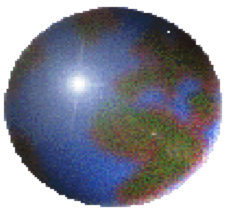

CEN445
Network Protocols & Algorithms

Chapter 5

Network Layer

Prepared by

Dr. Mohammed Amer Arafah

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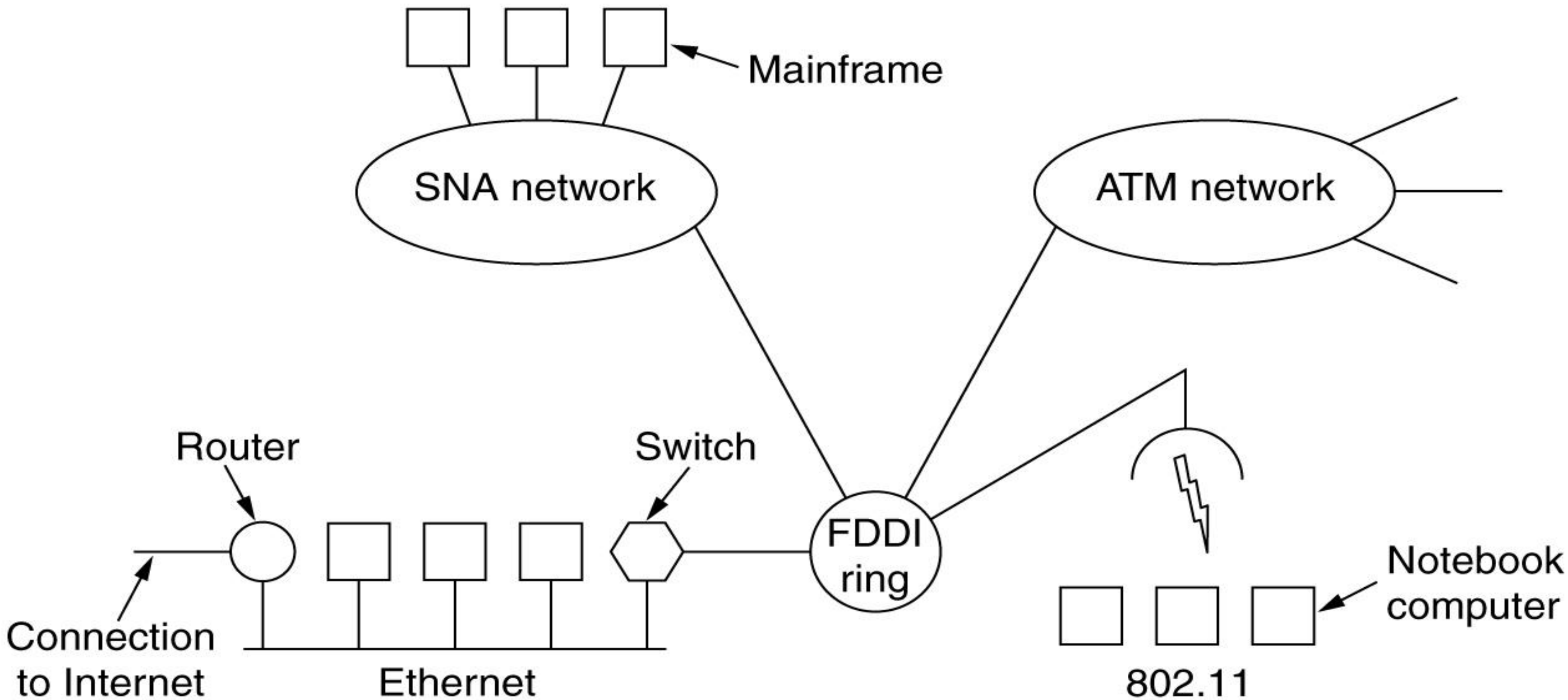
Internetworking

- Two or more networks can be connected together to form an **Internet**.
- A variety of different networks will always be around, for the following reasons:
  - The installed base of different networks is large and growing.
  - As computers and networks get cheaper, the place where decisions get made moves downward.
  - Different networks (e.g., ATM and wireless) have radically different technology.

