# INTERNETWORKING :

**Until now, we have implicitly assumed that there is a single homogeneous network, with each machine using the same protocol in each layer. Unfortunately, this assumption is wildly optimistic. Many different networks exist, including LANs, MANs, and WANs. Numerous protocols are in widespread use in every layer. Here, we will take a careful look at the issues that arise when two or more networks are connected to form an internet.**

# INTERNETWORKING

We believe that a variety of different networks (and thus protocols) will always be around, for the following reasons.

First of all, the installed base of different networks is large. Nearly all personal computers run TCP/IP. Many large businesses have mainframes running IBM's SNA (System Network Architecture). A substantial number of telephone companies operate ATM networks. Some personal computer LANs still use Novell NCP/IPX or AppleTalk. Finally, wireless is an up-and-coming area with a variety of protocols. This trend will continue for years due to legacy problems, new technology, and the fact that not all vendors perceive it in their interest for their customers to be able to easily migrate to another vendor's system.

# INTERNETWORKING

Second, as computers and networks get cheaper, the place where decisions get made moves downward in organizations.

Many companies have a policy to the effect that purchases costing over a million dollars have to be approved by top management, purchases costing over 100,000 dollars have to be approved by middle management, but purchases under 100,000 dollars can be made by department heads without any higher approval. This can easily lead to the engineering department installing UNIX workstations running TCP/IP and the marketing department installing Macs with AppleTalk.

# INTERNETWORKING

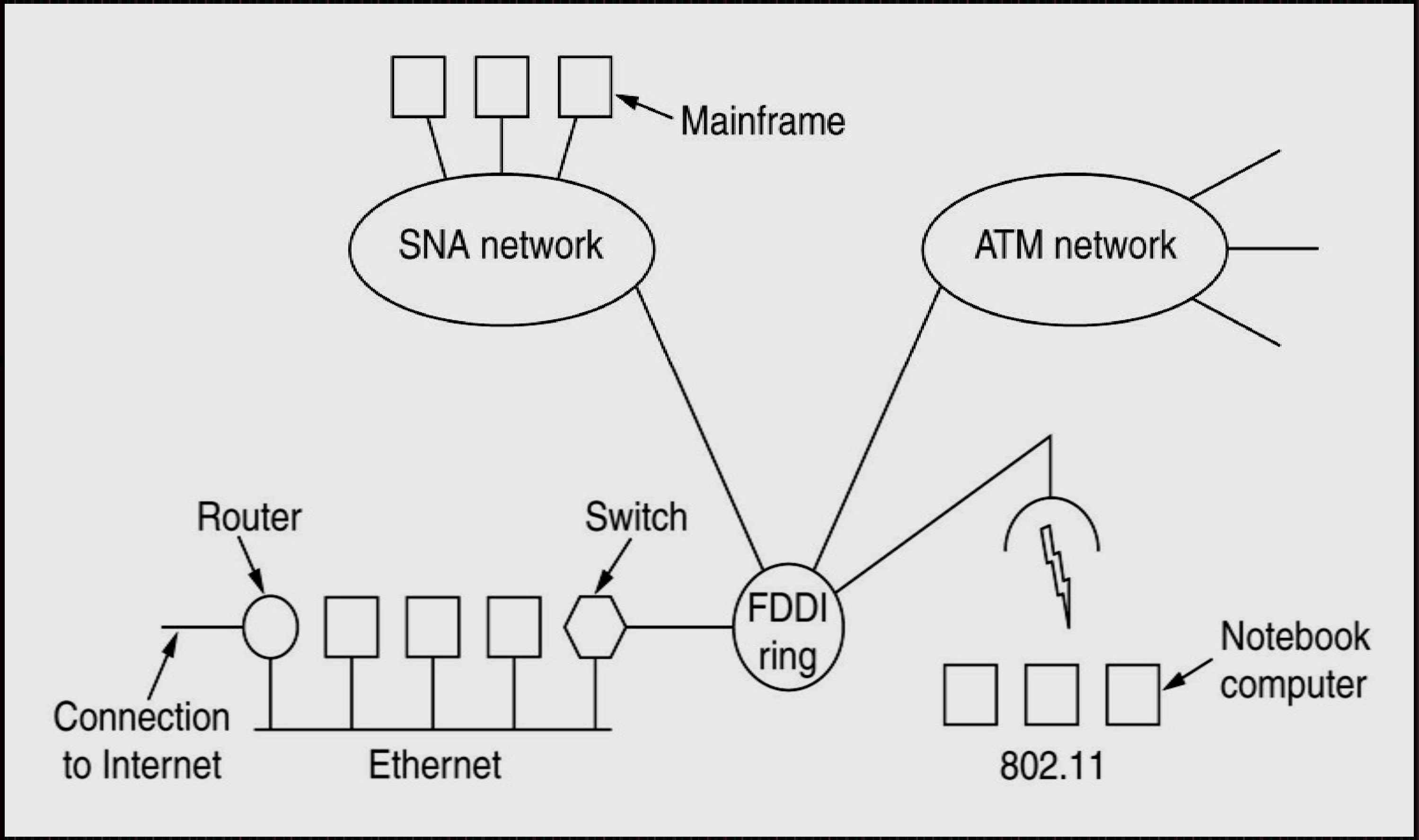
Third, different networks (e.g., ATM and wireless) have radically different technology, so it should not be surprising that as new hardware developments occur, new software will be created to fit the new hardware.

