Switching & Bridging

Problems

- In Chapter 2 we saw how to connect one node to another, or to an existing network. How do we build networks of global scale?
- How do we interconnect different types of networks to build a large global network?

Chapter Outline

- Switching and Bridging
- Basic Internetworking (IP)
- Routing

Chapter Goal

- Understanding the functions of switches, bridges and routers
- Discussing Internet Protocol (IP) for interconnecting networks
- Understanding the concept of routing

Switching and Forwarding

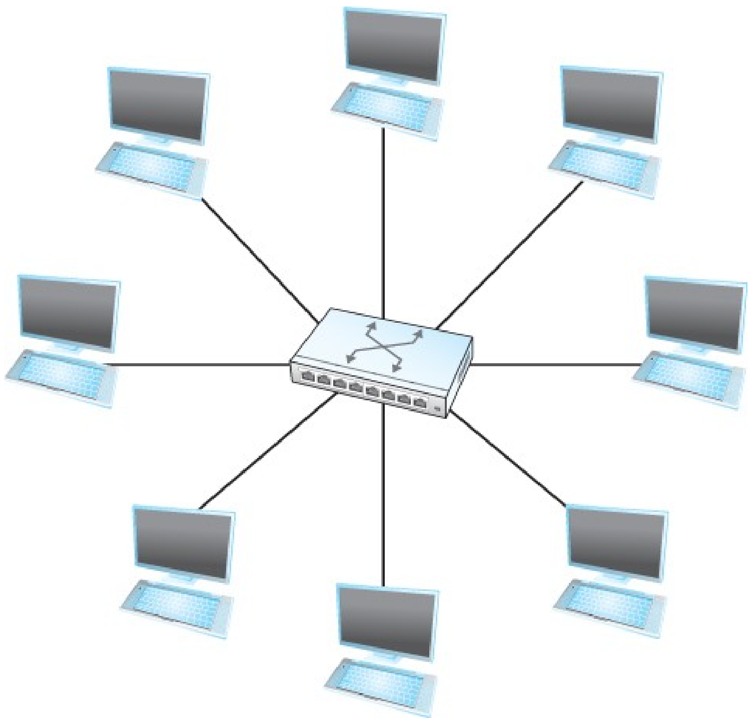
- Store-and-Forward Switches
- Bridges and Extended LANs
- Cell Switching
- Segmentation and Reassembly

Switching and Forwarding

- Switch
  - A mechanism that allows us to interconnect links to form a large network
  - A multi-input, multi-output device which transfers packets from an input to one or more outputs

Switching and Forwarding

Adds the star topology to the point-to-point link, bus (Ethernet), and ring (802.5 and FDDI) topologies



Switching and Forwarding

Properties of this star topology

- Even though a switch has a fixed number of inputs and outputs, which limits the number of hosts that can be connected to a single switch, large networks can be built by interconnecting a number of switches
- We can connect switches to each other and to hosts using point-to-point links, which typically means that we can build networks of large geographic scope
- Adding a new host to the network by connecting it to a switch does not necessarily mean that the hosts already connected will get worse performance from the network

Switching and Forwarding

The last claim cannot be made for the shared media network (discussed in Chapter 2)

- It is impossible for two hosts on the same Ethernet to transmit continuously at 10Mbps because they share the same transmission medium
- Every host on a switched network has its own link to the switch
  - So it may be entirely possible for many hosts to transmit at the full link speed (bandwidth) provided that the switch is designed with enough aggregate capacity

Switching and Forwarding

- A switch is connected to a set of links and for each of these links, runs the appropriate data link protocol to communicate with that node
- A switch’s primary job is to receive incoming packets on one of its links and to transmit them on some other link
  - This function is referred as *switching and forwarding*
  - According to OSI architecture this is the main function of the network layer

