Lecture 6

Wide Area Networks (WANs)

Learning Objectives

- Describe basic WAN characteristics
- Describe WAN standards
- Describe WAN technologies

Wide Area Networks (WANs)

- There are two prevailing definitions of a **Wide Area Network (WAN)**
  - **Book definition**
    - A network that spans large geographical locations, usually to interconnect multiple Local Area Networks (LANs)
  - **Practical definition**
    - A network that traverses a public network or commercial carrier, using one of several WAN **technologies**

Wide Area Networks (WANs)

- Consider the following examples:
  - A connection between two buildings using Ethernet as a medium would generally be considered a **LAN.**
    - However, this is because of the technology used, and not the zombie infested distance between the two buildings.
  - A connection between the same two buildings, using a dedicated T1 line as a medium, would generally be considered a **WAN**
- **Note!!!**
  - Remember, the difference is the technology used

Wide Area Networks (WANs)

- WANs are structured with irregular placement of the nodes, relatively far apart from each other as shown in fig1.
- Uses transmission facilities provided by common carriers, such as telephone companies.
- Connect 2 or more LANs or MANs that are interconnected using slow-speed.
- WAN technologies function at the lower three layers of the OSI reference model: the physical layer, the data link layer, and the network layer.

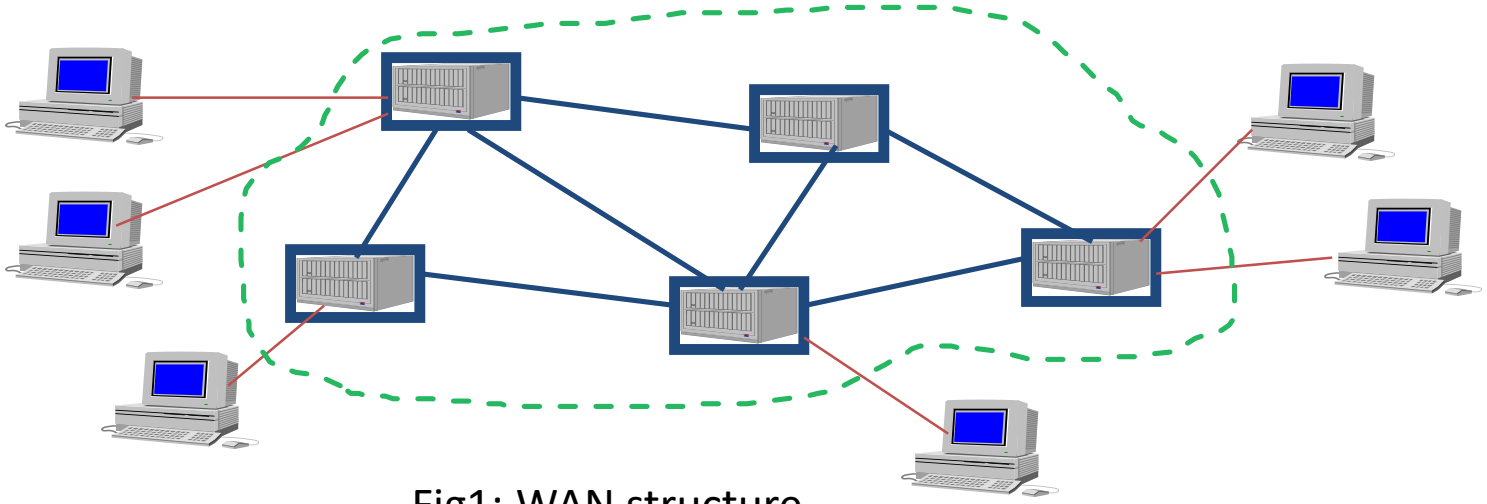


Fig1: WAN structure

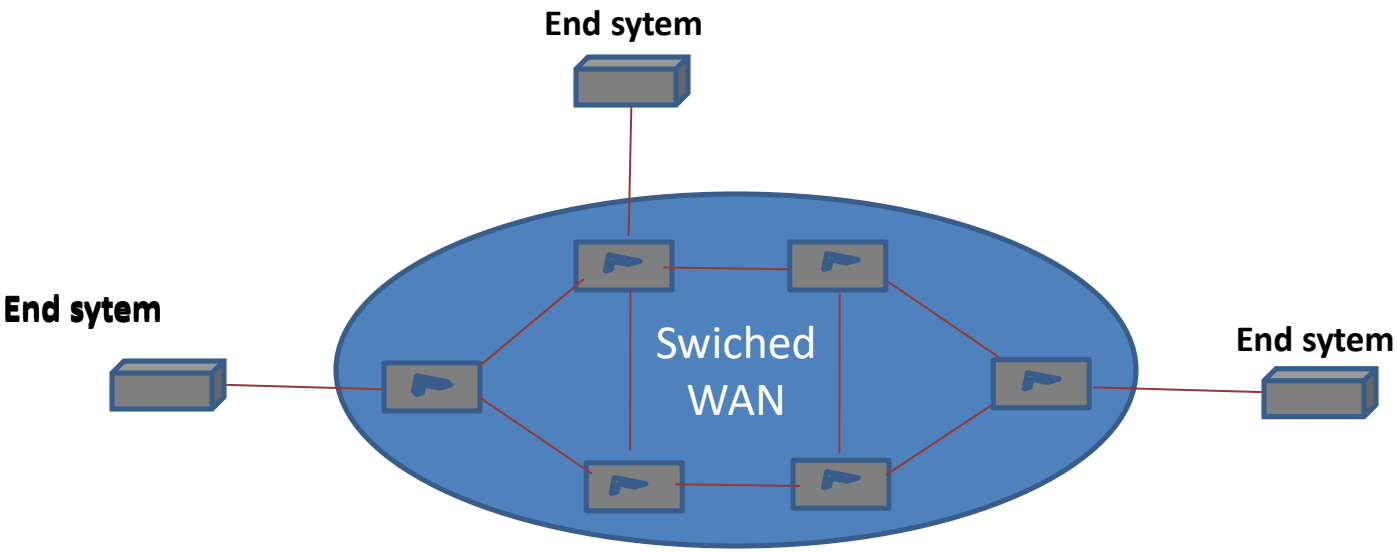
Wide Area Networks (WANs)

- WAN consists of a number of interconnected switching nodes as seen in fig1.
- Communication is achieved by transmitting data from source to destination through these intermediate switching nodes to the specified destination device.
- Purpose
  - Provide remote access to individuals who are off site
  - Link sites within the same corporation
  - Provide Internet access

