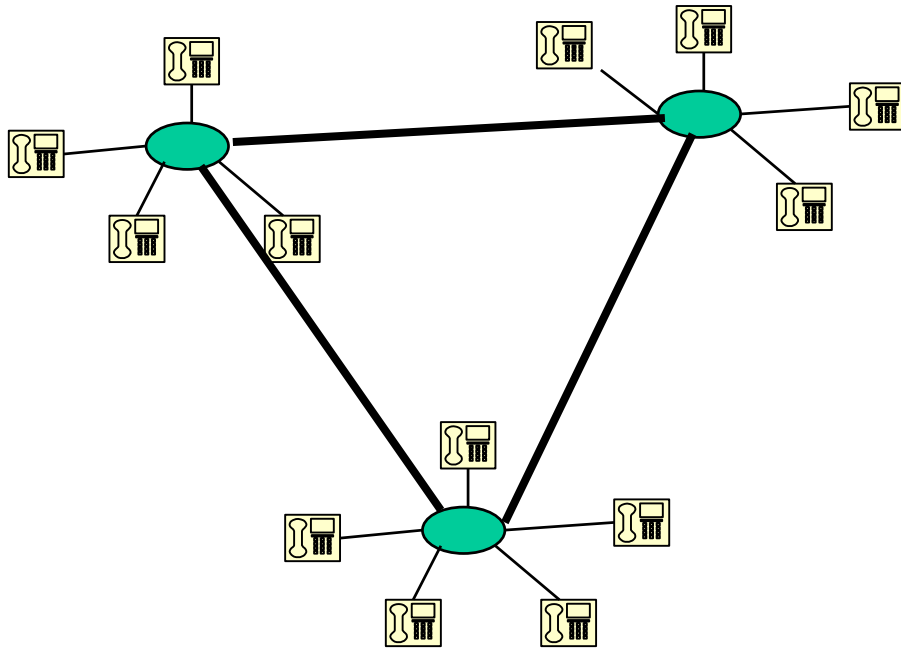
- 1878: First telephone directory; white house line
- 1881: Insulated, balanced twisted pair as local loop
- 1885: AT&T formed
- 1892: First automatic commercial telephone switch
- 1903: 3 million telephones in U.S.
- 1915: First transcontinental telephone line
- 1927: First commercial transatlantic commercial service

Telephony Milestones

- **1937: Multiplexing introduced for inter-city calls**



Without Multiplexing



With Multiplexing

Telephony Milestones

- **1939: Pulse Code Modulation (PCM) invented**
- **1948: Transistor invented by Bell scientists**
- **1951: Direct dialing for long-distance demonstrated**
- **1963: Digital transmission introduced**
- **1965 1ESS central office switch introduced**
  - Stored Program Control (computerized)
- **1976 4ESS: first digital electronic switch**
- **1982 Bell System split into ATT and 7 RBOCs**
- **1983 First fiber-optic cable in ATT long distance network**
- **1989 SONET standard published by CCITT**
- **1999 Last 4ESS switch installed in ATT network**

Summary

- **Communication long before computer**
- **Evolutions of modern communication and computer intertwined**
- **Important concepts**
  - Switching
  - Multiplexing
  - Analog vs. Digital
  - Bandwidth
  - Latency

Data or Computer Networks

- **Networks designed for computers to computers or devices**
  - vs. communication between human beings
- **Digital information**
  - vs. analog voice

What is a Communication Network? (from end-system point of view)

- **Network offers a service: move information**
  - Bird, fire, messenger, truck, telegraph, telephone, Internet …
  - Another example, transportation service: move objects
    - Horse, train, truck, airplane ...
- **What distinguish different types of networks?**
  - The services they provide
- **What distinguish the services?**
  - Latency
  - Bandwidth
  - Loss rate
  - Number of end systems
  - Service interface
  - Other details
    - Reliability, unicast vs. multicast, real-time, message vs. byte ...

What is a Communication Network? Infrastructure Centric View

- Electrons and photons as communication medium
- Links: fiber, copper, satellite, …
- Switches: electronic/optic, crossbar/Banyan
- Protocols: TCP/IP, ATM, MPLS, SONET, Ethernet, X.25, FrameRelay, AppleTalk, IPX, SNA
- Functionalities: routing, error control, flow control, congestion control, Quality of Service (QoS)
- Applications: telephony, FTP, WEB, X windows, ...

Types of Networks

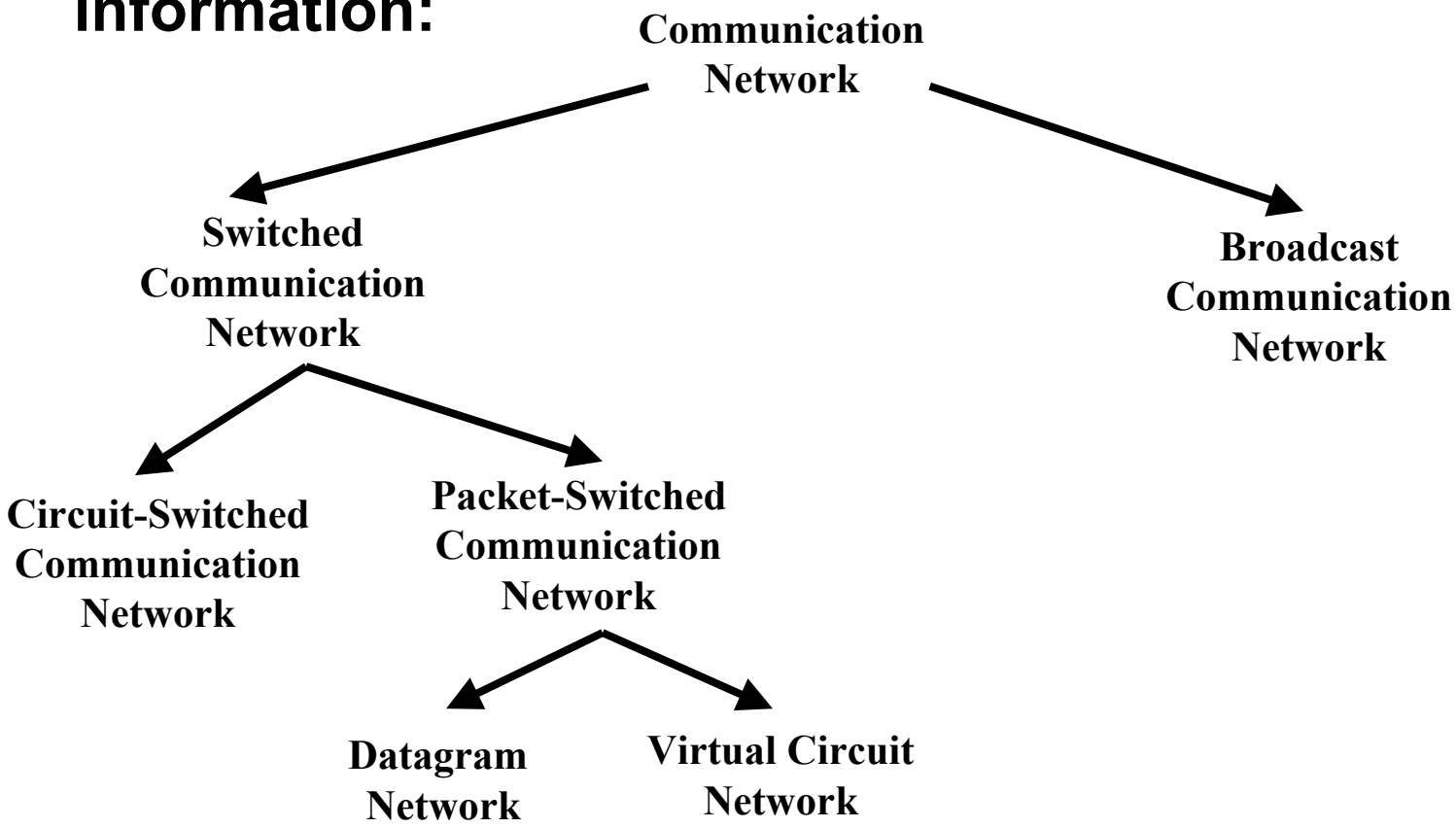
- **Geographical distance**
  - Local Area Networks (LAN): Ethernet, Token ring, FDDI
  - Metropolitan Area Networks (MAN): DQDB, SMDS
  - Wide Area Networks (WAN): X.25, ATM, frame relay
- **Information type**
  - Data networks vs. telecommunication networks
- **Application type**
  - Special purpose networks: airline reservation network, banking network, credit card network, telephony
  - General purpose network: Internet

