CS 425: Computer Networks **Jan-Apr 2020**

Lecture 14: Computer Networks – February 25, 2020

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Disclaimer: *These notes aggregate content from several texts and have not been subjected to the usual scrutiny deserved by formal publications. If you find errors, please bring to the notice of the Instructor.*

This lecture's notes illustrate some uses of various LaTeX macros. Take a look at this and imitate.

14.1 The Network Layer

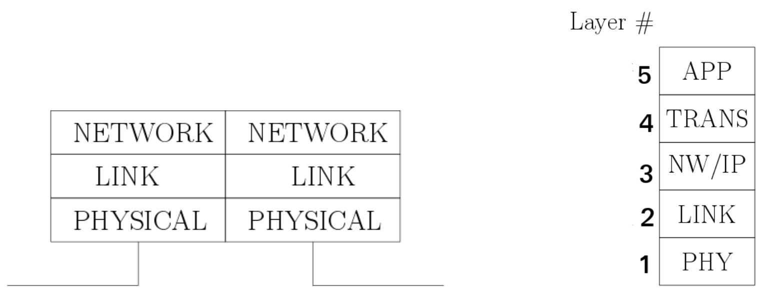


Figure 14.1: Router and Network Layer Stack

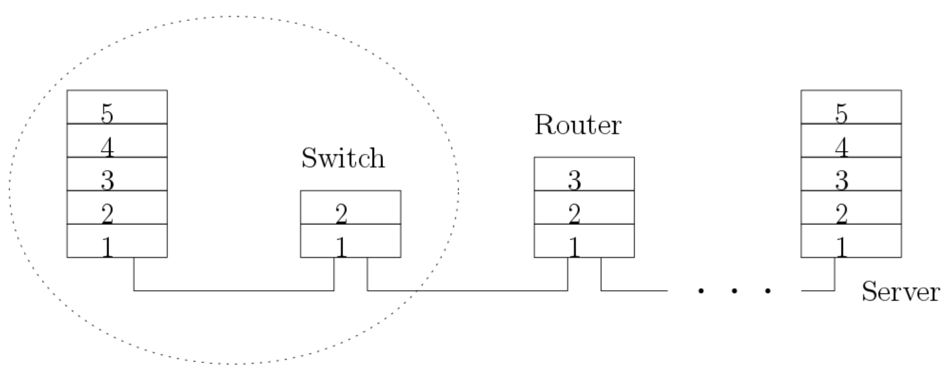


Figure 14.2: Typical 5 layer diagram

- The network layer is concerned with getting packets from the source all the way to the destination.
- It builds on link layer, sends packets over multiple connected networks (private e.g ISPs, Institutional).
- The function clearly contrasts with that of the data link layer, where goal was just to send the frame within one network, or over the link.

- If we want to communicate with any device within a LAN, then till that level the LINK layer can be sufficient for communication. But if we want to do inter-networking, i.e., someone from an institutional network like that of IITK wants to connect to another institutional network, then there is a need for NETWORK layer.

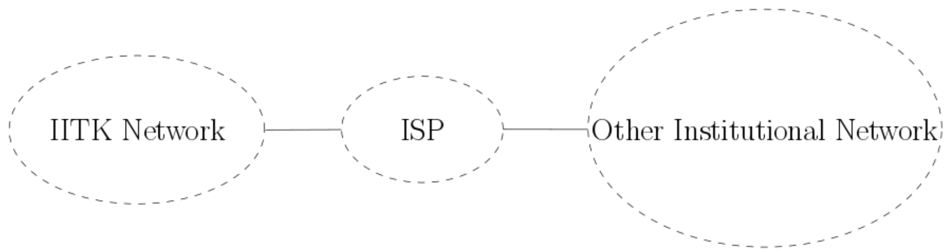


Figure 14.3: Inter-networking Diagram

Q: Why network layer at all? finding path between hosts is part of LL switches also.