Switching and Forwarding

- How does the switch decide which output port to place each packet on?
  - It looks at the header of the packet for an identifier that it uses to make the decision
  - Two common approaches
    - *Datagram or Connectionless approach*
    - *Virtual circuit or Connection-oriented approach*
  - A third approach *source routing* is less common

Switching and Forwarding

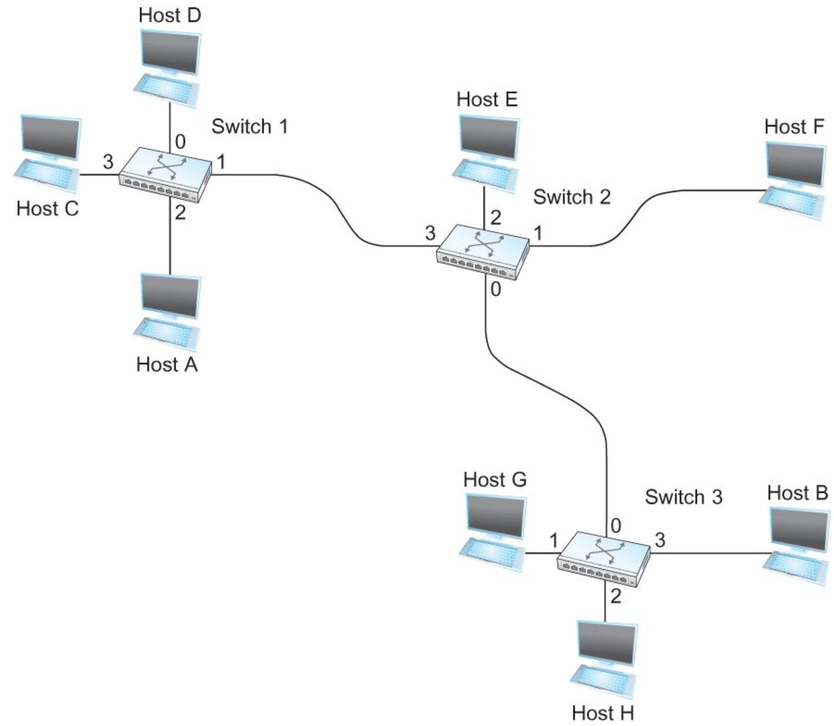
- Assumptions
  - Each host has a globally unique address
  - There is some way to identify the input and output ports of each switch
    - We can use numbers
    - We can use names

Switching and Forwarding

- Datagrams
  - Key Idea
    - Every packet contains enough information to enable any switch to decide how to get it to destination
      - Every packet contains the complete destination address