Types of Networks

- **Right to use**
  - Private: enterprise networks
  - Public: telephony network, Internet
- **Ownership of protocols**
  - Proprietary: SNA
  - Open: IP
- **Technologies**
  - Terrestrial vs. satellite
  - Wired vs. wireless
- **Protocols**
  - IP, AppleTalk, SNA

A Taxonomy of Communication Networks

- **Communication networks can be classified based on the way in which the nodes exchange information:**



Broadcast vs. Switched Communication Networks

- **Broadcast communication networks**
  - Information transmitted by any node is received by every other node in the network
    - Examples: usually in LANs (Ethernet, Wavelan)
  - Problem: coordinate the access of all nodes to the shared communication medium (Multiple Access Problem)
- **Switched communication networks**
  - Information is transmitted to a sub-set of designated nodes
    - Examples: WANs (Telephony Network, Internet)
  - Problem: how to forward information to intended node(s)
    - This is done by special nodes (e.g., routers, switches) running routing protocols

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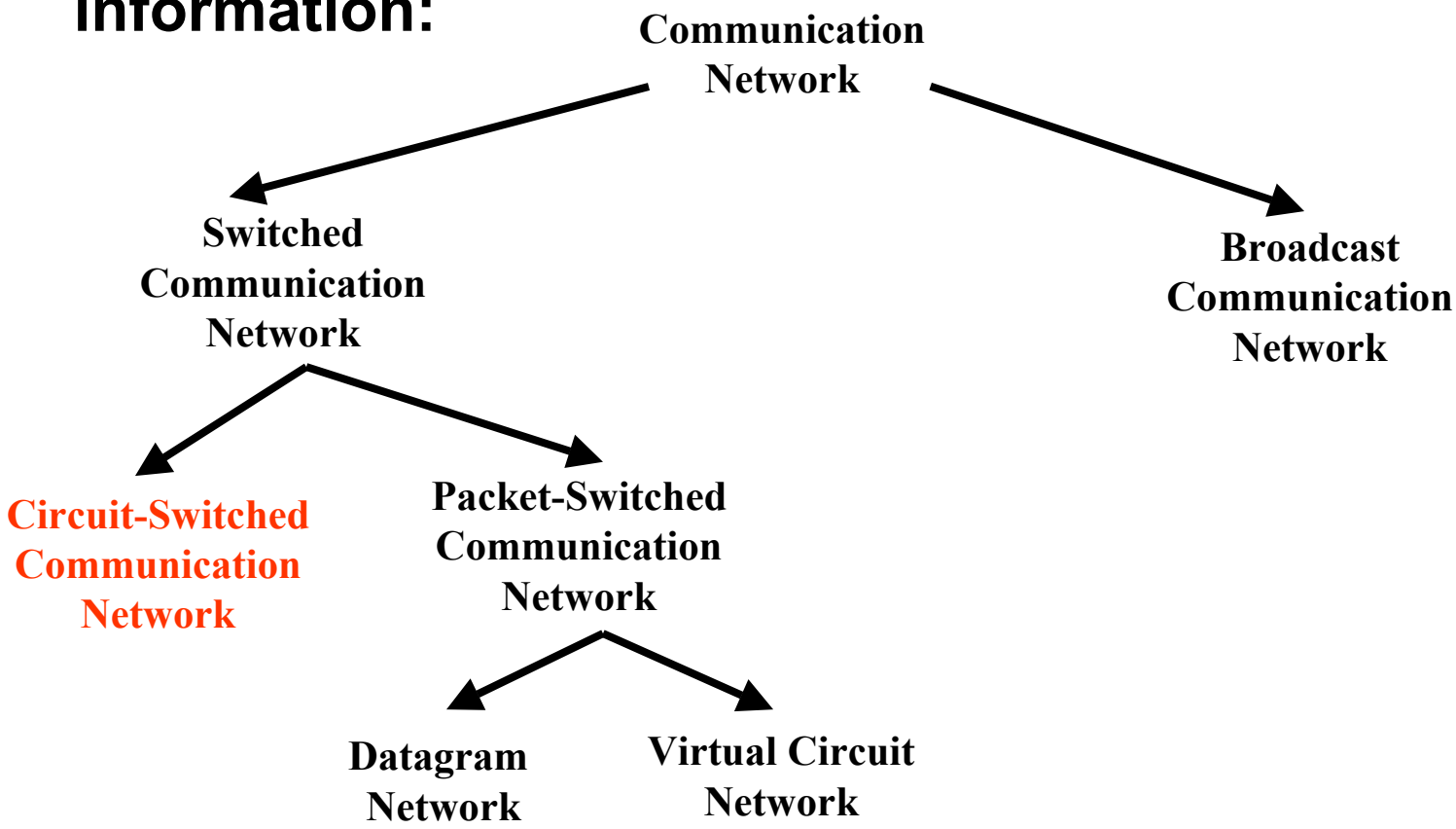
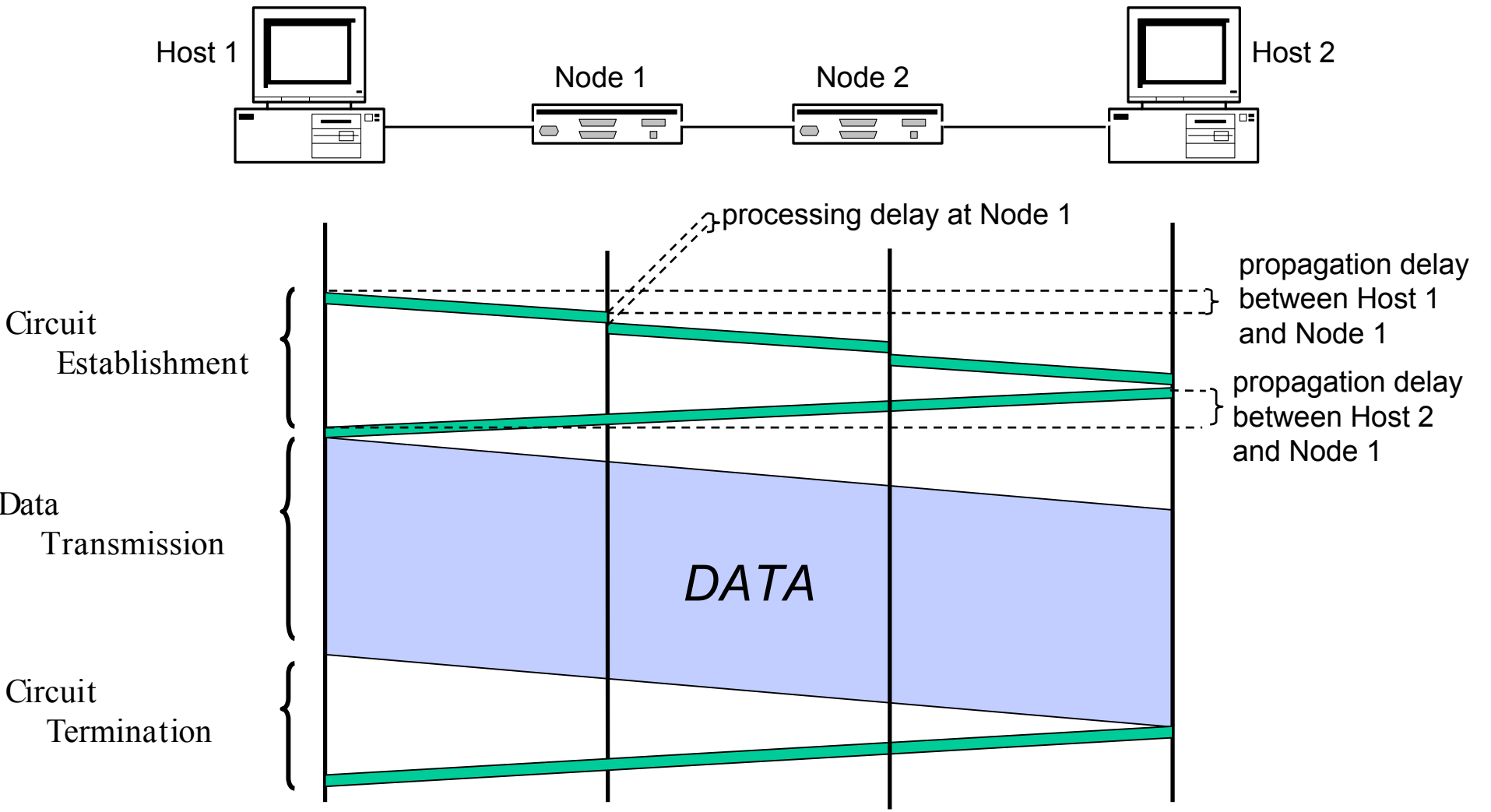