14.1.1 Limitations of Switch-based Routing Protocol

- **Scalability**:
  - Table sizes are infeasible, needs entry for every MAC address, billion entries in table not possible.
  - *Broadcasting*: Chews the bandwidth for populating these tables.
  - Spanning Tree Algorithm does not scale efficiently to billion entries.
- **Wireless**: The example of spanning tree works for wired networks, does not work for wireless networks as they are generally not fully duplex.

dissimilar networks (BL was designed for link layer – only one type of link)

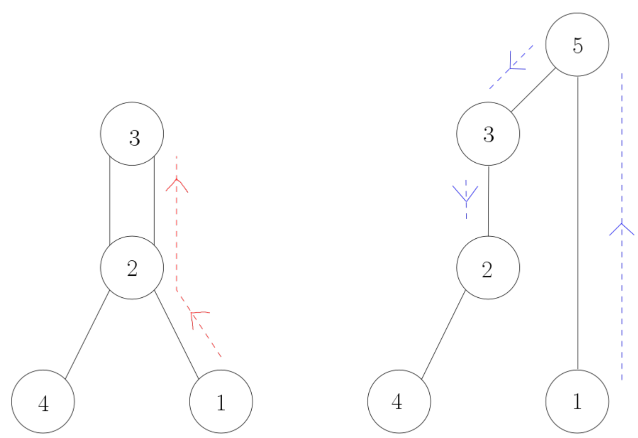


Figure 14.4: Paths by Decentralised Spanning Tree Algorithm

- It is not **cost-effective** for routing packets as the Decentralised Spanning Tree Algorithm chooses its path according to the tree, not the shortest path.

14.1.2 Network Layer Approach

- **Scalability**: Routers are able to read upto network layer headers, and hence determine from the blocks of prefix, the destination network of the packet.

- **Heterogenity**: IP for networking, connecting multiple dissimilar networks.
- **Bandwidth Efficiency**: Facillitates Lowest Cost Routing and efficient *Quality of Service (QoS)* (voice or video calls), ensures bandwidth for specific application.

14.2 Topics in Network Layer

We will delve deeper into the network layer, in the following sequence:

- **Network Service Models**
  - Datagram
  - Virtual Cicuit
- **IP (Internet Protocol), IPv4**
  - Internetworking
  - Forwarding
  - Helper Protocols: ARP & DHCP
  - Fragmentation & MTU Discoveries
  - ICMP (errors)
- **IPv6 (Future of IP)**
- **NAT (Network Address Translation), Middlebox**
- **Routing Algorithms**

14.2.1 Routing vs Forwarding – an important distinction

- **Routing** is the process of selecting a path for traffic in a network or between or across multiple networks. It is a global and expensive process (in terms of the bandwidth which it uses).
- **Forwarding** is the transit of network packets from one network interface to another. It is an effect of routing and a local process.

14.3 Network Service Models

This section deals with the services provided by the **network layer** to the **transport layer**, the layer just above. The services can be divided into two types based on whether the network layer should provide connection-oriented or connectionless service:

- **Datagram (Connectionless Service)**: Analogous to the **traditional postal model**.
- **Virtual Circuit (Connection-Oriented Service)**: Analogous to the **telephone system** (although telephone system is not an example of Virtual Circuit).

14.3.1 General Implementation

- Both the services use the **store-and-forward** packet switching mechanism.

- A host with a packet to send transmits it to the nearest router, either on its own LAN or over a point-to-point link to the ISP. The packet is stored there until it has fully arrived and the link has finished its processing by verifying the checksum. Then it is forwarded to the next router along the path until it reaches the destination host, where it is delivered. This mechanism is **store-and-forward** packet switching

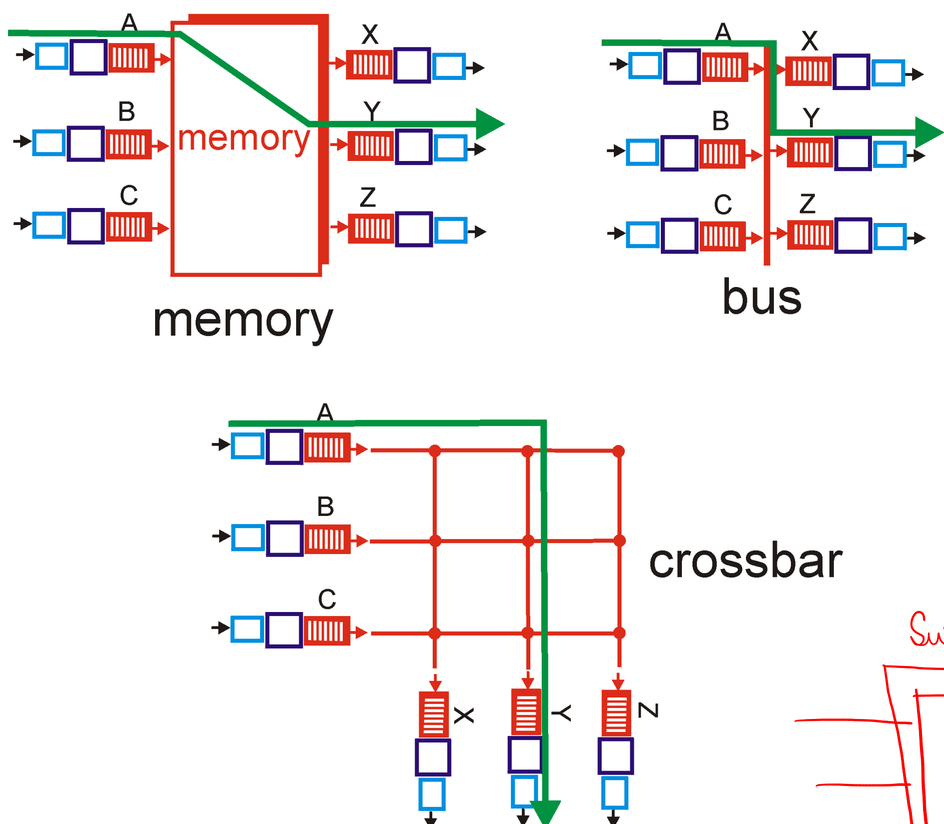
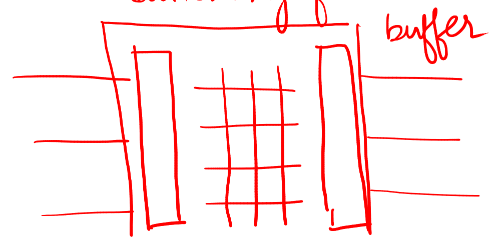