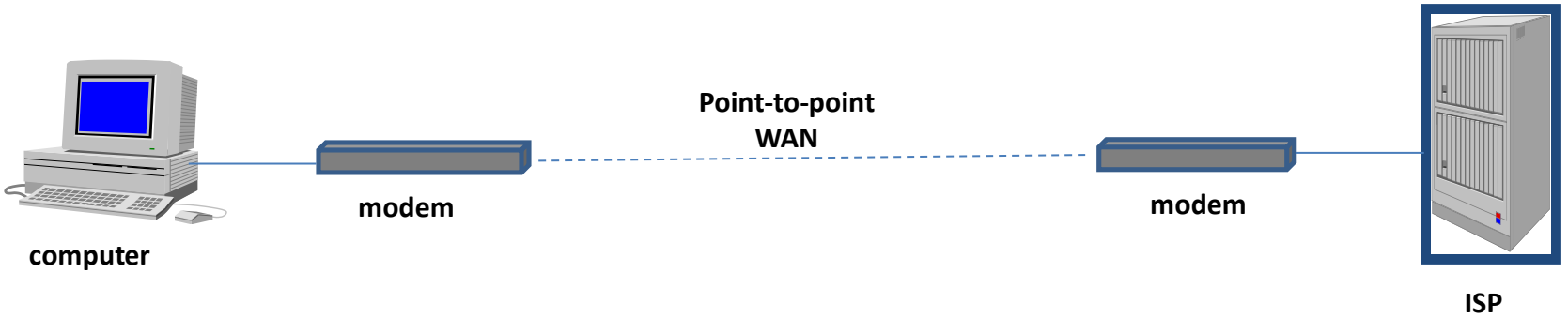
Switched Vs Point-to-point WANs

- Switched WAN
  - Can be as complex as the backbones that connect the internet
  - Connects the end systems, which usually comprise a router that connects to another LAN or WAN
- Point-to-point WAN
  - Can be as simple as a dial-up line that connects a home computer to the internet
  - Normally a line leased from a telephone or cable TV provider that connects a home computer or a small LAN to an internet service provider (ISP)
    - This type of WAN is used to provide internet access

Switched WANs



Point-to-point WANs



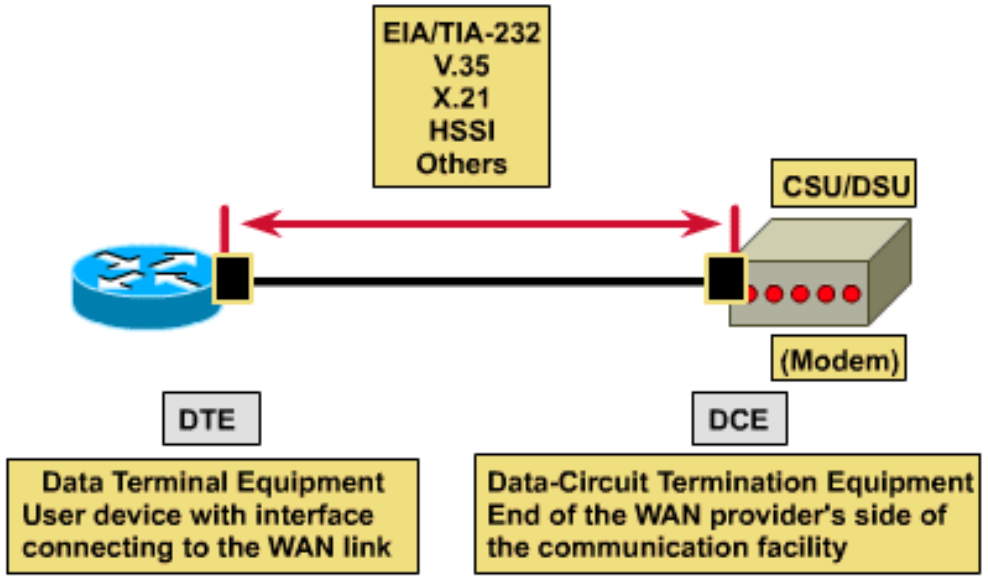
WAN Standards

- What layers of the OSI model do WAN standards describe?
  - Physical and Data Link Layers

- WAN Physical Layer
  - Protocols that describe how to provide electrical, mechanical, operational, and functional connections for WAN services.
  - These services are most often obtained from WAN service providers such as telephone companies, cable companies, and dedicated fiber sellers.

WAN Standards (cont'd)

- WAN Physical Layer (cont'd)
  - Several physical layer standards specifying this interface between the ISP and your router are...
    - EIA/TIA-232
    - EIA/TIA-449
    - V.24
    - V.35
    - X.21
    - G.703
    - EIA-530



WAN Standards (cont'd)

- WAN Data-Link Layer
  - WAN data link protocols describe how frames are carried between systems on a single data link.
  - They include protocols designed to operate over all physical layer standards.
  - Most common Layer 2 WAN Technologies include:
    - ISDN
    - Frame relay
    - ATM

WAN Switch Functionality

- WAN switches use store and forward technology.
- The store operation occurs when the packet arrives: the I/O hardware copies the packet, sticks it in memory, and signals the processor to forward the packet.
- The forward operation is the act of removing the packet from memory, and sends it to the appropriate interface.

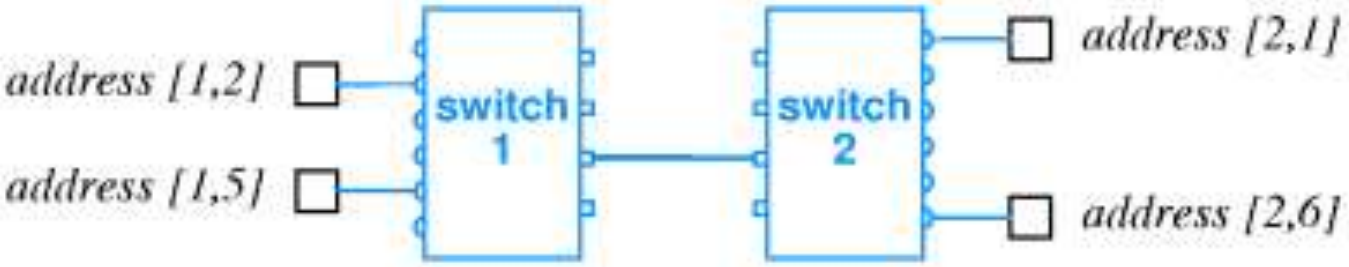
WAN Switch Functionality (cont'd)

- Storing the packets also leads to a form of queuing for each interface.
- If the destination interface is busy, the packet is queued until the destination interface is idle, then the forward occurs.
- The store and forward paradigm allows to handle the maximum bandwidth of the WAN connection, since all data is buffered!

Physical Addressing in the WAN Environment

- A hierarchical scheme is used with WAN addressing.
- The simplest form of this scheme: The first part of the address holds the destination switch, the second part holds the specific machine that the packet is destined for on that switch.
- This is scheme is used in many WAN environments.