Circuit Switching

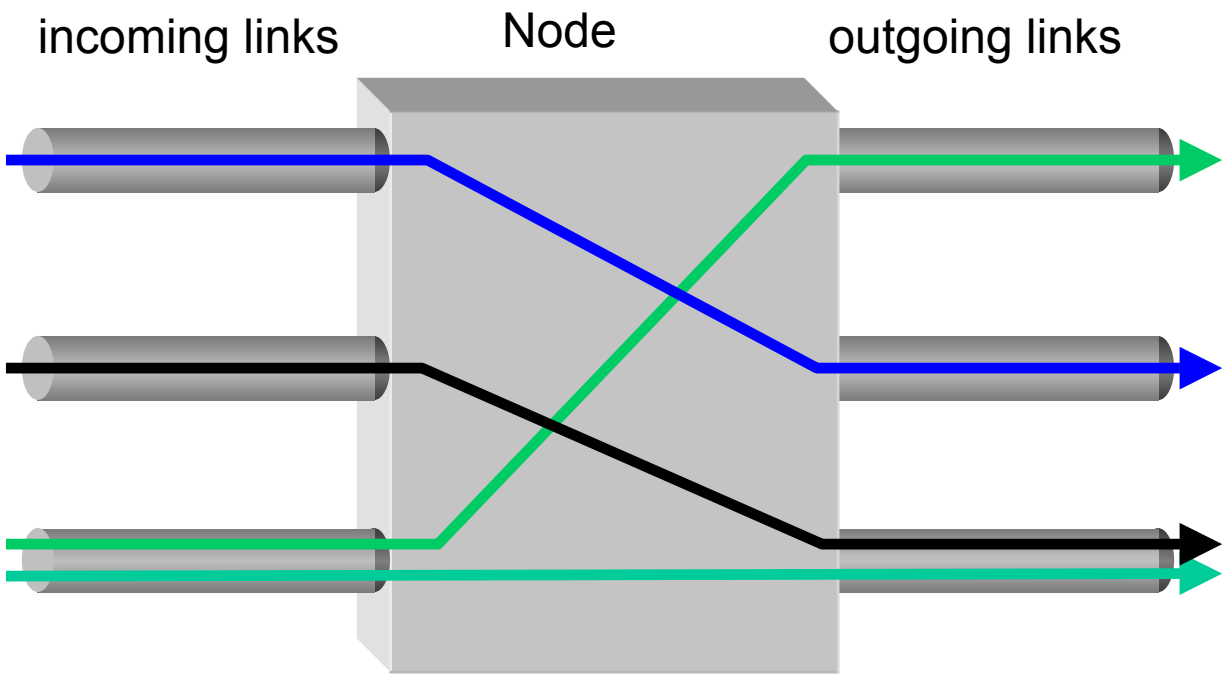
- **Three phases**
  1. circuit establishment
  2. data transfer
  3. circuit termination
- **If circuit not available: “Busy signal”**
- **Examples**
  - Telephone networks
  - ISDN (Integrated Services Digital Networks)