Figure 14.5: Internal structure of Router

Switching fabric with buffer

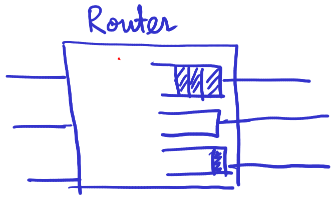


- The internal structure of the router contains a switch fabric. The figure contains three different types in which switching can be done.

- The buffer at the input and at the output contains a Queue that runs on the First In First Out basis.

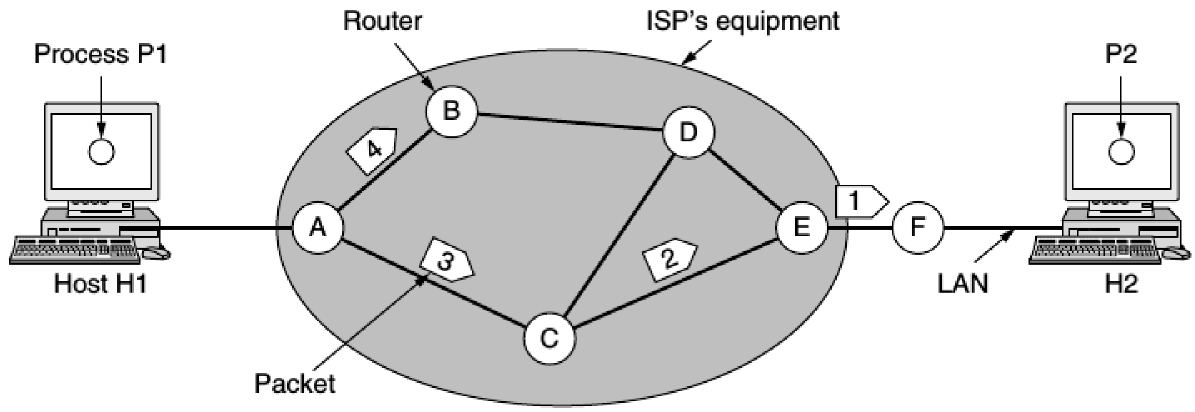
- There is a limit to the size of the Queue(Buffer) that determines the limit on the number of transmissions that can be done across the router.

Router



queues have finite capacity
discards when full.

14.3.2 Datagram Model



Dest.	A's table (initially) Line	A's table (later)	C's table	E's table
A	–	–	A	C
B	B	B	A	D
C	C	C	–	C
D	B	B	E	D
E	C	B	E	–
F	C	B	E	F

Figure 14.6: Routing within Datagram Network

- Packets are injected into the network individually and routed independently of each other. No advance setup is needed.
- Assume there are 4 packets 1,2,3 and 4, and H1 needs to send each of them in turn to H2.
- Every router has an internal routing table that tells it where to send packets for each of the possible destinations. Each table entry is a pair consisting of a destination and the outgoing line to use for that destination. A's initial routing table is shown in figure.
- The ~~routing~~ forwarding tables are not static. They keep changing in a dynamic way.
- At A, packets 1, 2, and 3 are stored briefly, having arrived on the incoming link and had their checksums verified.
- Then each packet is forwarded according to As table, onto the outgoing link to C within a new frame. Packet 1 is then forwarded to E and then to F. Packets 2 and 3 follow the same route.
- Now suppose, A updates its routing table subject to certain failure, or traffic jam along ACE path, and forwards the packet 4 to B, instead of C. A's "later" table is shown in figure.
- The algorithms that manage routing tables are called routing algorithms, we will learn about them later.
- Structure of IP Packet is given in the figure below.