WAN Addressing (cont'd)

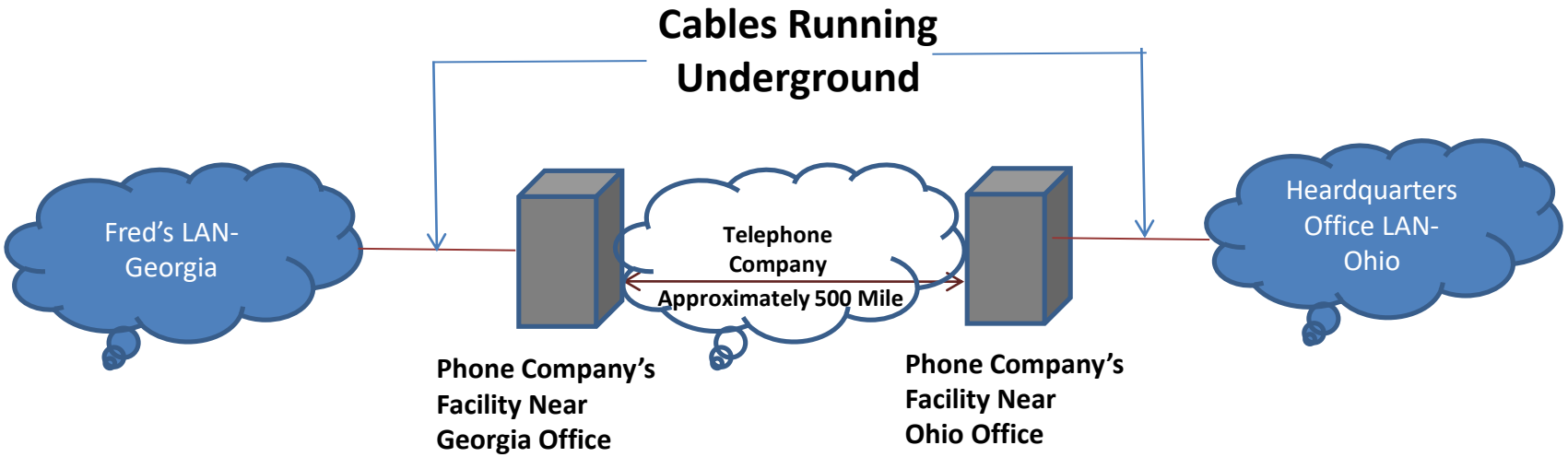


Next-Hop Forwarding

- In order for networking to occur, each device must have some knowledge of the devices which it is connected to.
- Next-hop forwarding is a scheme where devices know their neighbors, but don’t know the specifics of what is connected to each neighbor.

Standards For Physical Networking Far Away

Fred's Alternative to running a cable 500 Miles: A WAN Using Leased Lines



- The cloud in the figure represents the telephone company network
- This means that there is a lot more to the telephone company's network but the details aren't important right now.
- The leased line gives him the physical ability to send packets from his office, and vice versa
- The leased line, and the related equipment, is one way you can implement a WAN
- Just like for WANs, the TCP/IP network model does not define all the details of WAN cabling and logic.
- The International Telecommunications Union (ITU) defines the standard for WANs

Evolution of WAN Technology

- Layer 1
  - Leased line service and networks
- Layer 2
  - Public switched data networks (PSDNs)
- Layer 3
  - Virtual Private Networks (VPNs) over the Internet and IP carrier networks

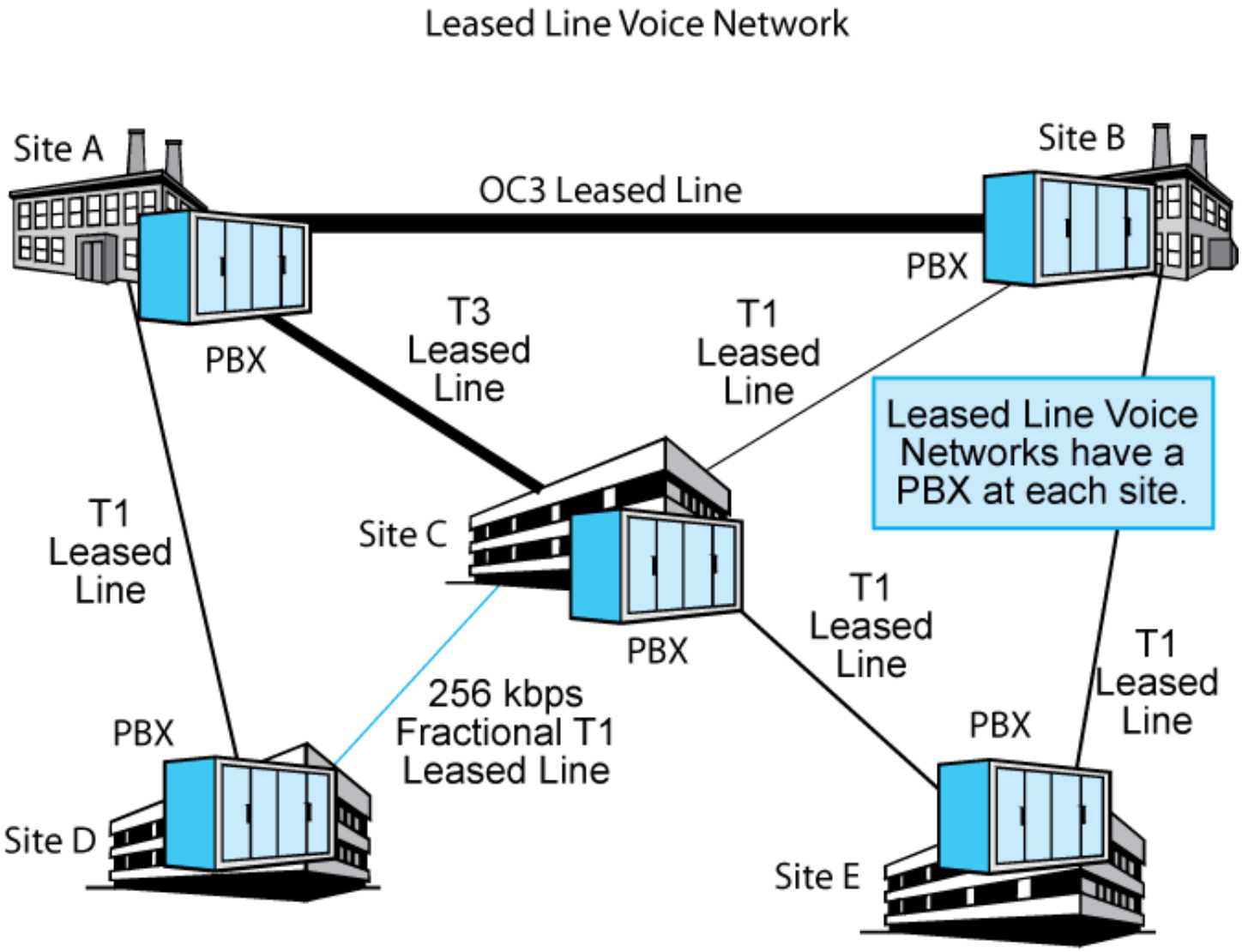
WAN – Carriers

- Beyond their physical premises, companies must use the services of regulated carriers for transmission
- Companies are limited to whatever services the carriers provide
- Prices for carrier services often change abruptly and without technological reasons
- Prices and service availability vary from country to country