Timing in Circuit Switching

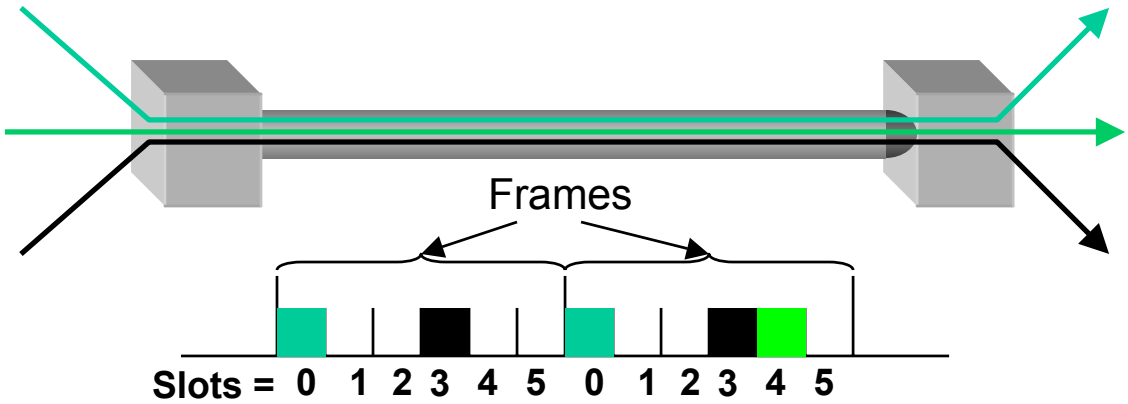


Circuit Switching

- A node (switch) in a circuit switching network



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 green conversation
- **Needs synchronization between sender and receiver**
- **In case of non-permanent conversations**
  - Needs to dynamic bind a slot to a conservation
  - How to do this?
- **If a conversation does not use its circuit the capacity is lost!**

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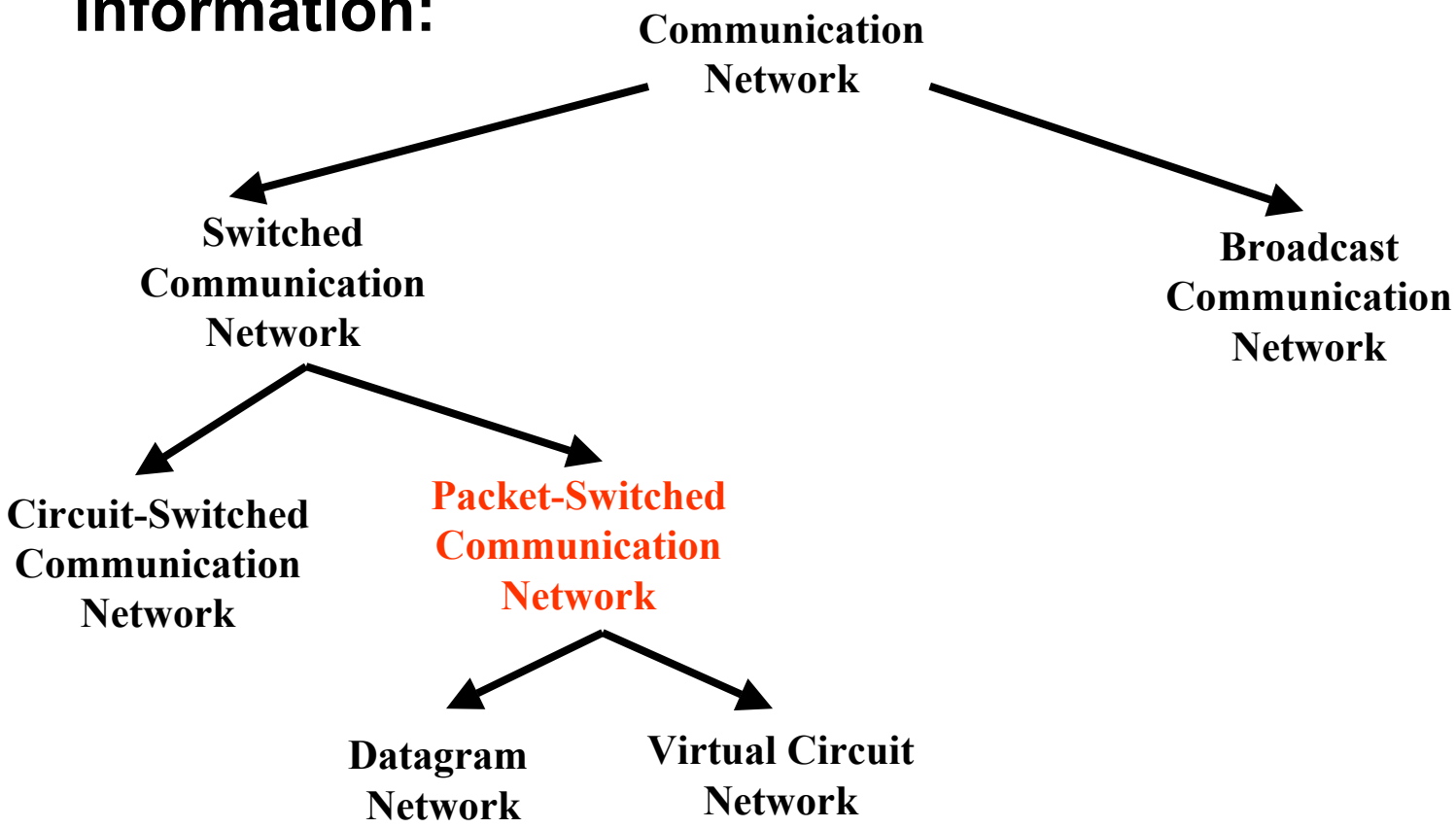