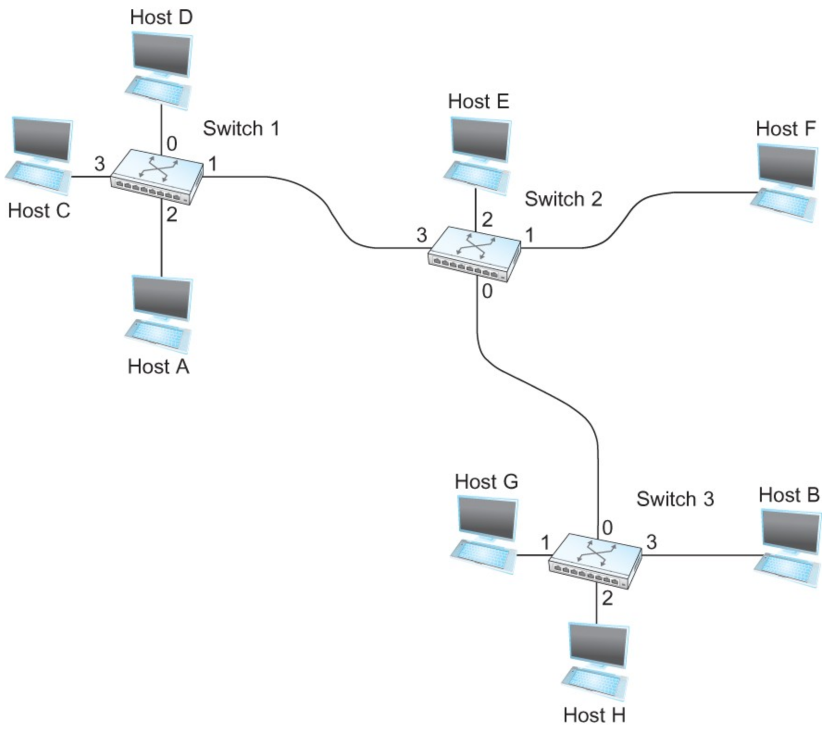
Switching and Forwarding

An example network



- To decide how to forward a packet, a switch consults a *forwarding table* (sometimes called a *routing table*)

Switching and Forwarding



Destination	Port
A	3
B	0
C	3
D	3
E	2
F	1
G	0
H	0

Forwarding Table for Switch 2

Switching and Forwarding

Characteristics of Connectionless (Datagram) Network

- A host can send a packet anywhere at any time, since any packet that turns up at the switch can be immediately forwarded (assuming a correctly populated forwarding table)
- When a host sends a packet, it has no way of knowing if the network is capable of delivering it or if the destination host is even up and running
- Each packet is forwarded independently of previous packets that might have been sent to the same destination.
  - Thus two successive packets from host A to host B may follow completely different paths
- A switch or link failure might not have any serious effect on communication if it is possible to find an alternate route around the failure and update the forwarding table accordingly

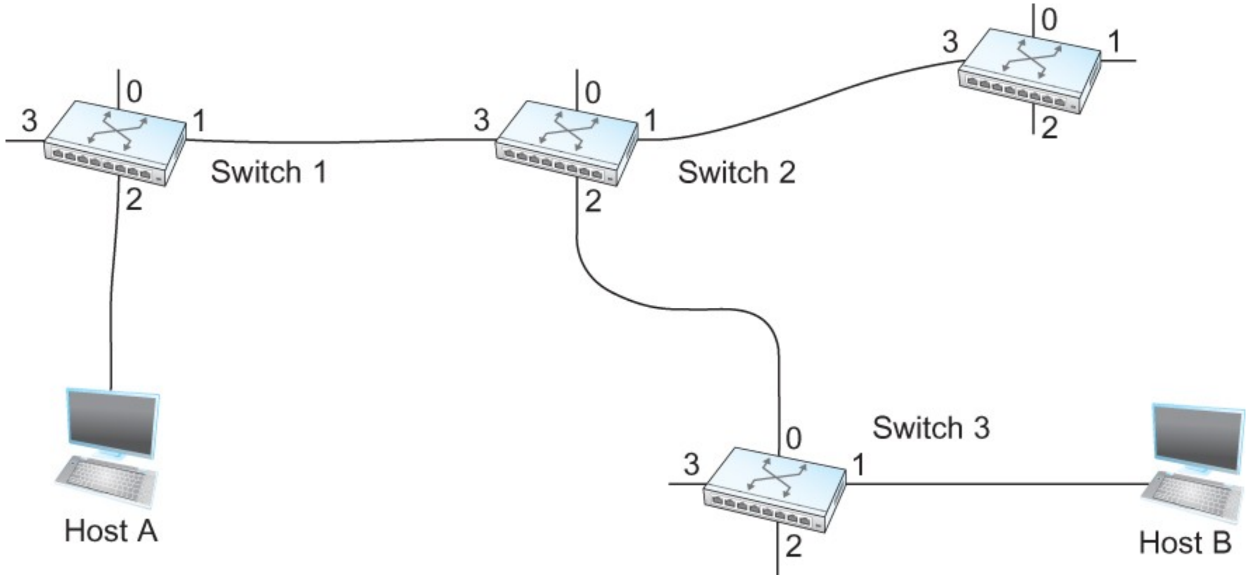
Switching and Forwarding

Virtual Circuit Switching

- Widely used technique for packet switching
- Uses the concept of *virtual circuit* (VC)
- Also called a connection-oriented model
- First set up a virtual connection from the source host to the destination host and then send the data