Connecting Networks



A collection of interconnected networks

How Networks Differ

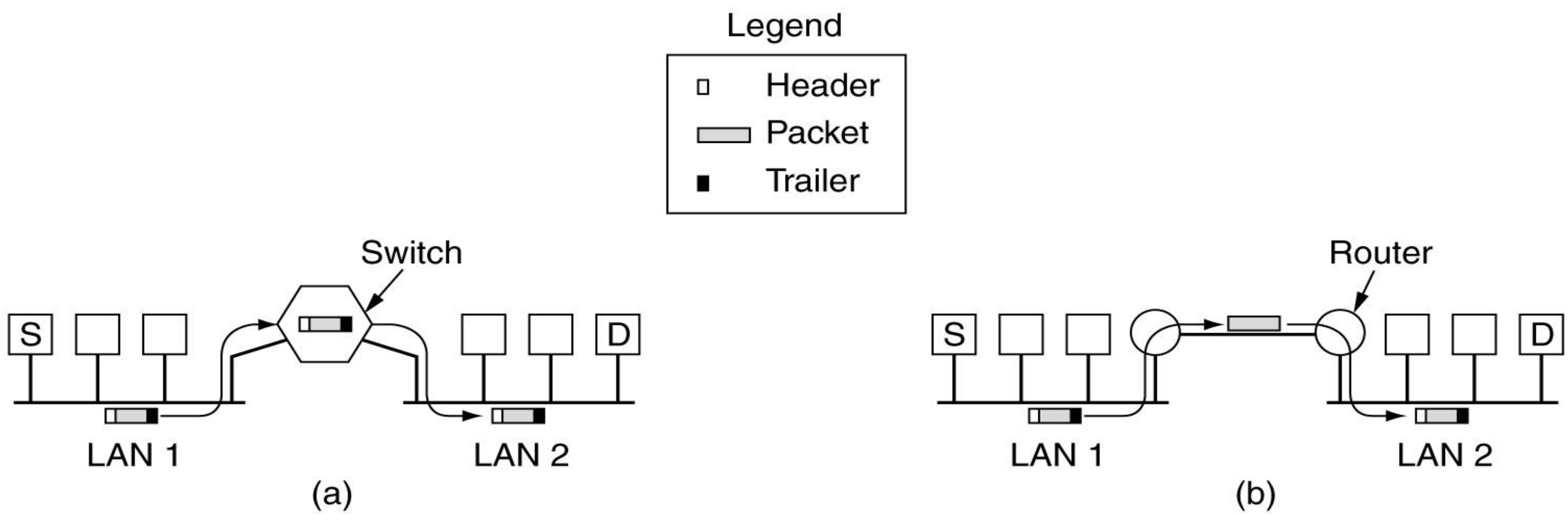
Item	Some Possibilities
Service offered	Connection oriented versus connectionless
Protocols	IP, IPX, SNA, ATM, MPLS, AppleTalk, etc.
Addressing	Flat (802) versus hierarchical (IP)
Multicasting	Present or absent (also broadcasting)
Packet size	Every network has its own maximum
Quality of service	Present 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

How Networks Can Be Connected

- A **repeater** is a low-level device that just amplifies or regenerates weak signals.
- A **bridge** accepts an entire frame and passes it up to the data link layer where the checksum is verified. Then the frame is sent down to the physical layer for forwarding on different network. Bridges can make minor changes to the frame before forwarding it, such adding or deleting some fields from the frame header.
- A **multiprotocol router** takes the incoming packets from one line and forwards them on another. They lines may belong to different networks and use different protocols. Multiprotocol routers operate at the level of the *network layer*.
- A **transport gateway** makes a connection between two networks at the transport layer (e.g., between a TCP network and a SNA network).
- An **Application gateway** connects two parts of an application in the application layer. For example, The mail gateway would unpack the message, convert it to the different format used by the other network.