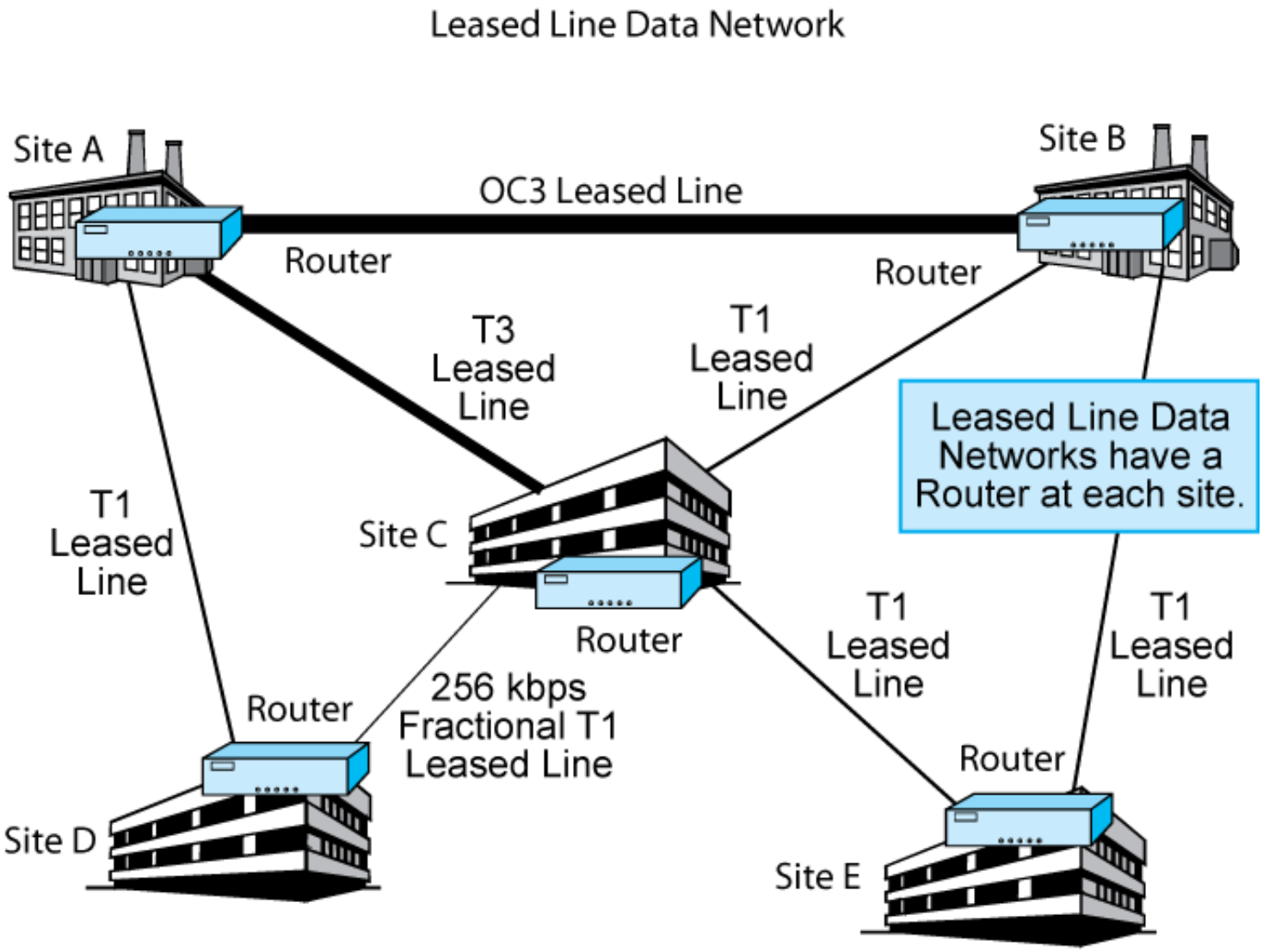
High Cost and High Speed

- High cost per bit transmitted, compared with LANs
- Consequently, lower speeds (most commonly 256 kbps to about 50 megabits per second)
- Why? Simple economics. When price increases, quantity demanded increases

Leased Line Networks for Voice and Data

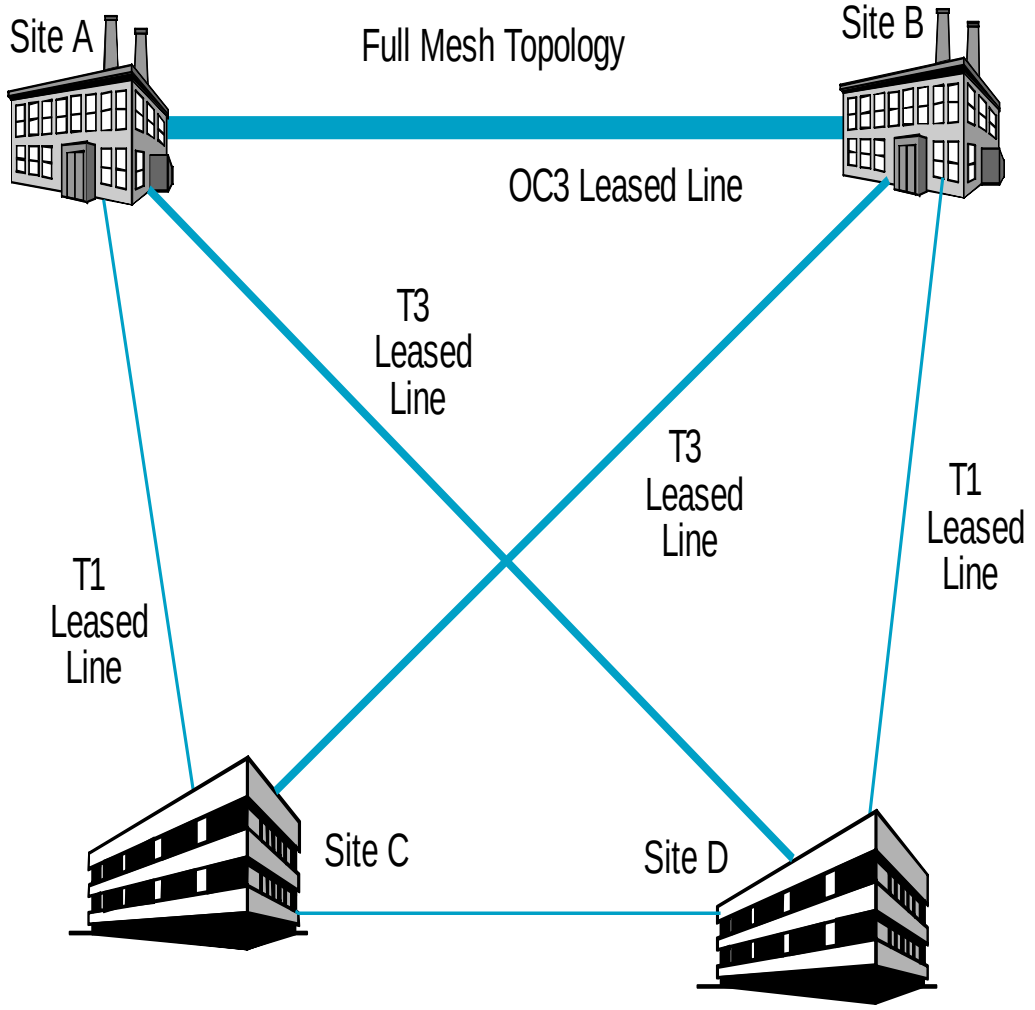


Leased Line Networks for Voice and Data (cont'd)