Switching and Forwarding

- Host A wants to send packets to host B



Switching and Forwarding

Two-stage process

- Connection setup
- Data Transfer

- Connection setup
  - Establish "connection state" in each of the switches between the source and destination hosts
  - The connection state for a single connection consists of an entry in the "VC table" in each switch through which the connection passes

Switching and Forwarding

One entry in the VC table on a single switch contains

- A virtual circuit identifier (VCI) that uniquely identifies the connection at this switch and that will be carried inside the header of the packets that belong to this connection
- An incoming interface on which packets for this VC arrive at the switch
- An outgoing interface in which packets for this VC leave the switch
- A potentially different VCI that will be used for outgoing packets

- The semantics for one such entry is
  - If a packet arrives on the designated incoming interface and that packet contains the designated VCI value in its header, then the packet should be sent out the specified outgoing interface with the specified outgoing VCI value first having been placed in its header

Switching and Forwarding

Note:

- The combination of the VCI of the packets as they are received at the switch and the interface on which they are received uniquely identifies the virtual connection
- There may be many virtual connections established in the switch at one time
- Incoming and outgoing VCI values are not generally the same
  - VCI is not a globally significant identifier for the connection; rather it has significance only on a given link
- Whenever a new connection is created, we need to assign a new VCI for that connection on each link that the connection will traverse
  - We also need to ensure that the chosen VCI on a given link is not currently in use on that link by some existing connection.

Switching and Forwarding

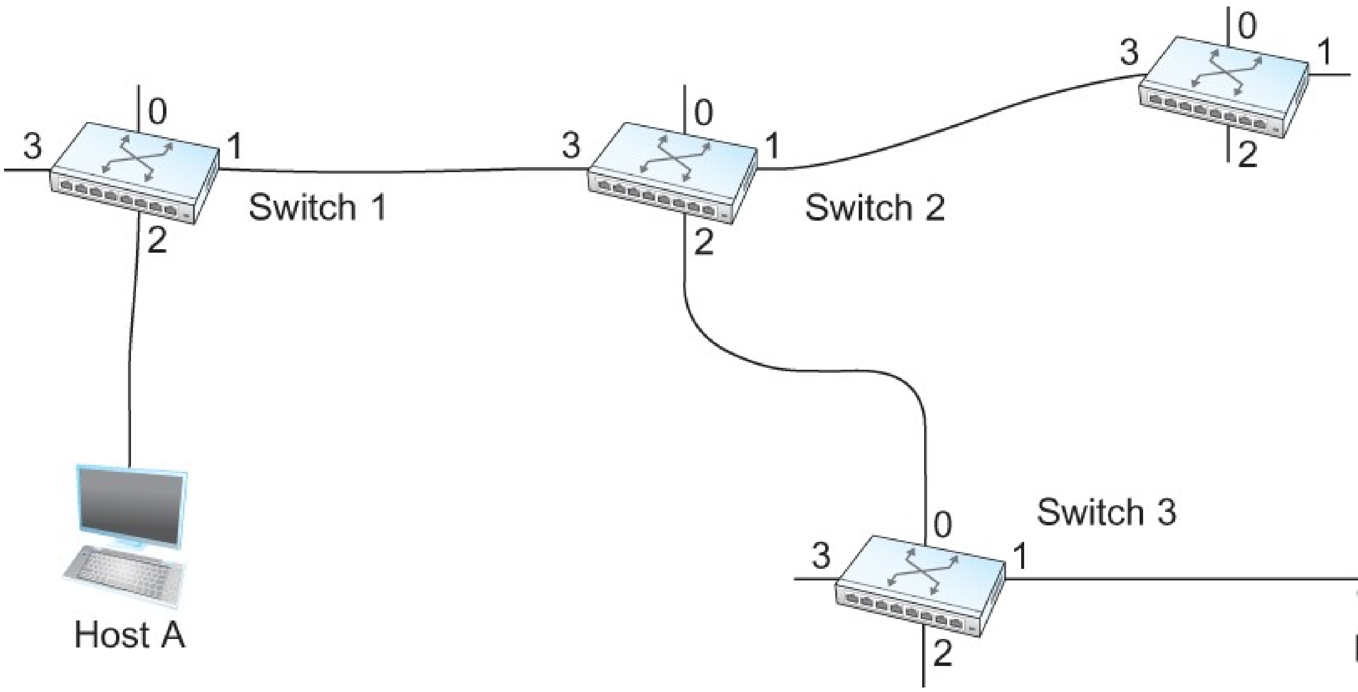
Two broad classes of approach to establishing connection state