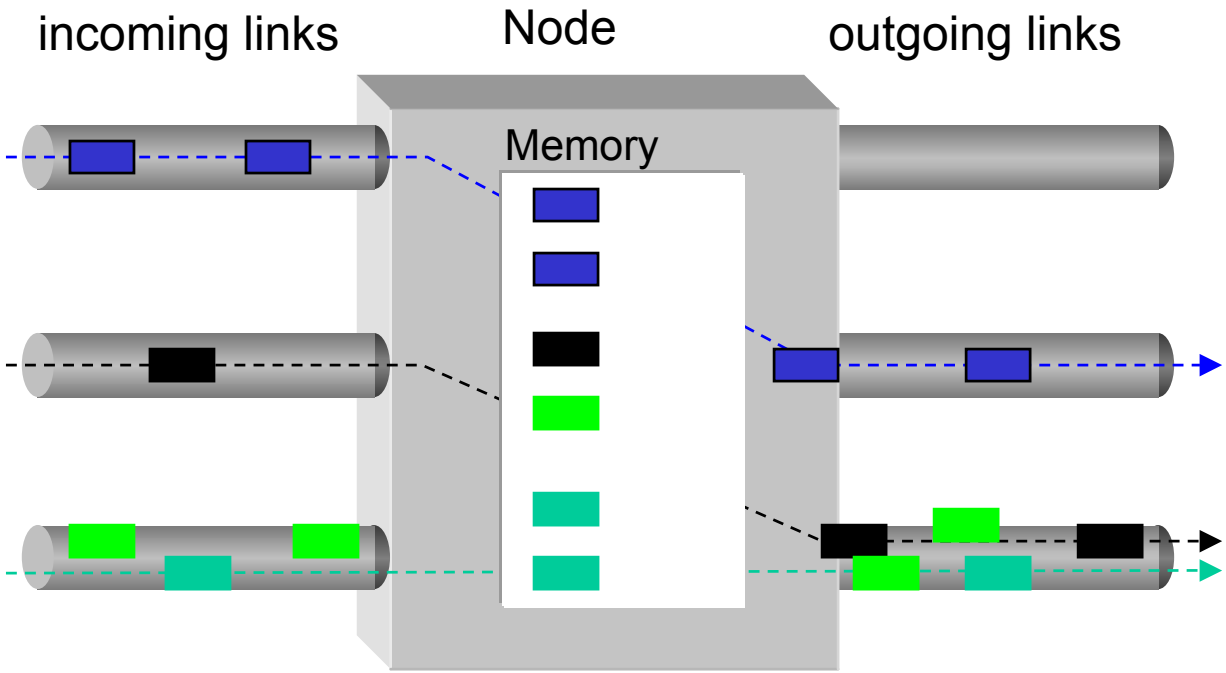
Packet Switching

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

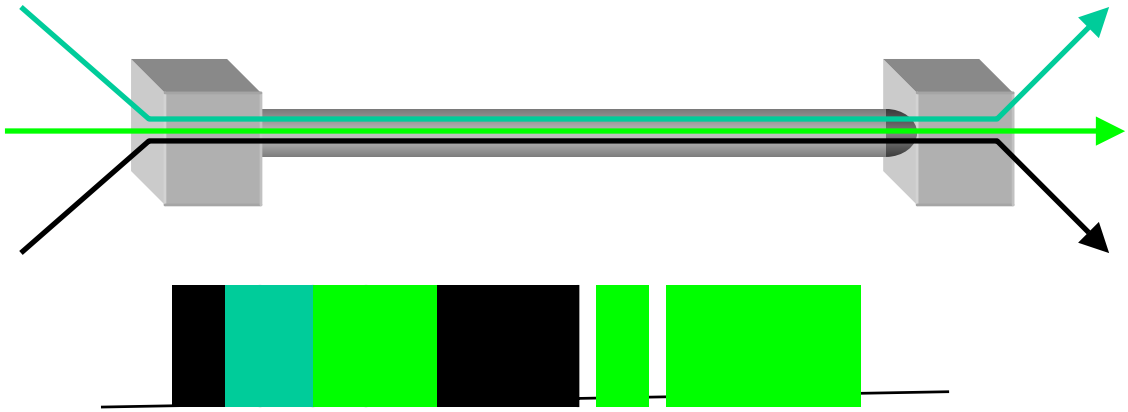
  - Header and Trailer carry control information (e.g., destination address, check sum)
- **At each node the entire packet is received, stored briefly, and then forwarded to the next node (**Store-and-Forward Networks**)**
- **Statistical sharing of the link capacity**

Packet Switching

- A node in a packet switching network



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 tell them apart?**
  - Use meta-data (header) to describe data