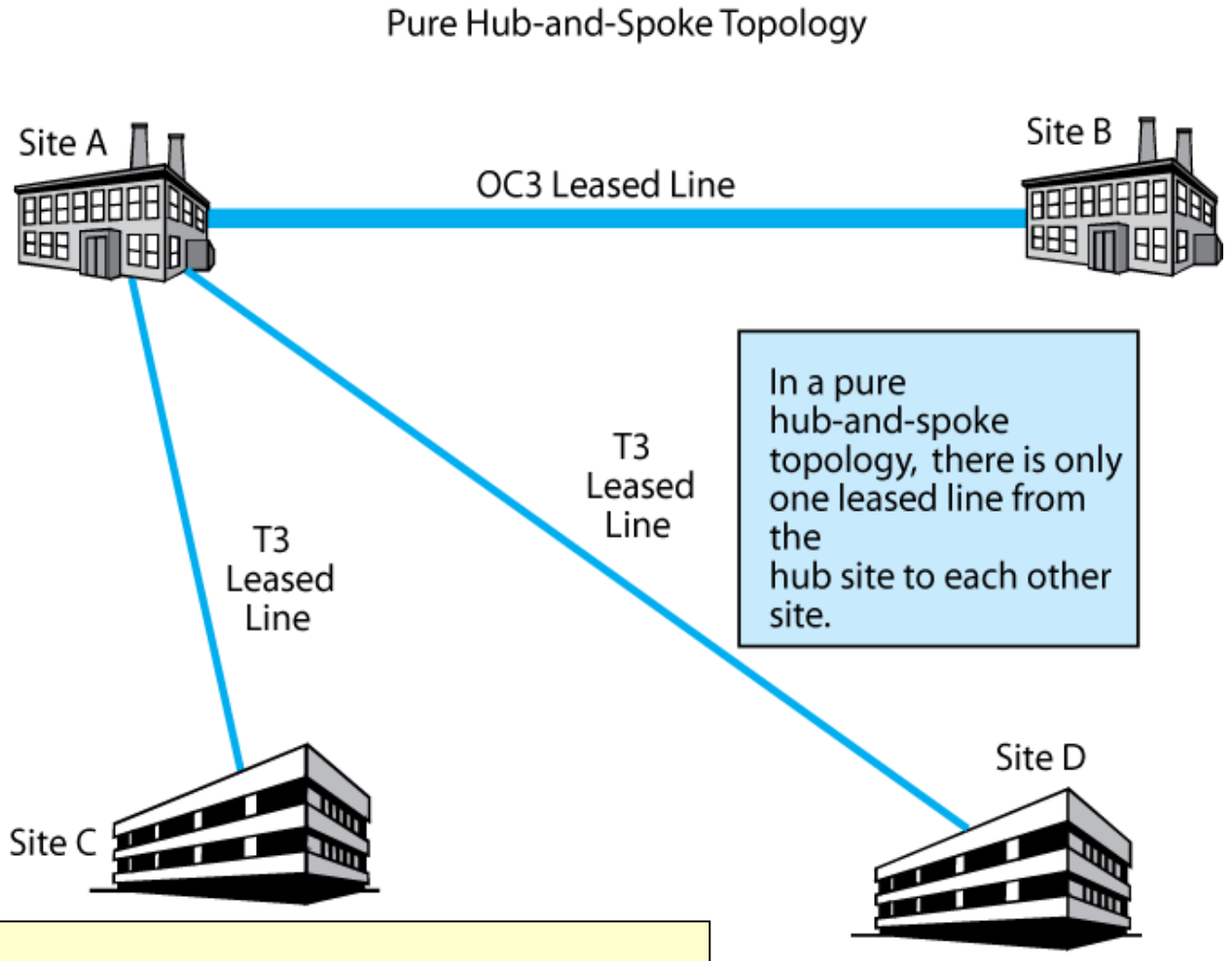
Full Mesh and Pure Hub-and-Spoke Topologies for Leased Line Data Networks

- In a full mesh topology, there is a leased line between each pair of sites
- Highly reliable
- Highly expensive



Full Mesh and Pure Hub-and-Spoke Topologies for Leased Line Data Networks

- In a pure hub-and-spoke topology, there is only one leased line from the hub site to each other site
- Very inexpensive
- Very unreliable



Few companies use either of these extreme topologies.
They have *some* backup links

Leased Lines

- Leased Lines are Long-Term Circuits
  - Point-to-Point
  - Always On
  - High-speeds
- Operate at Layer 1
  - Companies must add their own switching and management
- Device at Each Site
  - PBX for leased line voice networks
  - Router for leased line data networks
- Pure Hub-and-Spoke, Full Mesh, and Mixed Topologies

Leased Lines

- Many Leased Line Speeds
  - Fractional T1, T1, and bonded T1 dominate in the U.S.
  - Slowest leased lines run over 2-pair data-grade UTP
  - Below about 3 Mbps, 2-pair data grade UTP
  - Above 3 Mbps, run over optical fiber
  - North American Digital Hierarchy, CEPT, and other standards below 50 Mbps
  - SONET/SDH above 50 Mbps
  - Symmetrical DSL lines with QoS

Leased Lines (cont'd)

Leased Line Speeds

North American Digital Hierarchy

Line	*Speed*	*Typical Transmission Medium*
56 kbps or 64 kbps (rarely offered)	56 kbps or 64 kbps	*2-Pair Data-Grade UTP
T1	1.544 Mbps	*2-Pair Data-Grade UTP
Fractional T1	128 kbps, 256 kbps, 384 kbps, 512 kbps, 768 kbps	*2-Pair Data-Grade UTP
Bonded T1s (multiple T1s acting as a single line)	Small multiples of 1.544 Mbps	*2-Pair Data-Grade UTP
T3	44.736 Mbps	*Optical Fiber

*Usually must be pulled to the customer's premises. This is expensive

Leased Lines (cont'd)

Leased Line Speeds (cont'd)

CEPT Hierarchy

Line	*Speed*	*Typical Transmission Medium*
64 kbps	64 kbps	2-Pair Data-Grade UTP
E1	2.048 Mbps	2-Pair Data-Grade UTP
E3	34.368 Mbps	Optical Fiber

The CEPT hierarchy is widely used in Europe

Leased Lines (cont'd)

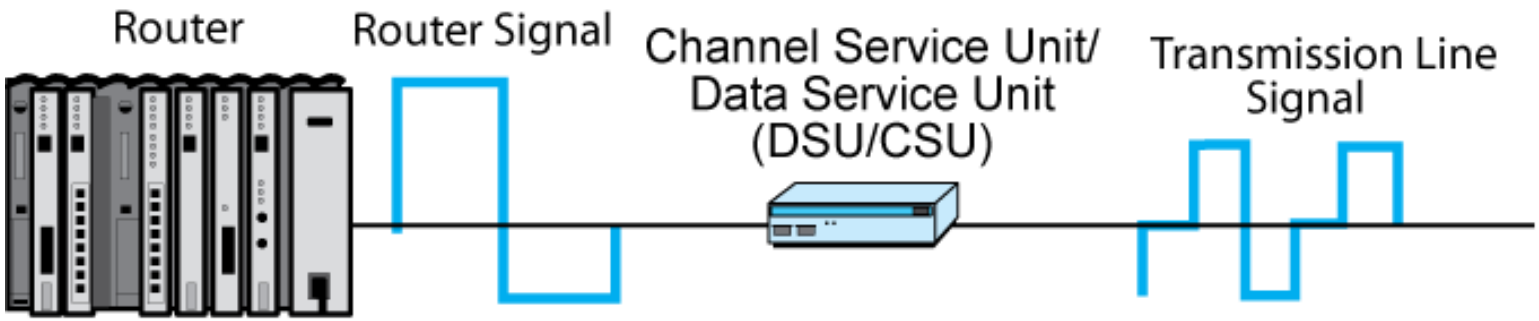
Leased Line Speeds (cont'd)

SONET/SDH Speeds

Line	*Speed (Mbps)*	*Typical Transmission Medium*
OC3/STM1	155.52	Optical Fiber
OC12/STM4	622.08	Optical Fiber
OC48/STM16	2,488.32	Optical Fiber
OC192/STM64	9,953.28	Optical Fiber
OC768/STM256	39,813.12	Optical Fiber

Above 50 Mbps, the world uses the same standard,
which has two slight variations: SONET (UH) and SDH (Europe).
These two variants interoperate without problems.