- Network Administrator will configure the state
  - The virtual circuit is permanent (PVC)
  - The network administrator can delete this
  - Can be thought of as a long-lived or administratively configured VC
- A host can send messages into the network to cause the state to be established
  - This is referred as signalling and the resulting virtual circuit is said to be switched (SVC)
  - A host may set up and delete such a VC dynamically without the involvement of a network administrator

Switching and Forwarding

Let's assume that a network administrator wants to manually create a new virtual connection from host A to host B

- First the administrator identifies a path through the network from A to B



Switching and Forwarding

The administrator then picks a VCI value that is currently unused on each link for the connection

- For our example,
  - Suppose the VCI value 5 is chosen for the link from host A to switch 1
  - 11 is chosen for the link from switch 1 to switch 2
  - So the switch 1 will have an entry in the VC table

Incoming Interface	Incoming VC	Outgoing Interface	Outgoing VC
2	5	1	11

Switching and Forwarding

Similarly, suppose

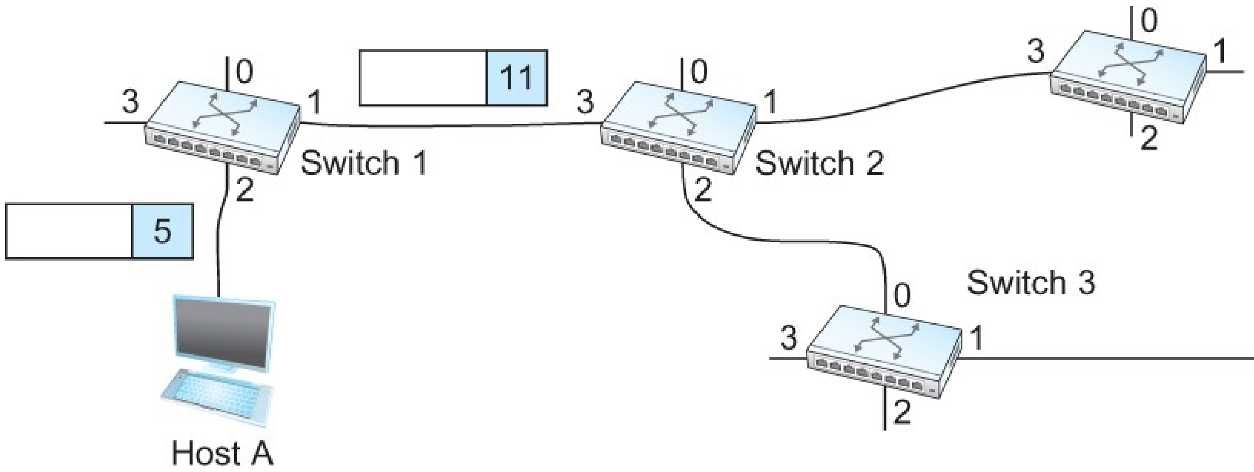
- VCI of 7 is chosen to identify this connection on the link from switch 2 to switch 3
- VCI of 4 is chosen for the link from switch 3 to host B
- Switches 2 and 3 are configured with the following VC table