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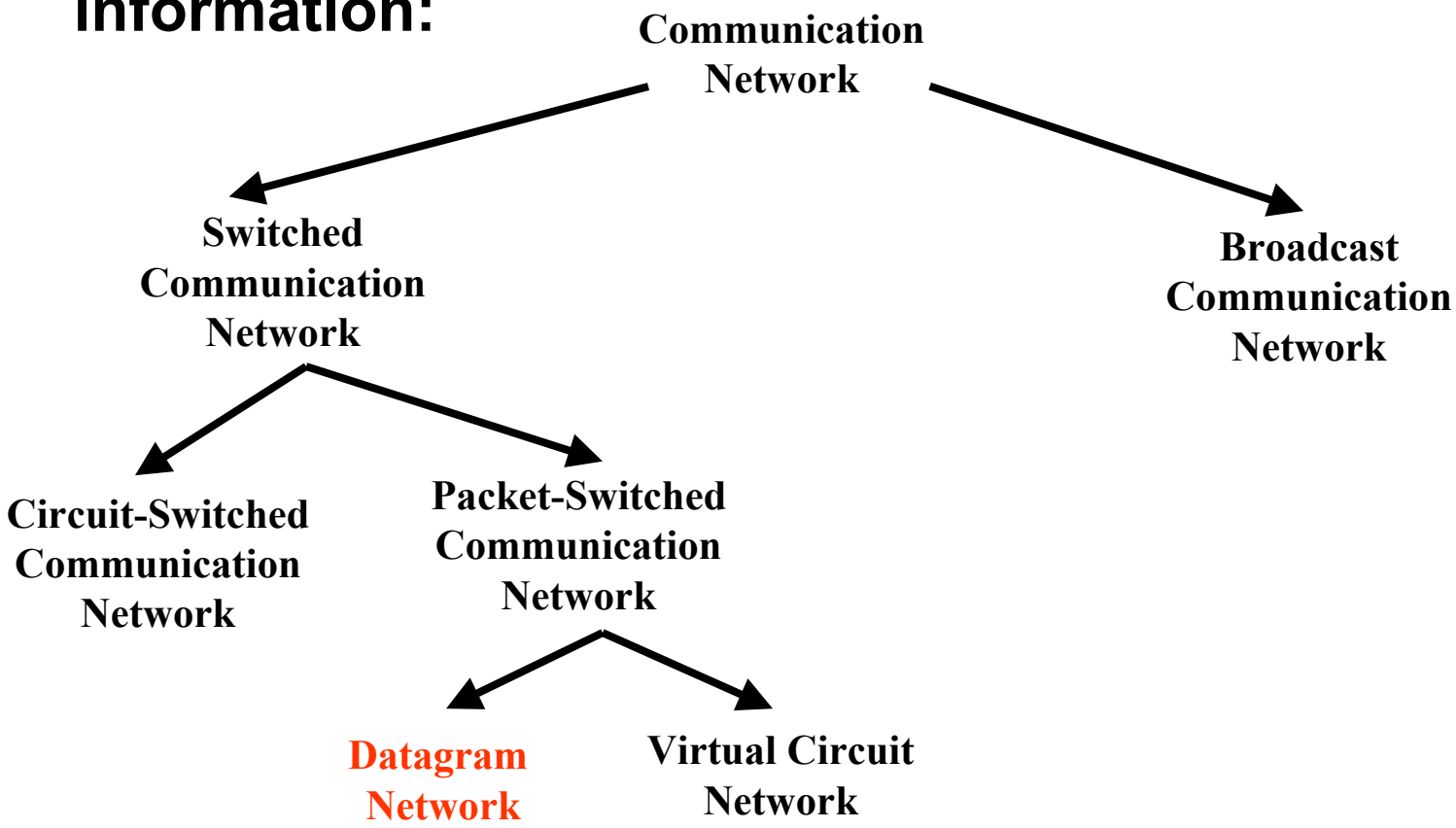
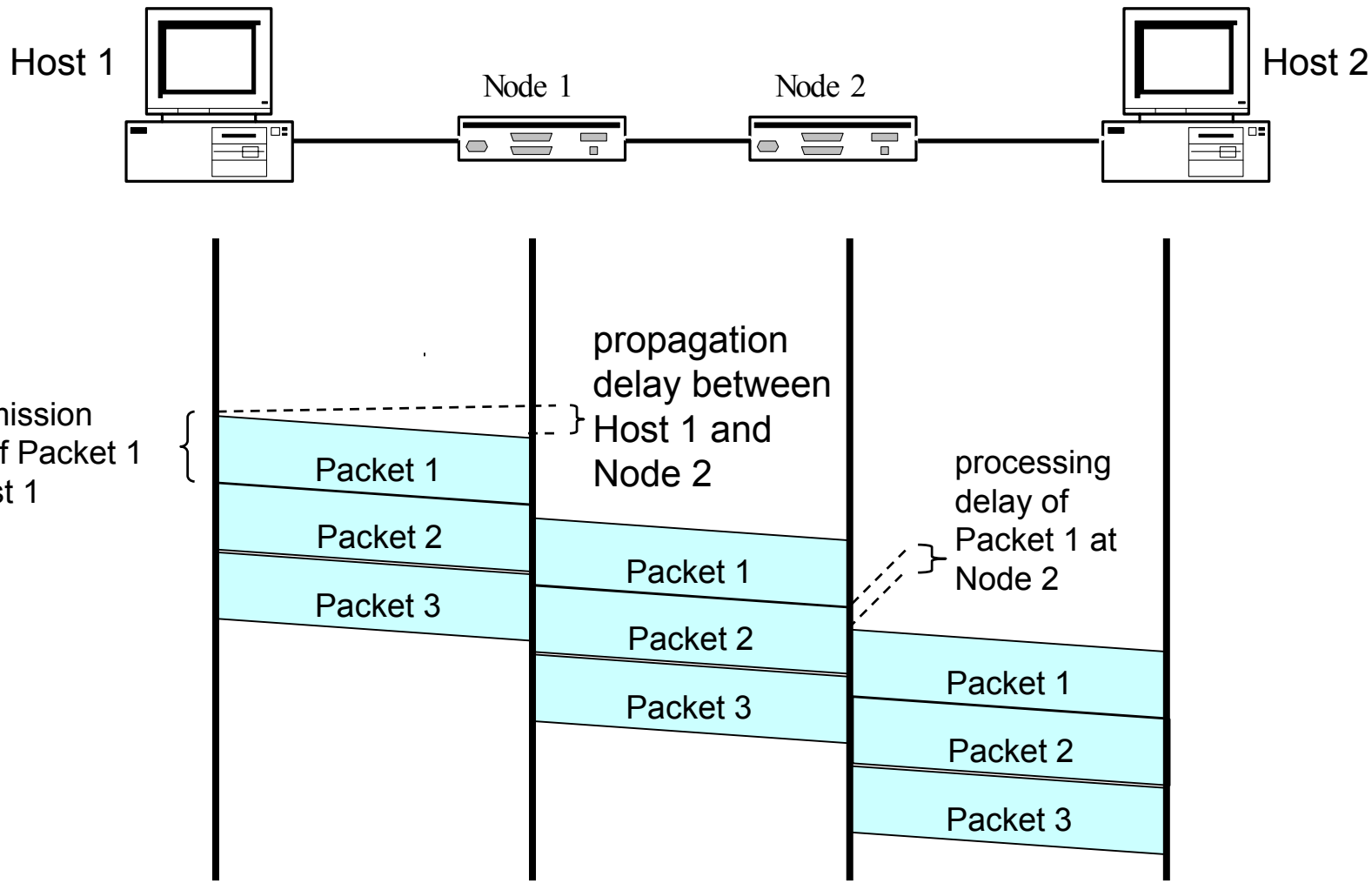