For example, the average home now is like the average office ten years ago: it is full of computers that do not talk to one another. In the future, it may be commonplace for the telephone, the television set, and other appliances all to be networked together so that they can be controlled remotely. This new technology will undoubtedly bring new networks and new protocols.

# INTERNETWORKING

**As an example of how different networks might be connected, consider the example of Fig-A. Here we see a corporate network with multiple locations tied together by a wide area ATM network. At one of the locations, an FDDI optical backbone is used to connect an Ethernet, an 802.11 wireless LAN, and the corporate data center's SNA mainframe network.**

# INTERNETWORKING



A collection of interconnected networks.

# INTERNETWORKING

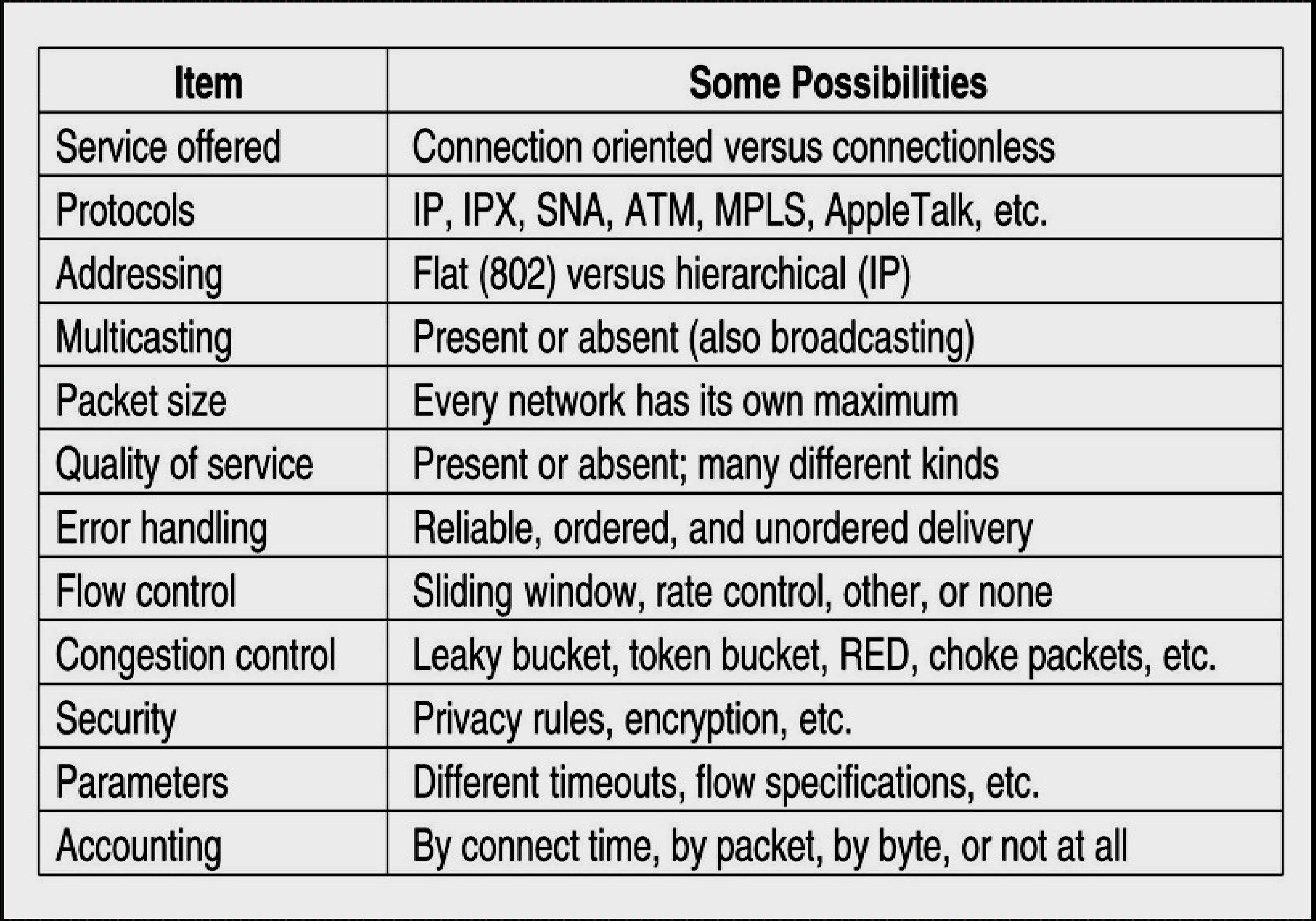
The purpose of interconnecting all these networks is to allow users on any of them to communicate with users on all the other ones and also to allow users on any of them to access data on any of them. Accomplishing this goal means sending packets from one network to another. Since networks often differ in important ways, getting packets from one network to another is not always so easy, as we will now see.