Incoming Interface	Incoming VC	Outgoing Interface	Outgoing VC
3	11	2	7

Incoming Interface	Incoming VC	Outgoing Interface	Outgoing VC
0	7	1	4

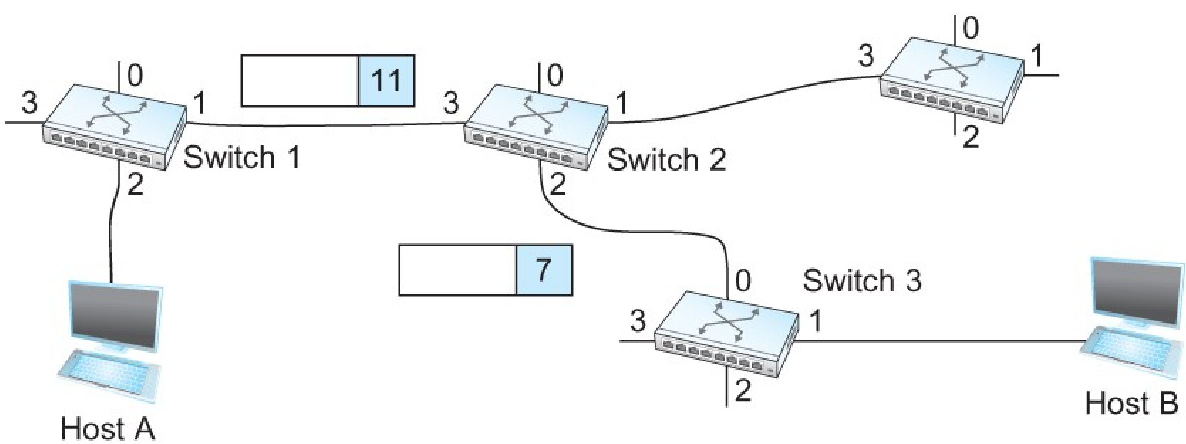
Switching and Forwarding

- For any packet that A wants to send to B, A puts the VCI value 5 in the header of the packet and sends it to switch 1
- Switch 1 receives any such packet on interface 2, and it uses the combination of the interface and the VCI in the packet header to find the appropriate VC table entry.
- The table entry on switch 1 tells the switch to forward the packet out of interface 1 and to put the VCI value 11 in the header



Switching and Forwarding

- Packet will arrive at switch 2 on interface 3 bearing VCI 11
- Switch 2 looks up interface 3 and VCI 11 in its VC table and sends the packet on to switch 3 after updating the VCI value appropriately
- This process continues until it arrives at host B with the VCI value of 4 in the packet
- To host B, this identifies the packet as having come from host A



Switching and Forwarding

- In real networks of reasonable size, the burden of configuring VC tables correctly in a large number of switches would quickly become excessive
  - Thus, some sort of signalling is almost always used, even when setting up “permanent” VCs
  - In case of PVCs, signalling is initiated by the network administrator
  - SVCs are usually set up using signalling by one of the hosts

Switching and Forwarding

- How does the signalling work
  - To start the signalling process, host A sends a setup message into the network (i.e. to switch 1)
    - The setup message contains (among other things) the complete destination address of B.
    - The setup message needs to get all the way to B to create the necessary connection state in every switch along the way
    - It is like sending a datagram to B where every switch knows which output to send the setup message so that it eventually reaches B
    - Assume that every switch knows the topology to figure out how to do that
  - When switch 1 receives the connection request, in addition to sending it on to switch 2, it creates a new entry in its VC table for this new connection
    - The entry is exactly the same shown in the previous table
    - Switch 1 picks the value 5 for this connection