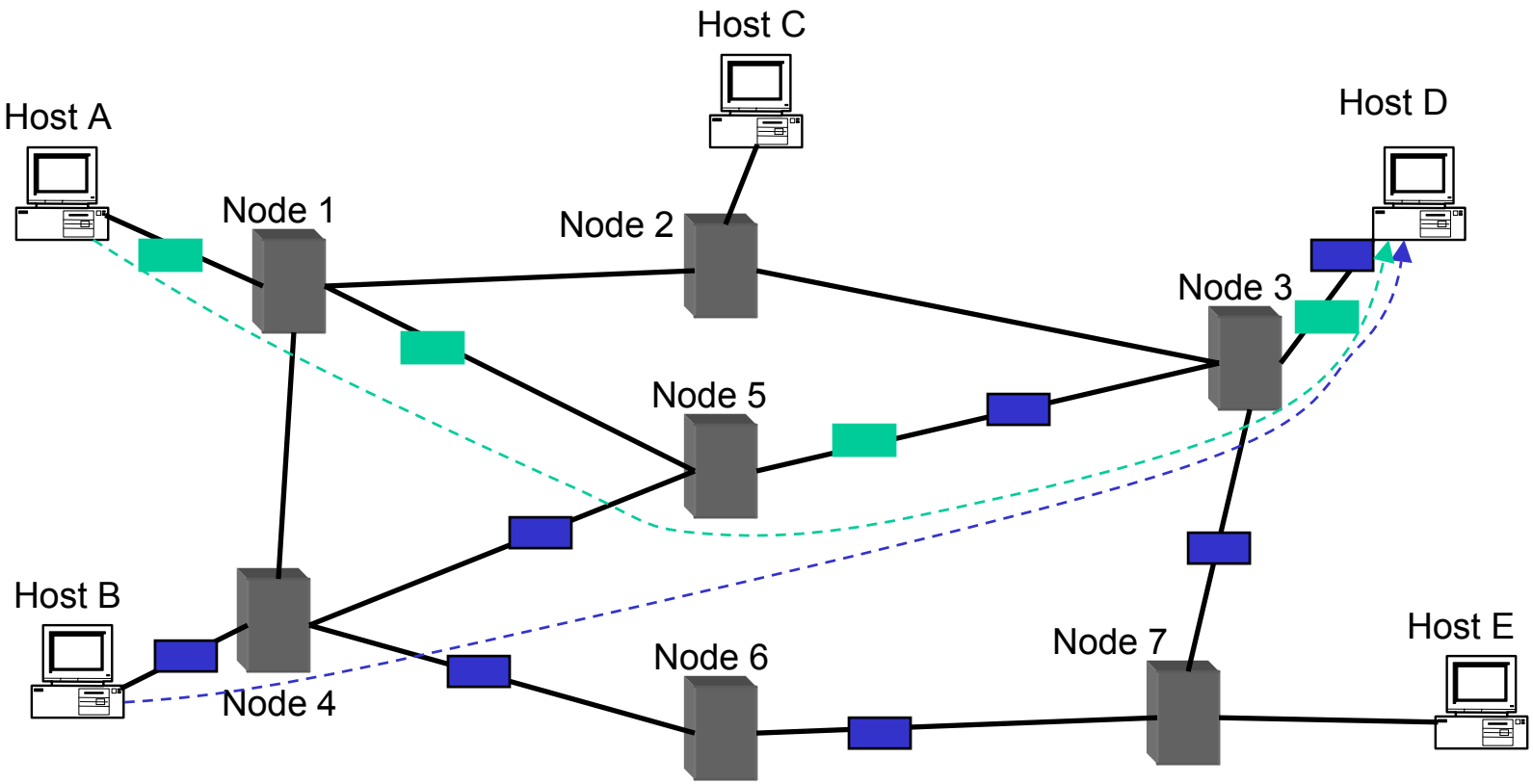
Datagram Packet Switching

- **Each packet is independently switched**
  - Each packet header contains destination address
- **No resources are pre-allocated (reserved) in advance**
- **Example: IP networks**

Timing of Datagram Packet Switching



Datagram Packet Switching



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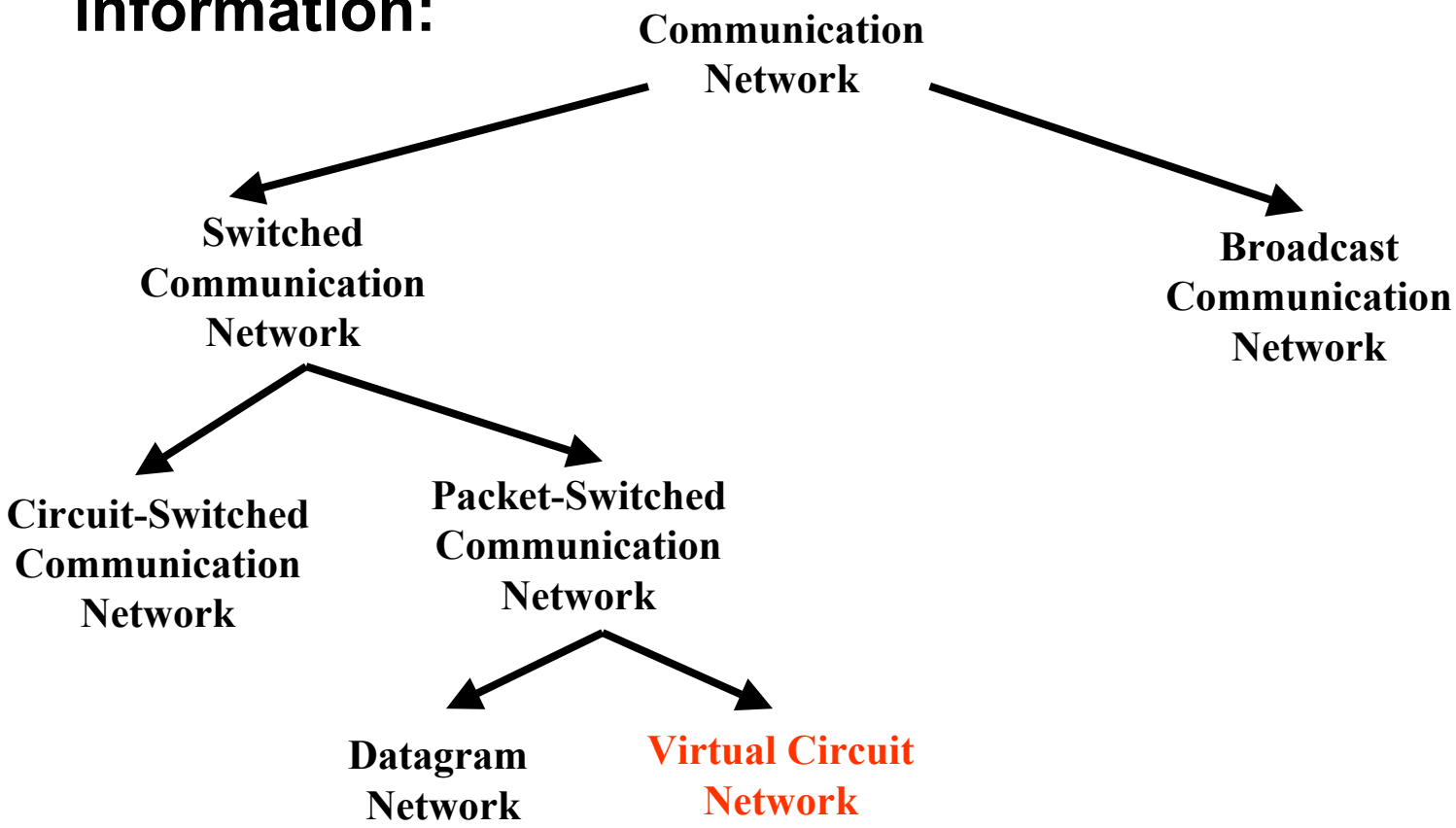