How Networks Can Be Connected



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

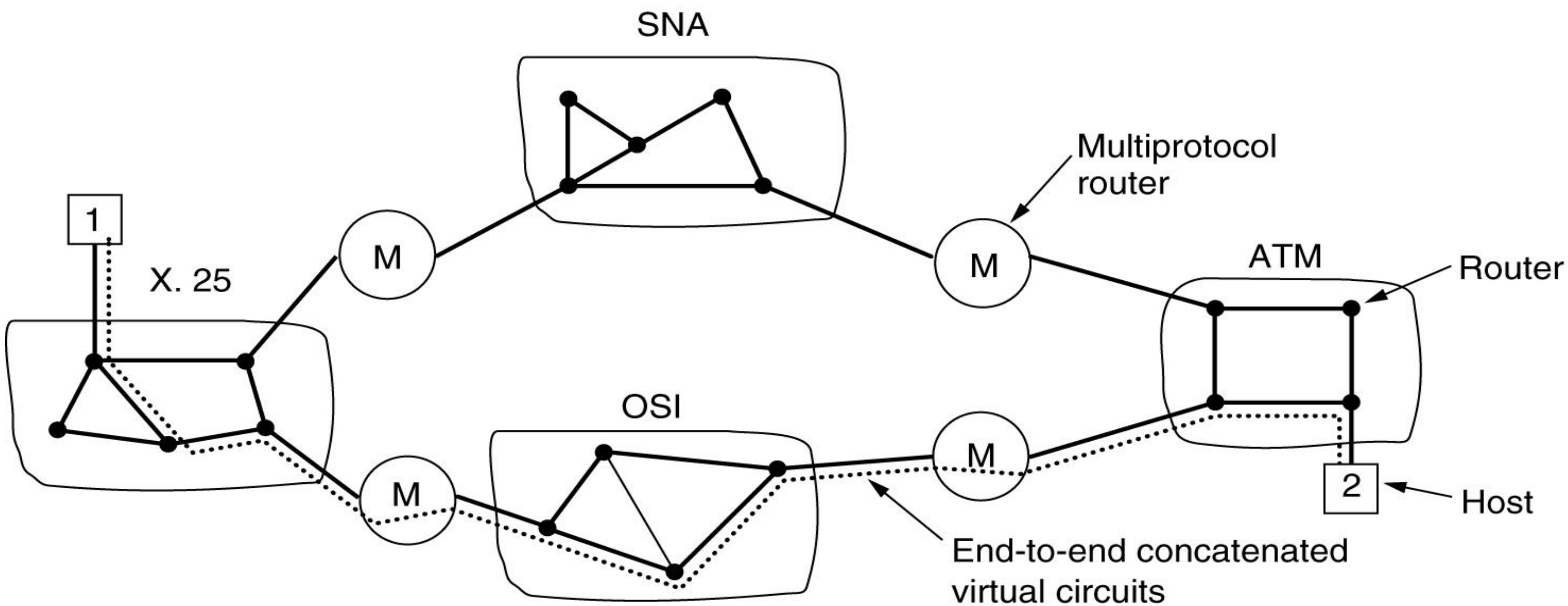
Concatenated Virtual Circuits

Procedure:

- When a connection to a host in a distant network is established, the subnet sees that the destination is remote, and builds a virtual circuit to the router nearest the destination network. Then it constructs a virtual circuit from that router to a external **gateway (multiprotocol router)**. The gateway records the existence of the virtual circuit in its tables and proceeds to build another virtual circuit to a router in the next subnet. This process continues until the destination host has been reached.

- Once Data packets begin flowing along the path, each gateway relays incoming packets, converting between packets formats and virtual circuit numbers as needed. Clearly, all data packets must traverse the same sequence of gateways, and thus arrive **in order**.