Switching and Forwarding

- How does the signalling work (contd.)
  - When switch 2 receives the setup message, it performs the similar process and it picks the value 11 as the incoming VCI
  - Similarly switch 3 picks 7 as the value for its incoming VCI
    - Each switch can pick any number it likes, as long as that number is not currently in use for some other connection on that port of that switch
  - Finally the setup message arrives at host B.
  - Assuming that B is healthy and willing to accept a connection from host A, it allocates an incoming VCI value, in this case 4.
    - This VCI value can be used by B to identify all packets coming from A

Switching and Forwarding

- Now to complete the connection, everyone needs to be told what their downstream neighbor is using as the VCI for this connection
  - Host B sends an acknowledgement of the connection setup to switch 3 and includes in that message the VCI value that it chose (4)
  - Switch 3 completes the VC table entry for this connection and sends the acknowledgement on to switch 2 specifying the VCI of 7
  - Switch 2 completes the VC table entry for this connection and sends acknowledgement on to switch 1 specifying the VCI of 11
  - Finally switch 1 passes the acknowledgement on to host A telling it to use the VCI value of 5 for this connection

Switching and Forwarding

- When host A no longer wants to send data to host B, it tears down the connection by sending a teardown message to switch 1
- The switch 1 removes the relevant entry from its table and forwards the message on to the other switches in the path which similarly delete the appropriate table entries
- At this point, if host A were to send a packet with a VCI of 5 to switch 1, it would be dropped as if the connection had never existed

Switching and Forwarding

- Characteristics of VC
  - Since host A has to wait for the connection request to reach the far side of the network and return before it can send its first data packet, there is at least one RTT of delay before data is sent
  - While the connection request contains the full address for host B (which might be quite large, being a global identifier on the network), each data packet contains only a small identifier, which is only unique on one link.
    - Thus the per-packet overhead caused by the header is reduced relative to the datagram model
  - If a switch or a link in a connection fails, the connection is broken and a new one will need to be established.
    - Also the old one needs to be torn down to free up table storage space in the switches
  - The issue of how a switch decides which link to forward the connection request on has similarities with the function of a routing algorithm

Switching and Forwarding

- Good Properties of VC
  - By the time the host gets the go-ahead to send data, it knows quite a lot about the network-
    - For example, that there is really a route to the receiver and that the receiver is willing to receive data
  - It is also possible to allocate resources to the virtual circuit at the time it is established

Switching and Forwarding

- For example, an X.25 network – a packet-switched network that uses the connection-oriented model – employs the following three-part strategy
  - Buffers are allocated to each virtual circuit when the circuit is initialized
  - The sliding window protocol is run between each pair of nodes along the virtual circuit, and this protocol is augmented with the flow control to keep the sending node from overrunning the buffers allocated at the receiving node
  - The circuit is rejected by a given node if not enough buffers are available at that node when the connection request message is processed

Switching and Forwarding

- Comparison with the Datagram Model
  - Datagram network has no connection establishment phase and each switch processes each packet independently
  - Each arriving packet competes with all other packets for buffer space
  - If there are no buffers, the incoming packet must be dropped

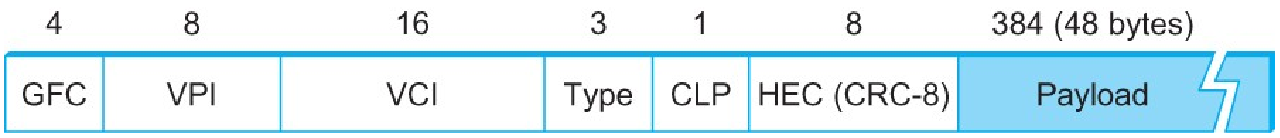
- In VC, we could imagine providing each circuit with a different quality of service (QoS)
  - The network gives the user some kind of performance related guarantee
    - Switches set aside the resources they need to meet this guarantee
      - For example, a percentage of each outgoing link's bandwidth
      - Delay tolerance on each switch
- Most popular examples of VC technologies are Frame Relay and ATM
  - One of the applications of Frame Relay is the construction of VPN