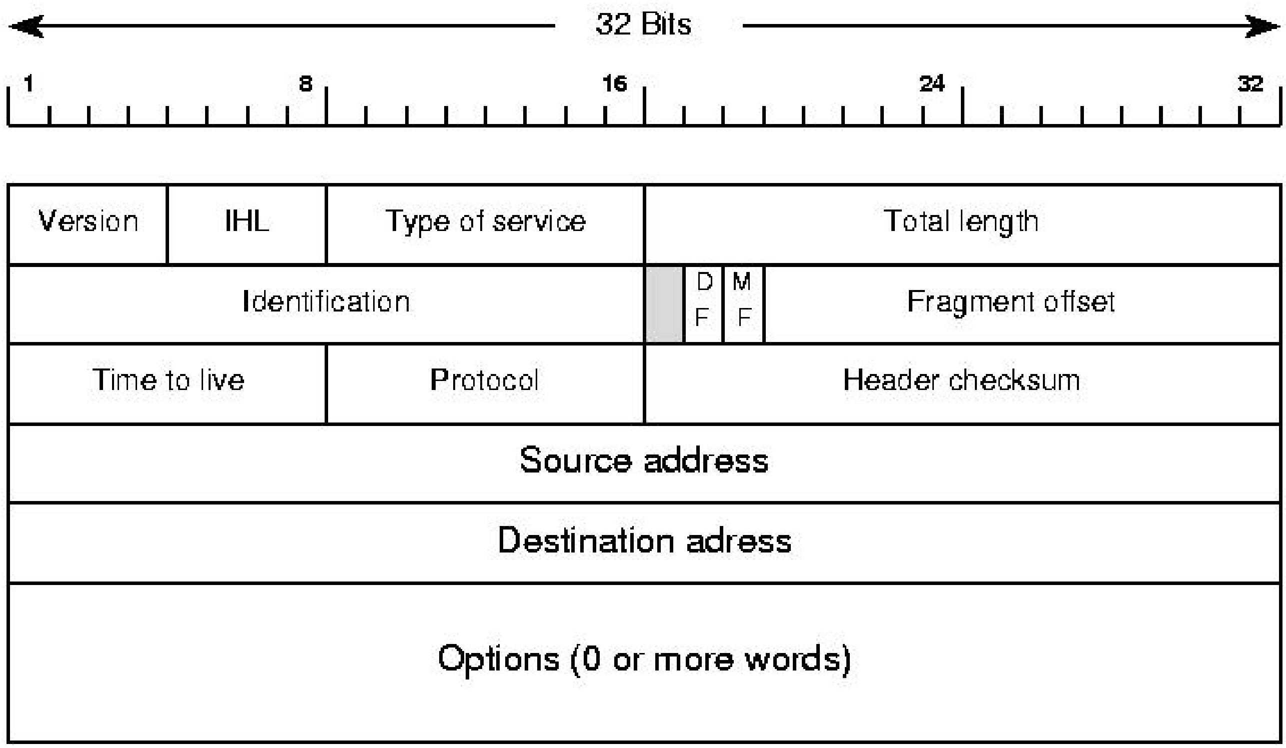


Figure 14.7: IP Datagram Header Format

- Internet Protocol (IP) being a layer-3 protocol takes data Segments from layer-4 (Transport) and divides it into packets.
- IP packet encapsulates data unit received from above layer and adds its own header information to it.
- The encapsulated data is referred to as IP Payload.
- IP header contains all the necessary information to deliver the packet at the other end.