Concatenated Virtual Circuits

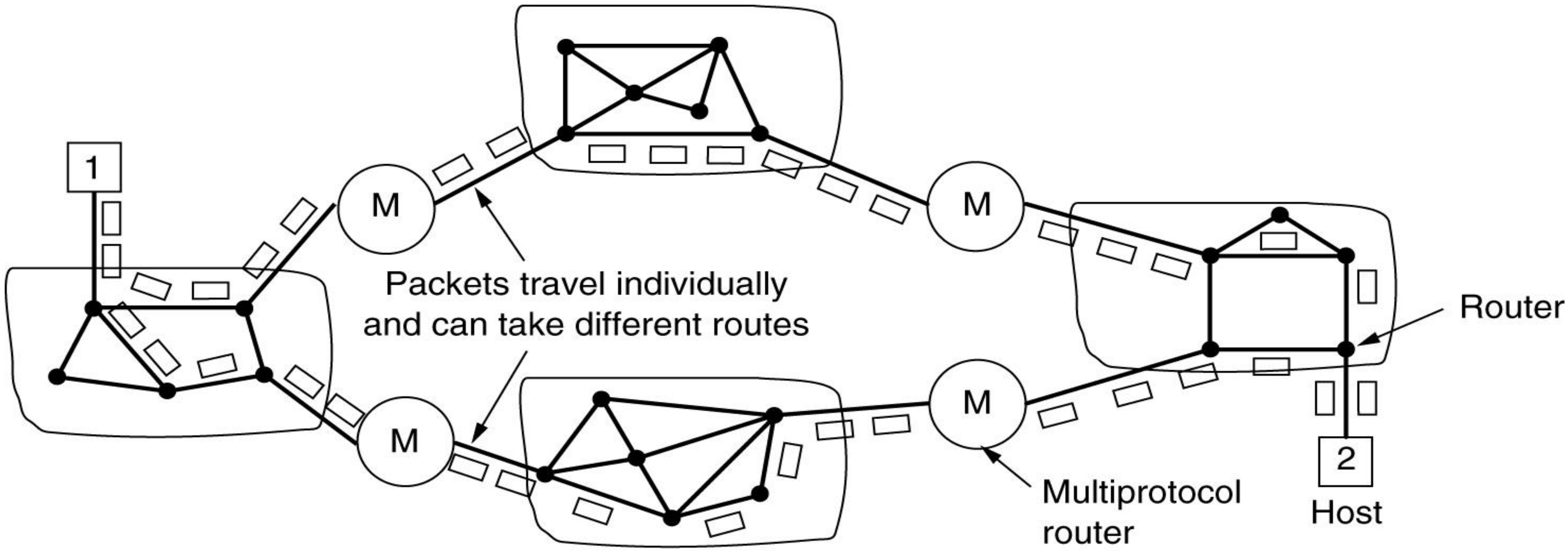


Internetworking using concatenated virtual circuits

Connectionless Internetworking

- In datagram model, the only service the network layer offers to the transport layer is the ability to inject datagrams into the subnet.
- This model *does not require all packets belonging to one connection to traverse the same sequence of gateways*.
- *Routing decision is made separately* for each packet, possibly depending on the traffic at the moment the packet is sent.
- There is no guarantee that the packets arrive at the destination in order.
- This model is not quite as simple as it looks. Some issues have to be considered such as:
  - The multiprotocol routers can translate from packet format to another when the two formats are close. Otherwise, the conversion is always incomplete.
  - Different addressing system.

Connectionless Internetworking



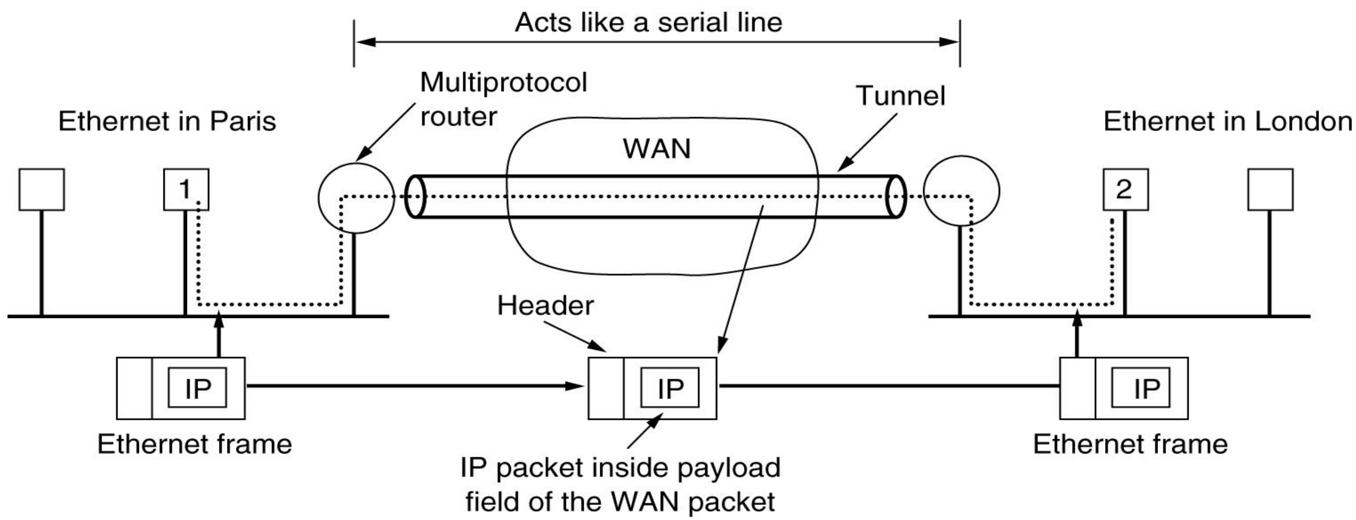
A connectionless internet

Tunneling

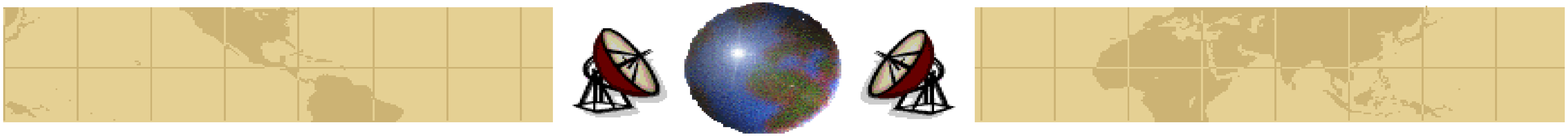
- Tunneling is used when both source and destination hosts are on the same type of networks, but there is a different network in between.