## How Networks Differ :

Networks can differ in many ways. Some of the differences, such as different modulation techniques or frame formats, are in the physical and data link layers.

Instead, in Fig-B, some of the differences that can occur in the network layer are shown. It is papering over these differences that makes internetworking more difficult than operating within a single network.

# INTERNETWORKING



| Item | Some Possibilities |
|---|---|
| Service offered | Connection oriented versus connectionless |
| Protocols | IP, IPX, SNA, ATM, MPLS, AppleTalk, etc. |
| Addressing | Flat (802) versus hierarchical (IP) |
| Multicasting | Present or absent (also broadcasting) |
| Packet size | Every network has its own maximum |
| Quality of service | Present or absent; many different kinds |
| Error handling | Reliable, ordered, and unordered delivery |
| Flow control | Sliding window, rate control, other, or none |
| Congestion control | Leaky bucket, token bucket, RED, choke packets, etc. |
| Security | Privacy rules, encryption, etc. |
| Parameters | Different timeouts, flow specifications, etc. |
| Accounting | By connect time, by packet, by byte, or not at all |

Some of the many ways networks can differ

# INTERNETWORKING

When packets sent by a source on one network must transit one or more foreign networks before reaching the destination network (which also may be different from the source network), many problems can occur at the interfaces between networks. To start with, when packets from a connection-oriented network must transit a connectionless one, they may be reordered, something the sender does not expect and the receiver is not prepared to deal with. Protocol conversions will often be needed, which can be difficult if the required functionality can not be expressed.

Address conversions will also be needed, which may require some kind of directory system. Passing multicast packets through a network that does not support multicasting requires generating separate packets for each destination.

The differing maximum packet sizes used by different networks can be a major nuisance. How do you pass an 8000-byte packet through a network whose maximum size is 1500 bytes? Differing qualities of service is an issue when a packet that has real-time delivery constraints passes through a network that does not offer any real-time guarantees.

# INTERNETWORKING

Error, flow, and congestion control often differ among different networks. If the source and destination both expect all packets to be delivered in sequence without error but an intermediate network just discards packets whenever it smells congestion on the horizon, many applications will break.

Also, if packets can wander around aimlessly for a while and then suddenly emerge and be delivered, trouble will occur if this behavior was not anticipated and dealt with. Different security mechanisms, parameter settings, and accounting rules, and even national privacy laws also can cause problems.

# How Networks Can Be Connected :

Networks can be interconnected by different devices, as we have discussed. In the physical layer, networks can be connected by repeaters or hubs, which just move the bits from one network to an identical network. These are mostly analog devices and do not understand anything about digital protocols (they just regenerate signals).

One layer up we find bridges and switches, which operate at the data link layer. They can accept frames, examine the MAC addresses, and forward the frames to a different network while doing minor protocol translation in the process, for example, from Ethernet to FDDI or to 802.11.

# INTERNETWORKING

In the network layer, we have routers that can connect two networks. If two networks have dissimilar network layers, the router may be able to translate between the packet formats, although packet translation is now increasingly rare. A router that can handle multiple protocols is called a multiprotocol router.