Connecting to a Leased Line



Routers need CSU/DSUs to connect to leased lines.
The CSU terminates the telephone line and protects the telephone system from harmful voltages and signals.

The DSU converts between the router's data signals and the digital Signals that the PSTN is expecting to receive from the firm.

Conversion is needed because digital signals can vary in transmission speed, voltage levels, clock cycle duration, etc.

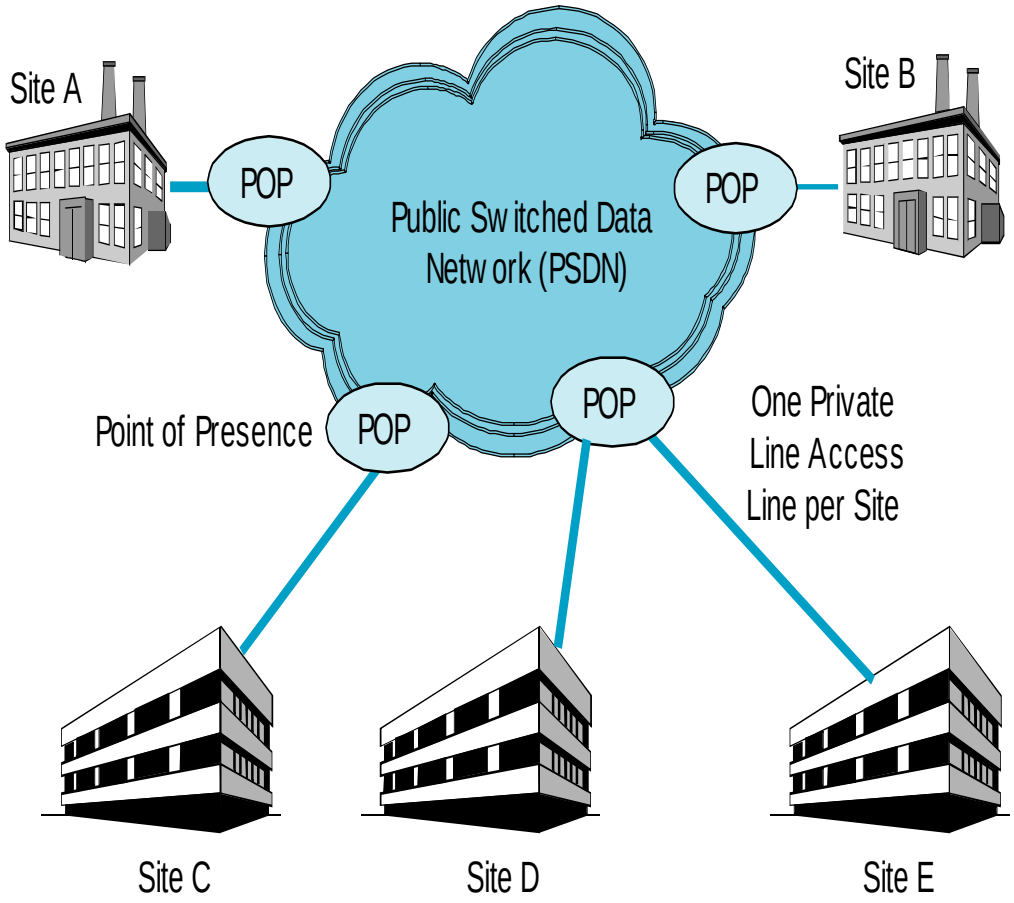
Public Switched Data Networks (PSDNs)

- Layer 2 Carrier WAN Services
  - Leased Line Data Networks
    - Use many leased lines, which must span long distances between sites
    - This is very expensive
    - Company must design and operate its leased line network
  - Public Switched Data Networks (PSDNs)
    - Carrier does more of the operational and management work
    - Total cost of technology, service, and management usually lower than leased line networks

Public Switched Data Networks (PSDNs)

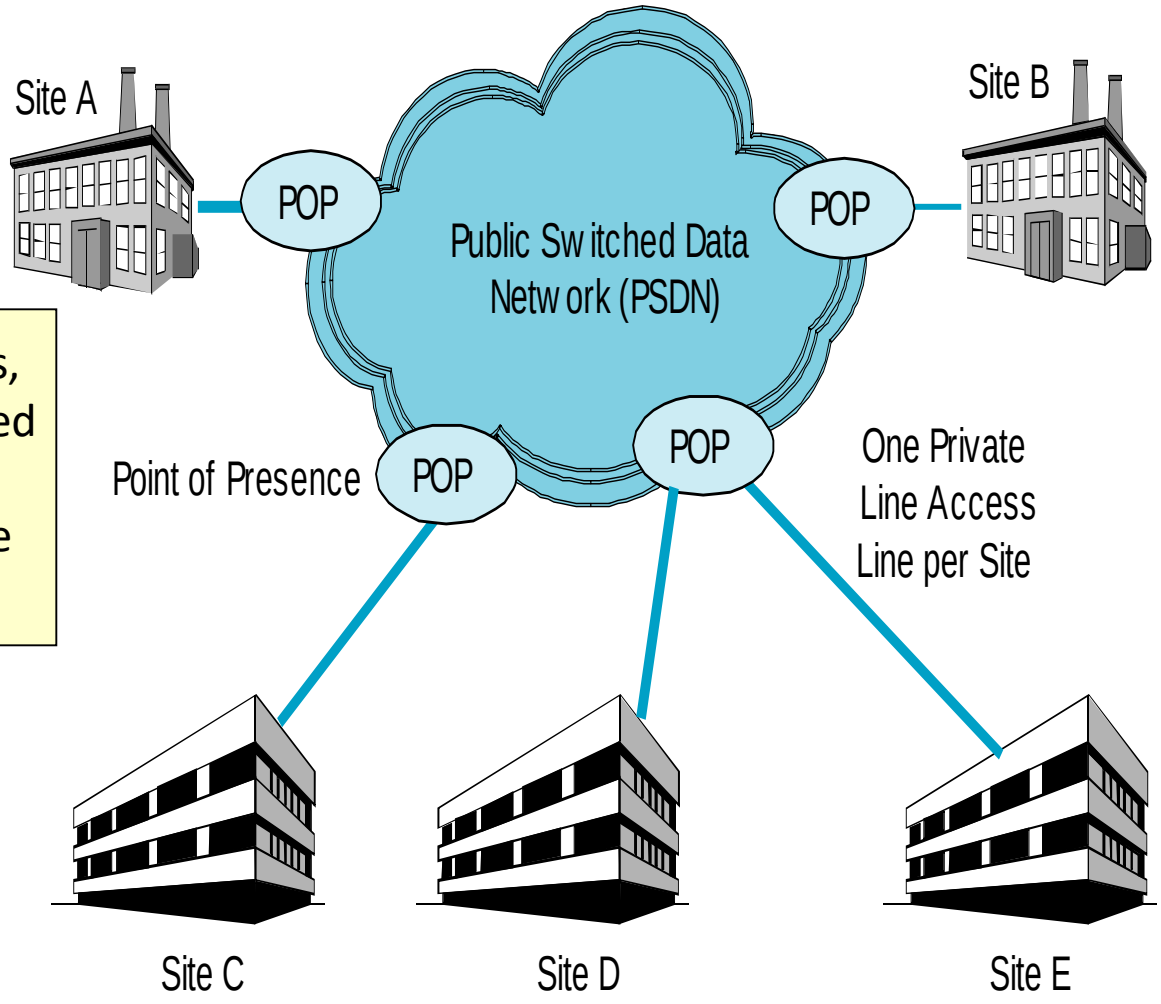
In Public Switched Data Networks, the PSDN carrier handles all switching. Reduces the load on the network staff.