Example:

- Assume an international bank with TCP/IP based Ethernet in Paris, a TCP/IP based Ethernet in London, and a WAN in between.



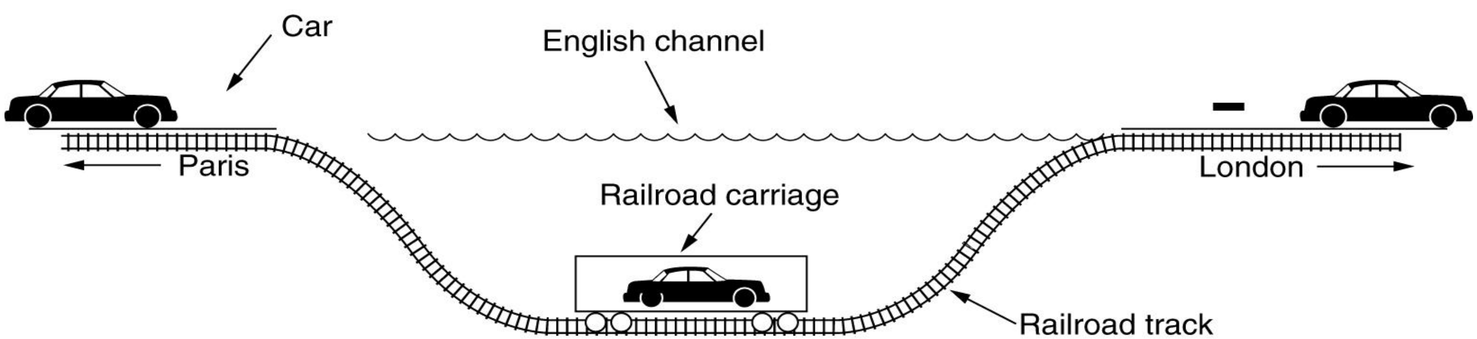
Tunneling a packet from Paris to London



Tunneling

Procedure of Tunneling:

- To send an IP packet to host 2, host 1 constructs the packet containing IP address of host 2, inserts it into an Ethernet frame addresses to Paris multiprotocol router, and puts it on the Ethernet.
- When the multiprotocol router gets the frame, it removes the IP packet, inserts it in the payload field of the WAN network layer packet, and addressed the later to the WAN address of the London multiprotocol router. When it gets there, the London router removes the IP packet and sends it to host 2 inside an Ethernet frame.



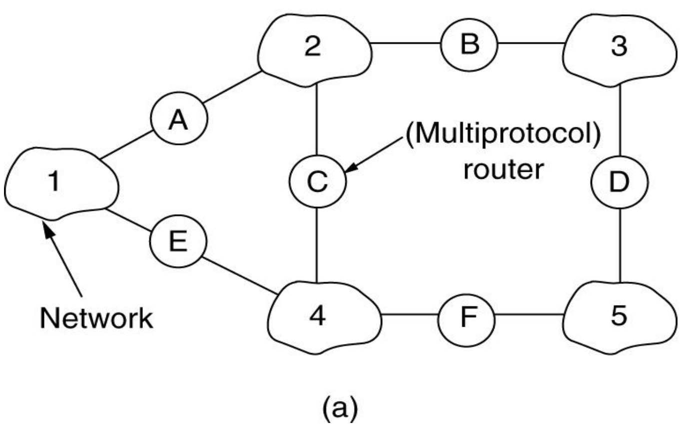
Tunneling a car from France to England

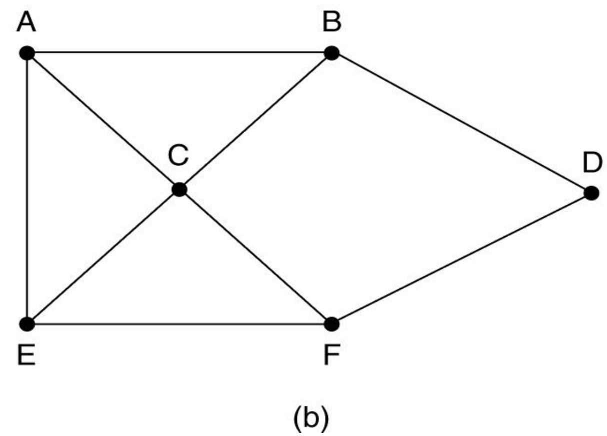
Internetwork Routing

- Consider, for example, the internetwork in which five networks are connected by six multiprotocol routers.
- The *procedure* for internetwork routing is:

  1. Construct a graph of the internetwork.

  2. Any known routing algorithm, such as the distance vector and link state algorithms, can be applied to the set of multiprotocol routers.