Switching and Forwarding

- ATM (Asynchronous Transfer Mode)
  - Connection-oriented packet-switched network
  - Packets are called cells
    - 5 byte header + 48 byte payload
  - Fixed length packets are easier to switch in hardware
    - Simpler to design
    - Enables parallelism

Switching and Forwarding

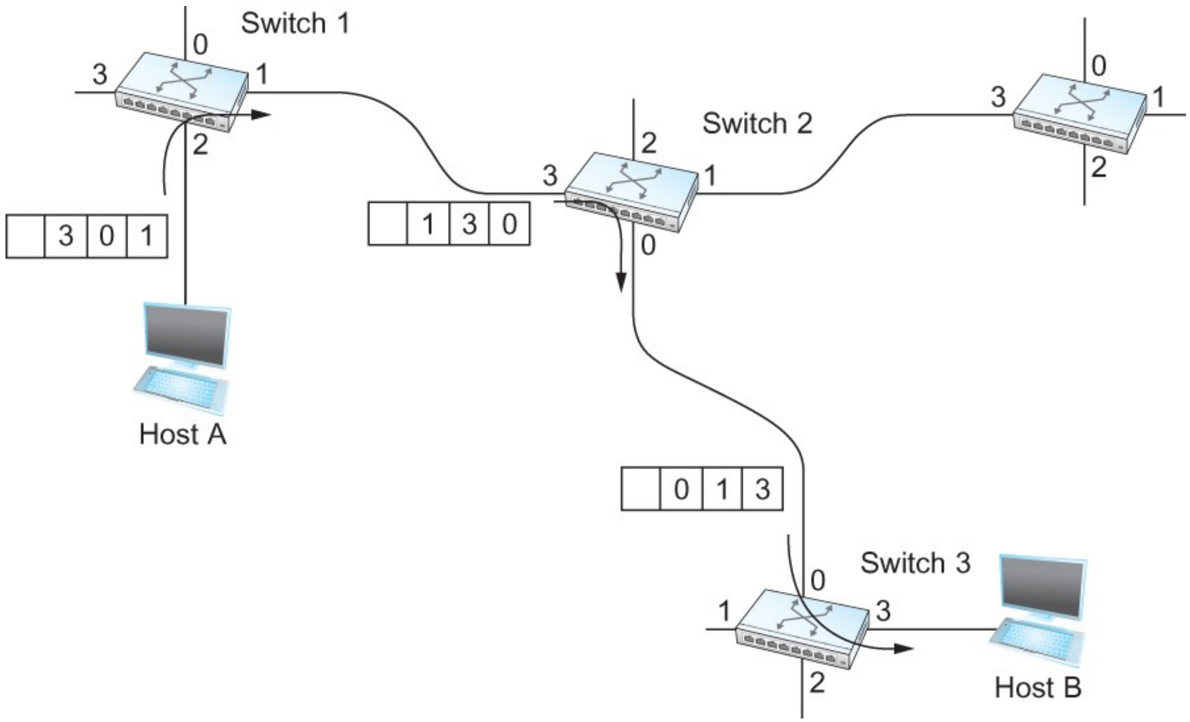
- ATM
  - User-Network Interface (UNI)
    - Host-to-switch format
    - GFC: Generic Flow Control
    - VCI: Virtual Circuit Identifier
    - Type: management, congestion control
    - CLP: Cell Loss Priority
    - HEC: Header Error Check (CRC-8)



  - Network-Network Interface (NNI)
    - Switch-to-switch format
    - GFC becomes part of VPI field

Switching and Forwarding

- **Source Routing**
  - All the information about network topology that is required to switch a packet across the network is provided by the source host



Switching and Forwarding

- Other approaches in Source Routing