The PSDN central core is shown as a Cloud to indicate that the user firm does not have to know how the network operates.



Public Switched Data Network (PSDN)

In Public Switched Data Networks, the customer needs a single leased line from each site to one of the PSDN carrier's points of presence (POPs)



PSDNs

- PSDNs Typically Offer Service Level Agreements
  - Guarantees for throughput, availability, latency, error rate, etc.
  - An SLA might guarantee a latency of no more than 100 ms 99.99 percent of the time
    - SLA guarantees no worse than a certain worst-case level of performance

WAN Technologies

X.25 Networks

- An ITU-T standard that offers 64Kbps network connections and specifies an interface between a host system and a packet-switching network.
- Almost universal on packet switched networks and packet switching in ISDN
- Very few public networks actually support this standard.
- It requires digital, rather than analog signaling on the telephone lines.

X.25 Networks (cont'd)

- Functionality
  - X.25 calls for three layers of functionality:
    - Physical layer
    - Data link layer
    - Packet (or network) layer.

X.25 Networks (cont'd)

- Physical
  - s
  - Two ends are distinct
    - Data Terminal Equipment DTE (user equipment)
    - Data Circuit-terminating Equipment DCE (node)
  - The physical layer called, X.21, specifies the physical, electrical, and procedural interface between the host and the network.
  - Can substitute alternative such as EIA-232

X.25 Networks (cont'd)

- Data Link
  - The data link layer protocol deals with transmission errors on the telephone line between the user's equipment (host or terminal) and the public network (router).
  - The data link layer standard is Link Access Protocol Balanced (LAPB)
    - Subset of High-Level Data Link Control (HDLC)
  - Provides reliable transfer of data over the physical link
  - Transmits the data as a sequence of frames

X.25 Networks (cont'd)

- Packet or Network Layer
  - Deals with addressing, flow control, delivery confirmation, interrupts, and related issues.
  - Thus, it provides a virtual circuit service.
    - This service enables any subscriber to the network to set up logical connections, called virtual circuits, to other subscribers.
    - In this context, the term *virtual circuit* refers to the logical connection between two stations through the network

X.25 Use of Virtual Circuits

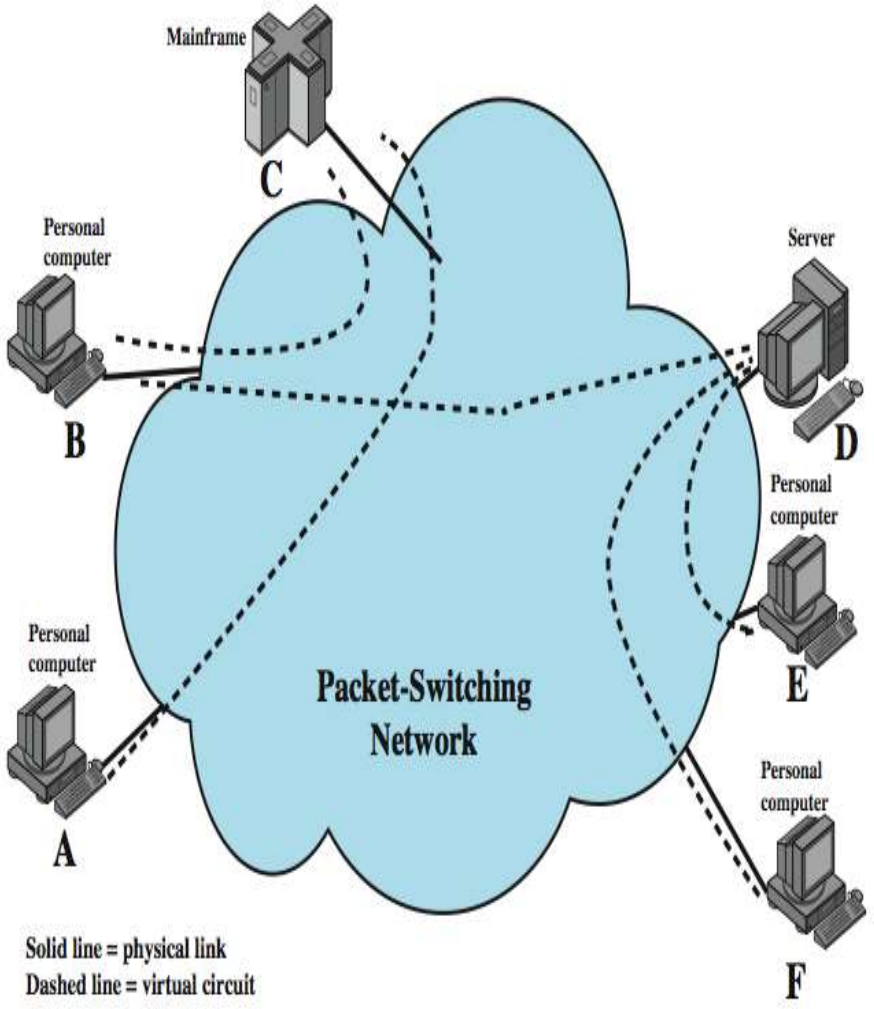
•An example of X.25 virtual circuits is shown in the figure on the right

• In this example, station A has a virtual circuit connection to C

•Station B has two virtual circuits established, one to C and one to D

•Stations E and F each have a virtual circuit connection to D

•As an example of how these external virtual circuits are used, station D keeps track of data packets arriving from three different workstations (B, E, F) on the basis of the virtual circuit number associated with each incoming packet.



User Data and X.25 Protocol Control Information

•The figure on the right illustrates the relationship among the levels of X.25.

•User data are passed down to X.25 level 3, which appends control information as a header, creating a packet.

•This control information serves several purposes, including identifying by number a particular virtual circuit with its associated data, and providing sequence numbers that can be used for flow and error control on a virtual circuit basis.