(a) An internetwork (b) A graph of the internetwork

Internetwork Routing

- This gives two-level routing algorithm:
  - An **interior gateway protocol** is used within each network, and
  - An **exterior gateway protocol** is used between the networks.
- In general, internet is made up of number of separately managed and run internets, each internet us treated as an **autonomous system (AS)**.

Internetwork Routing

Differences between Internetwork Routing and Intranetwork Routing:

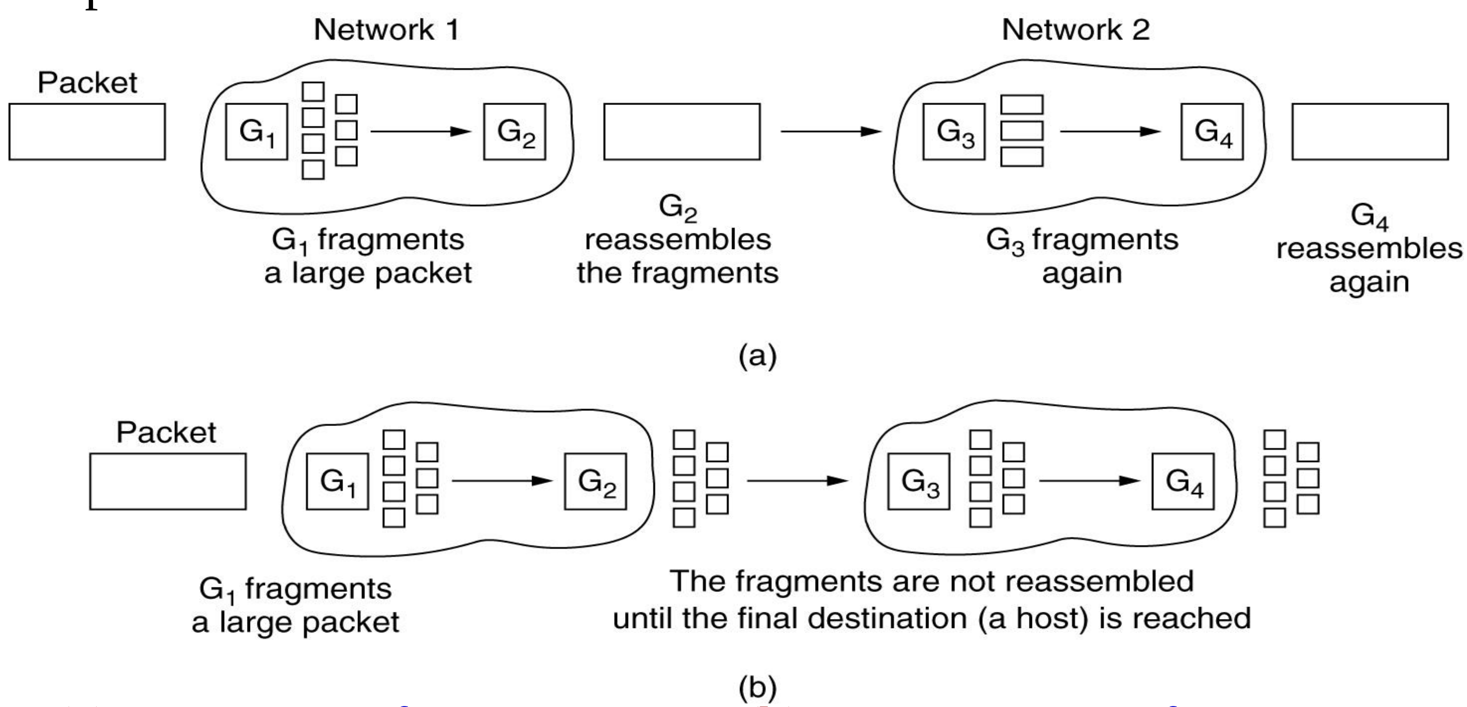
Internetwork Routing	Intranetwork Routing
It often requires crossing international boundaries.	It is not allowed for crossing international boundaries.
Different networks may be under different management. Therefore, multiple charging algorithms may be applied.	A single charging algorithm may be applied.