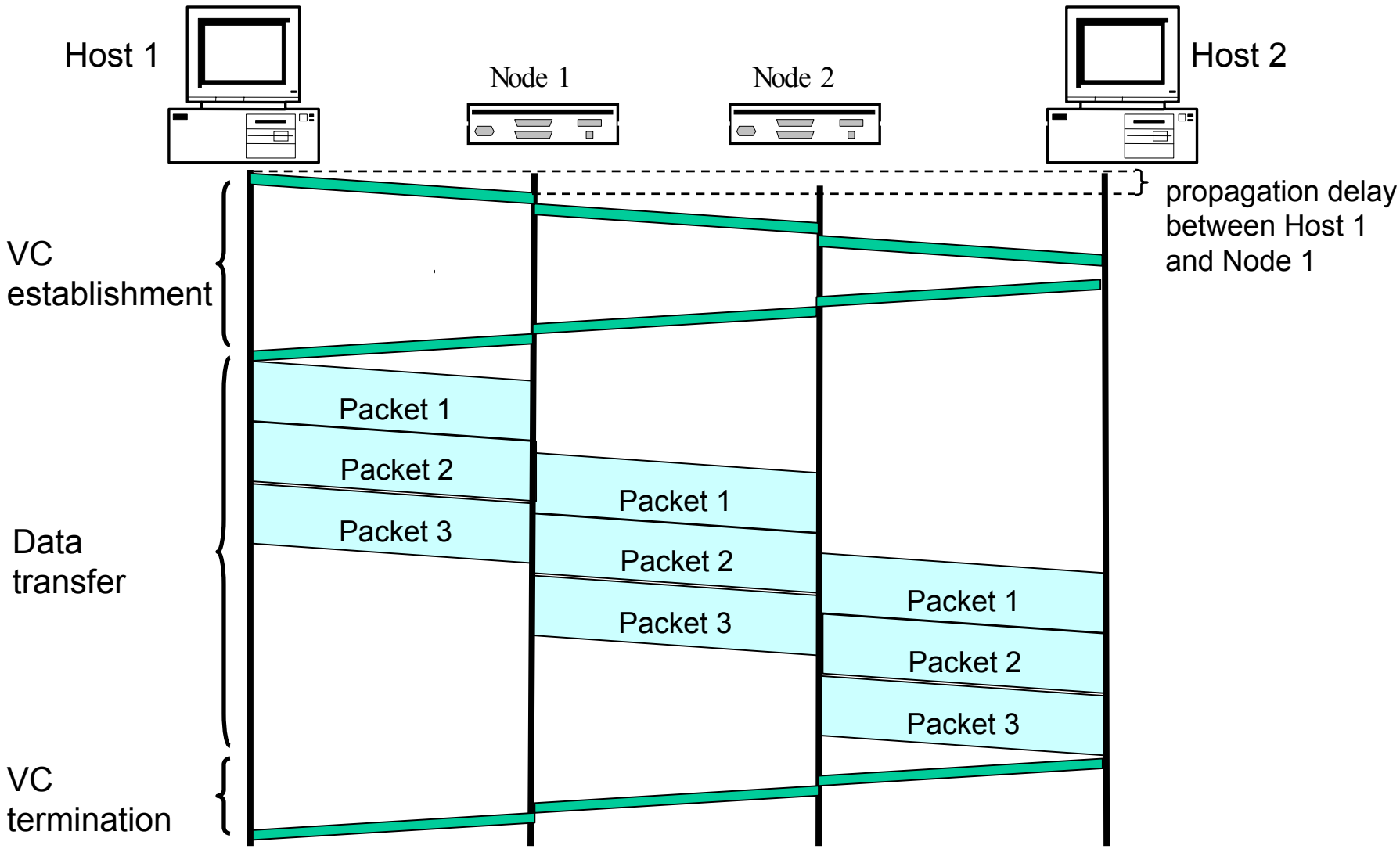
Virtual-Circuit Packet Switching

- **Hybrid of circuit switching and packet switching**
  - Data is transmitted as packets
  - All packets from one packet stream are sent along a pre-established path (=virtual circuit)
- **Guarantees in-sequence delivery of packets**
- **However, packets from different virtual circuits may be interleaved**
- **Example: ATM networks**

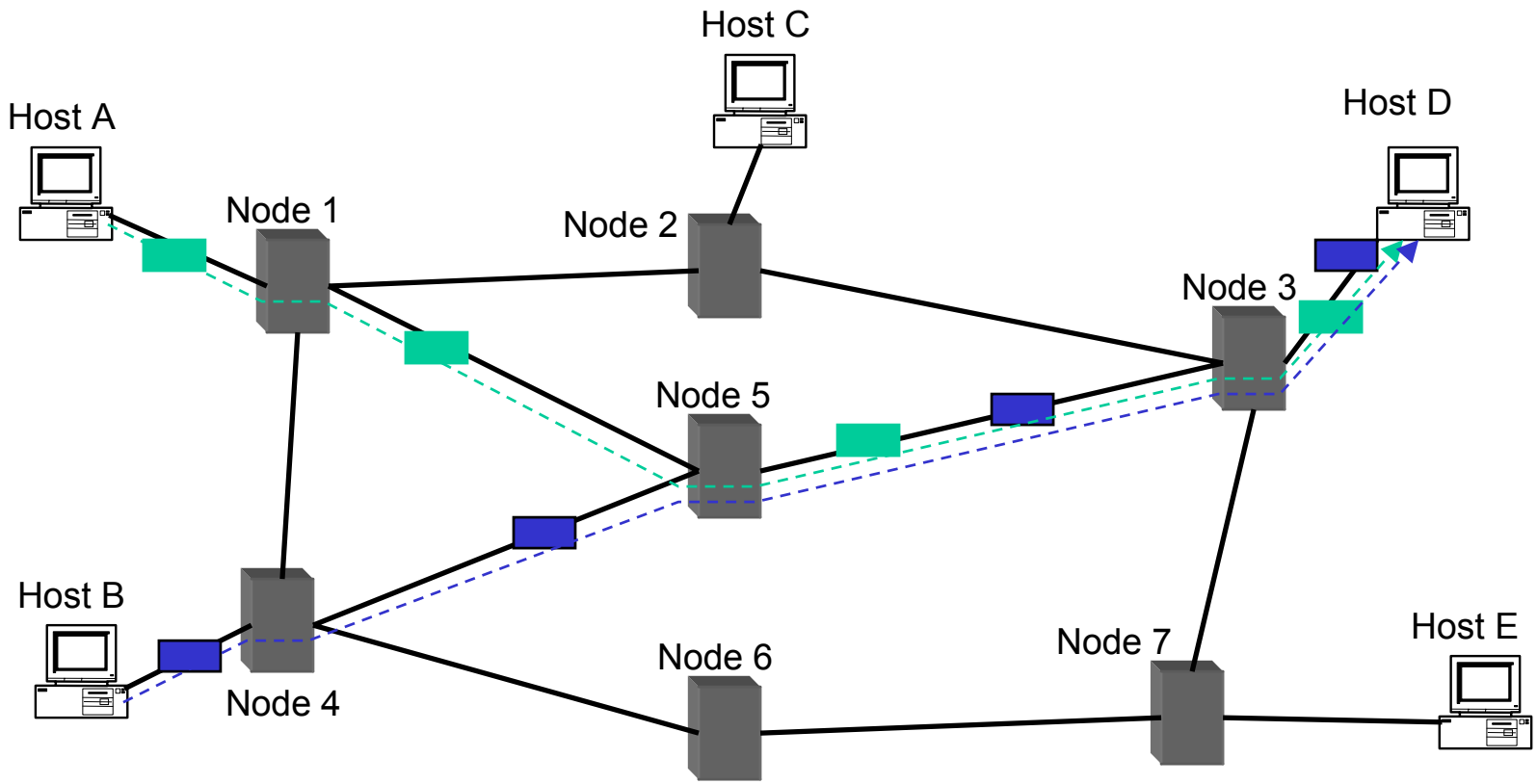
Virtual-Circuit Packet Switching

- **Communication with virtual circuits takes place in three phases**
  1. VC establishment
  2. data transfer
  3. VC disconnect
- **Note: packet headers don't need to contain the full destination address of the packet**

Timing of Virtual-Circuit Packet Switching



Datagram Packet Switching



Packet-Switching vs. Circuit-Switching

- **Most important advantage of packet-switching over circuit switching: ability to exploit statistical multiplexing:**
  - Efficient bandwidth usage for bursty traffic
- **However, packet-switching needs to deal with congestion:**
  - More complex routers
  - Harder to provide good network services (e.g., delay and bandwidth guarantees)

What Does Router Look Like?

M160 Router

M40 Router

M20 Router

M10 Router

M5 Router