14.3.3 Virtual Circuit (VC)

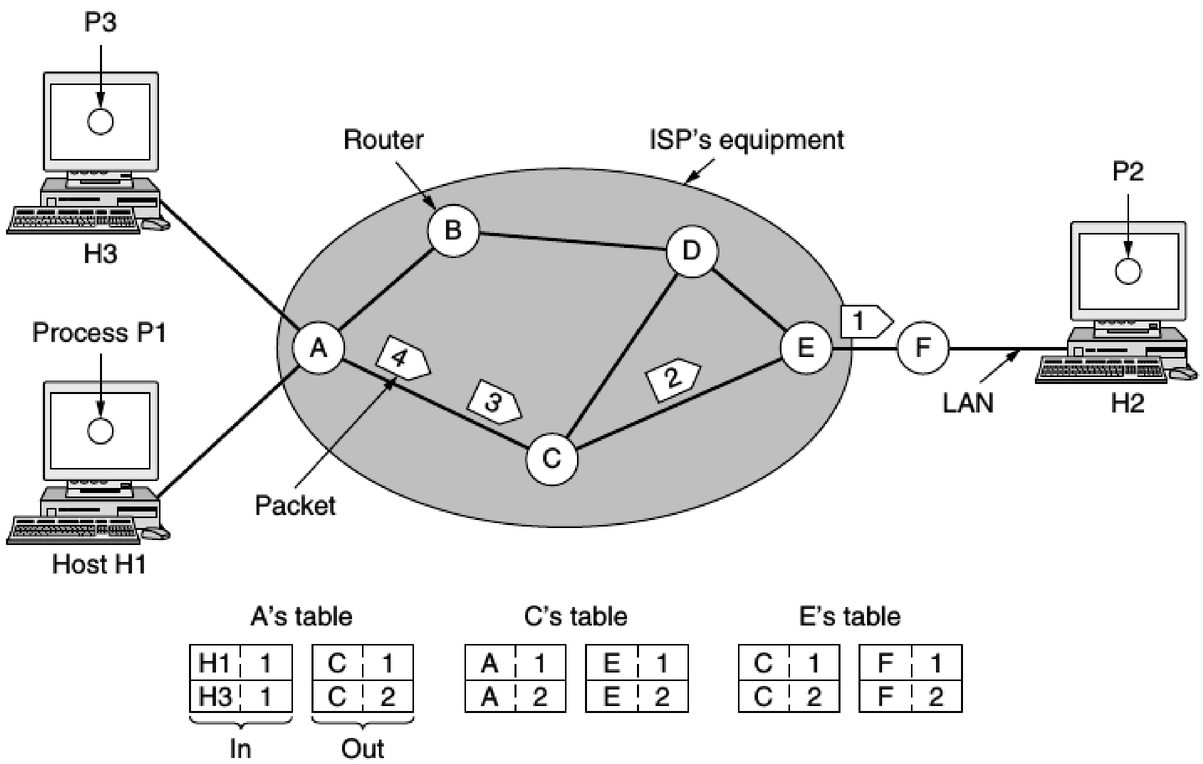
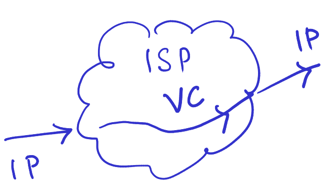


Figure 14.8: Routing within Virtual-Circuit Network

- Similar to a telephone network.
- Each link dedicates some bandwidth for a VC. VC has a label that can vary from link to link.
- The idea behind VC is to avoid having to choose new route for every packet sent.
- VC table is generated during a setup phase.
- All VC packets will be sent using this table
- In the figure, host H1 has established connection 1 with host H2, this is remembered as the first entry in each of the routing tables.
- The first line of As table says that if a packet bearing label 1 comes in from H1, it is to be sent to router C and given label 1. Similarly, the first entry at C routes the packet to E, also with label 1.
- Now, suppose H3 also establishes a connection with H2, this leads to second row of all tables. It also chooses label 1 for its packet.
- Now to distinguish packets of two connections, A has to give a different label to packet from H3, while forwarding to C.
- To avoid these conflicts, routers have the ability of **label switching**.
- An example of this service is **MPLS (Multi-Protocol Label Switching)** . It is used by ISPs.



PPP	MPLS	IP	TCP	user data	CRC

label	QoS	S	TTL

adds the MPLS header at ingress
takes off at egress

14.3.4 Comparison of Virtual Circuits and Datagram Networks

Issue	Datagram network	Virtual-circuit network
Circuit setup	Not needed	Required
Addressing	Each packet contains the full source and destination address	Each packet contains a short VC number
State information	Routers do not hold state information about connections	Each VC requires router table space per connection
Routing	Each packet is routed independently	Route chosen when VC is set up; all packets follow it
Effect of router failures	None, except for packets lost during the crash	All VCs that passed through the failed router are terminated
Quality of service	Difficult	Easy if enough resources can be allocated in advance for each VC
Congestion control	Difficult	Easy if enough resources can be allocated in advance for each VC

Figure 14.9: Comparison of Datagram and Virtual Circuit Networks