Fragmentation

- Each network imposes some maximum size on its packets. These limits have various causes, among them:
  - Hardware (e.g., the width of a TDM transmission slot).
  - Operating system (e.g., all buffers are 512 bytes).
  - Protocols (e.g., the number of bits in the packet length field).
  - Compliance with some (inter)national standard.
  - Desire to reduce error induced retransmissions to some levels.
  - Desire to prevent one packet from occupying the channel to long.
- Maximum payloads range from 48 bytes (ATM cells) to 65,515 bytes (IP packets).
- An obvious problem appears when a large packet wants to travel through a network whose maximum packet size is too small.

Fragmentation

- The solution to this problem is to allow gateways to break packets up into **fragments**, sending each fragment as a separate internet packet.
- Two opposing strategies exist for **recombining the fragments** back into the original packet.



(a) Transparent fragmentation (b) Nontransparent fragmentation

Fragmentation

First: Transparent Fragmentation

- *When oversized packet arrives at a gateway, the gateway breaks it up into fragments. Each fragment is addressed to the same exit gateway, where the pieces are recombined.*

- ATM networks have special hardware to provide transparent fragmentation (segmentation) of packets into cells and then reassembly of cells into packets.

- Transparent fragmentation is simple but has some problems such as:
  - The exit gateway must know when *it has received all the pieces*, so that either a count field or an "end of packet" bit must be included in each packet.
  - *All packets must exit via the same gateway*. Therefore, some performance may be lost.
  - The *overhead required to repeatedly reassemble and then refragment a large packet* passing through a series of small-packet networks.

Fragmentation

Second: Nontransparent Fragmentation

- *It refrains from recombining fragments at any intermediate gateways. Once the packet has been fragmented, each fragment is treated as though it were an original packet. Recombination occurs only at the destination host.*

- Nontransparent fragmentation also have some problems:
  - It requires every host to be able to do reassembly.
  - When a large packet is fragmented, the total overhead increases, because every fragment must have a header.

- The **advantage** of this method is that *multiple exit* gateways can be used and higher performance can be achieved.

Fragmentation

- When a packet is fragmented, the fragments must be **numbered** in such a way that the original data stream can be reconstructed.

- One way of numbering the fragments is to use **a tree**. If a packet 0 must be split up, the pieces are called 0.0, 0.1, 0.2, etc. If these fragments themselves must be fragmented later on, the pieces are numbered 0.0.0, 0.0.1, 0.0.2, ..., 0.1.0, 0.1.1, 0.1.2, etc. Therefore, enough fields have to be reserved in the header for the worst case.

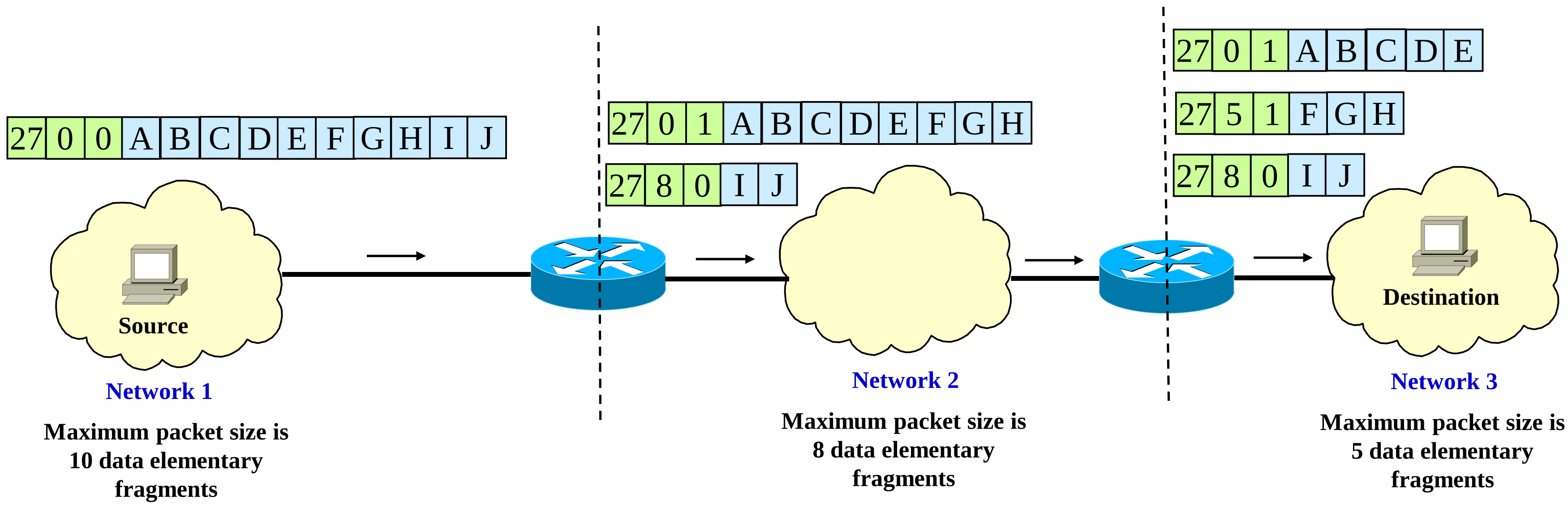
- If one network loses or discards packets, there is a need for **end-to-end retransmissions**. Suppose that a 1024-bit packet is fragmented into four equal-sized fragments 0.0, 0.1, 0.2, 0.3. If fragment 0.1 is discarded, but the other parts arrive at the destination. Eventually the source times out and retransmits the original packet again. At this time, the route taken passes through a network with a 512-bit limit, so two fragments are generated. When the new 0.1 arrives at the destination, it reconstructs the packet incorrectly