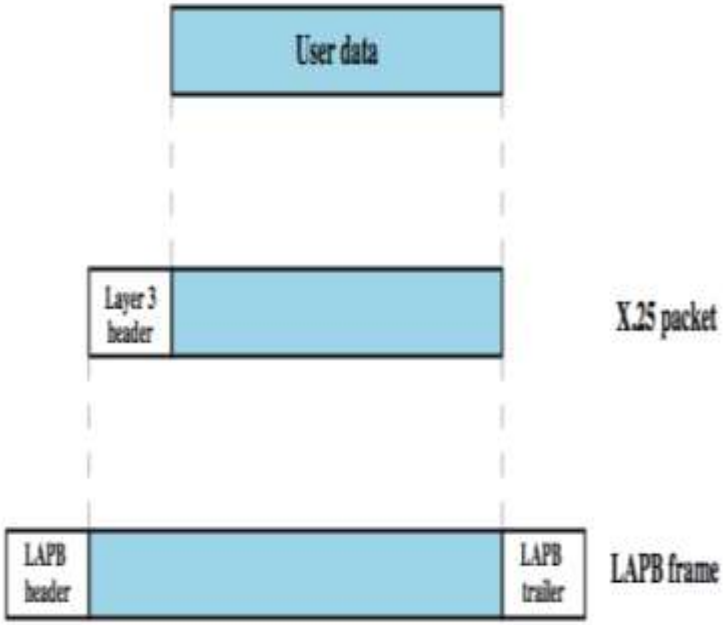
•The entire X.25 packet is then passed down to the LAPB entity, which appends control information at the front and back of the packet, forming a LAPB frame (see figure).

• Again, the control information in the frame is needed for the operation of the LAPB protocol.

•Each X.25 data packet includes send and receive sequence numbers.

•The send sequence number, P(S), is used to number sequentially all outgoing data packets on a particular virtual circuit.

•The receive sequence number, P(R), is an acknowledgment of packets received on that virtual circuit.



Issues with X.25

- Key features include:
  - call control packets, in band signaling
  - multiplexing of virtual circuits at layer 3
  - layers 2 and 3 include flow and error control
- Hence have considerable overhead
- Not appropriate for modern digital systems with high reliability

Frame Relay

- It is a virtual-circuit wide area network that was designed in response to demands for a new type of WAN in the late 1980s and and early 1990s
- Designed to eliminate most X.25 overhead
- Has large installed base
- Key differences:
  - call control carried in separate logical connection
  - multiplexing and switching at layer 2
  - no hop by hop error or flow control
  - hence end to end flow and error control (if used) are done by higher layer
- A single user data frame is sent from source to destination and higher layer ACK sent back

Frame Relay - Features

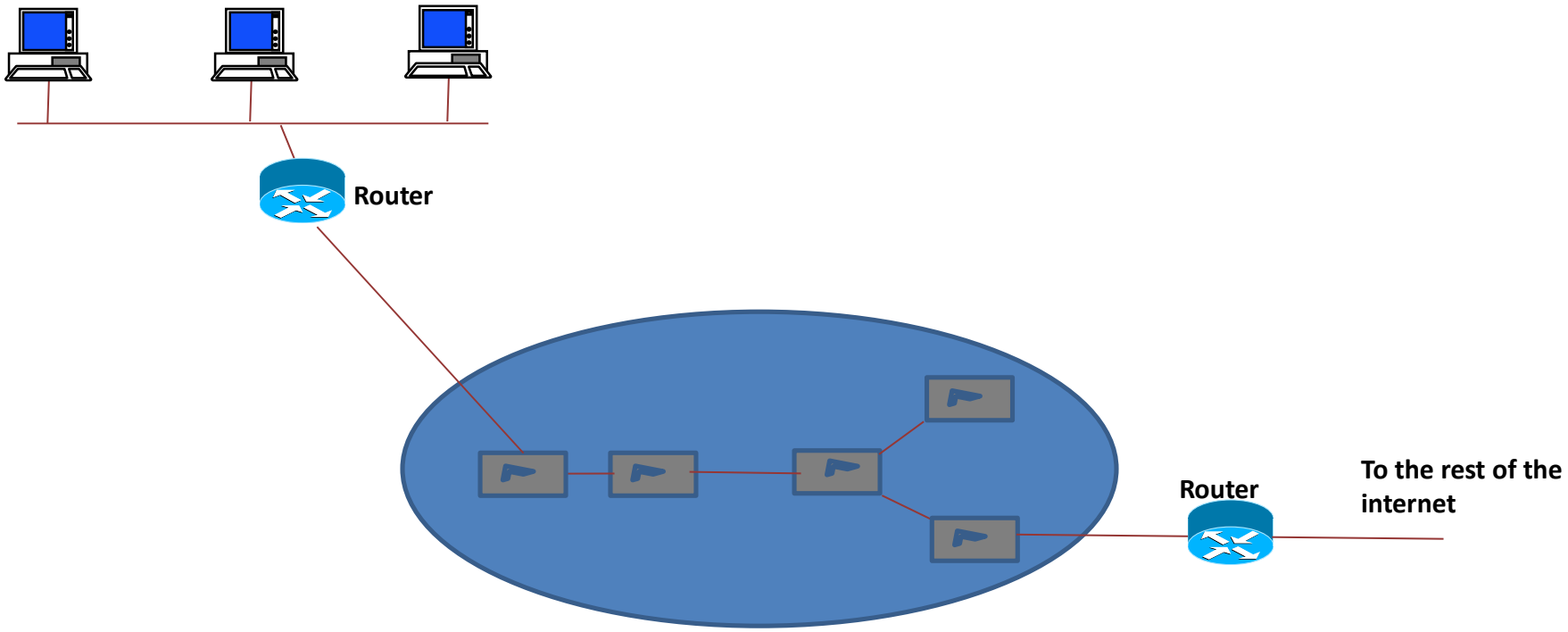
- Operates at a higher speed (1.544 Mbps and recently 44.376Mbps).
  - This means that it can easily be used instead of a mesh of T-1 or T-3 lines
- Operates in just the physical and data link layers
  - This means it can easily be used as a backbone network to provide services to protocols that already have a network layer protocol such as the internet
- Allows bursty data
  - That is, data with instantaneous transmission rates
- Allow a frame size of 9000 bytes, which can accomodate all local area network frame sizes

Frame Relay - Features (cont'd)

- Less expensive than other traditional WANs
- Has error detection at the data link layer only
- There is no flow control or error control
- There is not even retransmission policy if a frame is damaged; it is silently dropped.
- It was designed in this way to provide fast transmission capability for more reliable media and for those protocols thta have flow and error control at the higher layers

Frame Relay - Architecture

- Frame relay provides permanent virtual circuits and switched virtual circuits
- The figure below shows an example of a frame relay network connected to the internet
- The routers are used to connect LANs and WANs in the internet
- In the figure, frame relay WAN is used to link in the global internet



Frame Rely - Virtual circuits

- Frame relay is a virtual circuit network
- A virtual circuit in Frame Relay is identified by a number called a Data Link Connection Identifier (DLCI)

Permanent Vs Switched Virtual Circuit

- Permanent Virtual Circuit
  - A virtual transmission method in which the same virtual circuit is used between source and destination on a continual basis
- Switched Virtual Circuit
  - A virtual transmission method in which a virtual circuit is created and in existence only for the duration of the exchange

Frame Relay - Switches

- Each switch in a Frame Relay network has a table to route frames
- The table matches an incoming port DLCI combination with an outgoing port DLCI combination

Frame Relay - Layers

- Has only physical and data link layers and therefore operates only at the physical and data link layers
  - Physical layer
    - No specific protocol defined for the physical layer in Frame Relay
    - Instead, it is left to the implementer to use whatever is available
  - Data Link
    - At the data link Layer, Frame Relay uses a simple protocol that does not support flow or error control
    - It only has an error detection mechanism