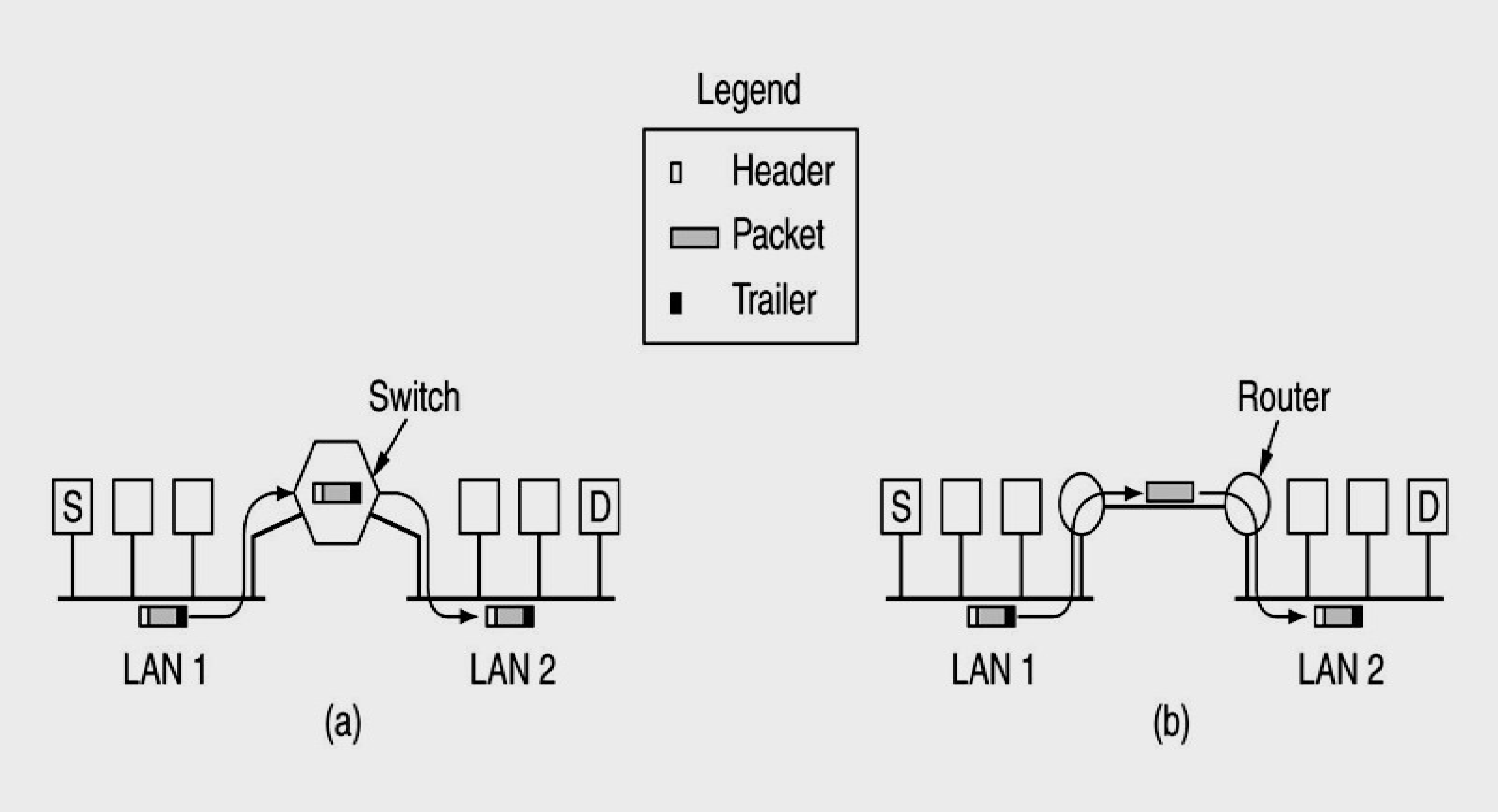
In the transport layer we find transport gateways, which can interface between two transport connections. For example, a transport gateway could allow packets to flow between a TCP network and an SNA network, which has a different transport protocol, by essentially gluing a TCP connection to an SNA connection.

# INTERNETWORKING

Finally, in the application layer, application gateways translate message semantics. As an example, gateways between Internet e-mail (RFC 822) and X.400 e-mail must parse the e-mail messages and change various header fields.

Here, we will focus on internetworking in the network layer. To see how that differs from switching in the data link layer, examine Figure. In Fig. (a), the source machine, S, wants to send a packet to the destination machine, *D.* These machines are on different Ethernets, connected by a switch. S encapsulates the packet in a frame and sends it on its way. The frame arrives at the switch, which then determines that the frame has to go to LAN 2 by looking at its MAC address. The switch just removes the frame from LAN1 and deposits it on LAN 2.

# INTERNETWORKING



(a) Two Ethernets connected by a switch.
(b) Two Ethernets connected by routers.

Now let us consider the same situation but with the two Ethernets connected by a pair of routers instead of a switch. The routers are connected by a point-to-point line, possibly a leased line thousands of kilometers long. Now the frame is picked up by the router and the packet removed from the frame's data field.

The router examines the address in the packet (e.g., an IP address) and looks tip this address in its routing table. Based on this address, it decides to send the packet to the remote router, potentially encapsulated in a different kind of frame, depending on the line protocol. At the far end, the packet is put into the data field of an Ethernet' frame and deposited onto LAN 2.

# INTERNETWORKING

An essential difference between the switched (or bridged) case and the routed case is this. With a switch (or bridge), the entire frame is transported on the basis of its MAC( Media Access Control ) address. With a router, the packet is extracted from the frame and the address in the packet is used for deciding where to send it. Switches do not have to understand the network layer protocol being used to switch packets. Routers do.