Fragmentation

- A better numbering system is for the internetwork protocol to define an elementary fragment size small enough that the elementary fragment can pass through every network.
- When a packet is fragmented, all the pieces are equal to the elementary fragment size except the last one, which may be shorter.
- The internet header must provide:
  - *The original header packet number.*
  - *The number of the first elementary fragment contained in the packet.*
  - *A bit to indicate that the last elementary fragment contained within the internet packet is the last one of the original packet.*

Fragmentation

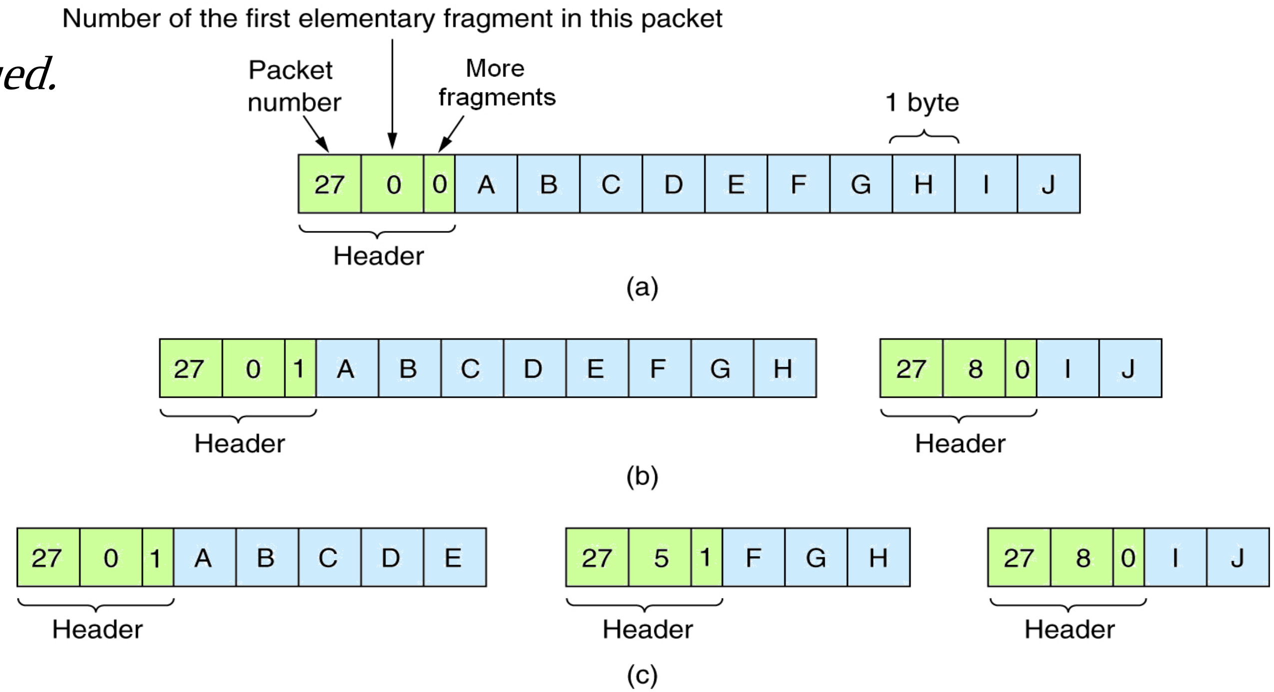
Example:



Sending an IP Packet from a source in network 1 to a destination in network 3

Fragmentation

Example: *Continued.*



Fragmentation when the elementary data size is 1 byte.

(a) Original packet, containing 10 data bytes.

(b) Fragments after passing through a network with maximum packet size of 8 payload bytes plus header.

(c) Fragments after passing through a size 5 gateway.