Business Data Communications and Networking

11th Edition

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Chapter 8

Wide Area Networks

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Outline

8.1 - Introduction

8.2 - Circuit-Switched Networks

8.3 - Dedicated-Circuit Networks

8.4 - Packet-Switched Networks

8.5 - Virtual Private Networks

8.6 - Best practice WAN design

8.7 - Improving WAN Performance

8.8 - Implications for Management

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8.1 Introduction

- **Wide area networks (WANs)**
  - **Connect BNs and LANs across longer distances, often hundreds of miles or more**
- **Typically built by using leased circuits from common carriers such as AT&T**
  - **Most organizations cannot afford to build their own WANs**

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Introduction (Cont.)

- **Focus of the Chapter**
  - **Examine WAN architectures and technologies from a network manager point of view**
- **Regulation of services**
  - **Federal Communications Commission (FCC) in the US**
  - **Canadian Radio Television and Telecomm Commission (CRTC) in Canada**
  - **Public Utilities Commission (PUC) in each state**
- **Common Carriers**
  - **Local Exchange Carriers (LECs) like Verizon**
  - **Interexchange Carriers (IXCs) like Sprint**

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Services Used by WANs

- **Use common carrier networks**
  - **Circuit-Switched Networks**
  - **Dedicated-Circuit Networks**
  - **Packet-Switched Networks**
- **Use public networks**
  - **Virtual Private Networks**

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8.2 Circuit Switched Services

- **Oldest and simplest WAN approach**
- **Uses the Public Switched Telephone Network (PSTN), or the telephone networks**
- **Provided by common carriers**
- **Basic types in use today:**
  - **POTS (Plain Old Telephone Service)**
    - **Via use of modems to dial-up and connect to ISPs (5% of US population uses)**
  - **ISDN (Integrated Services Digital Network)**

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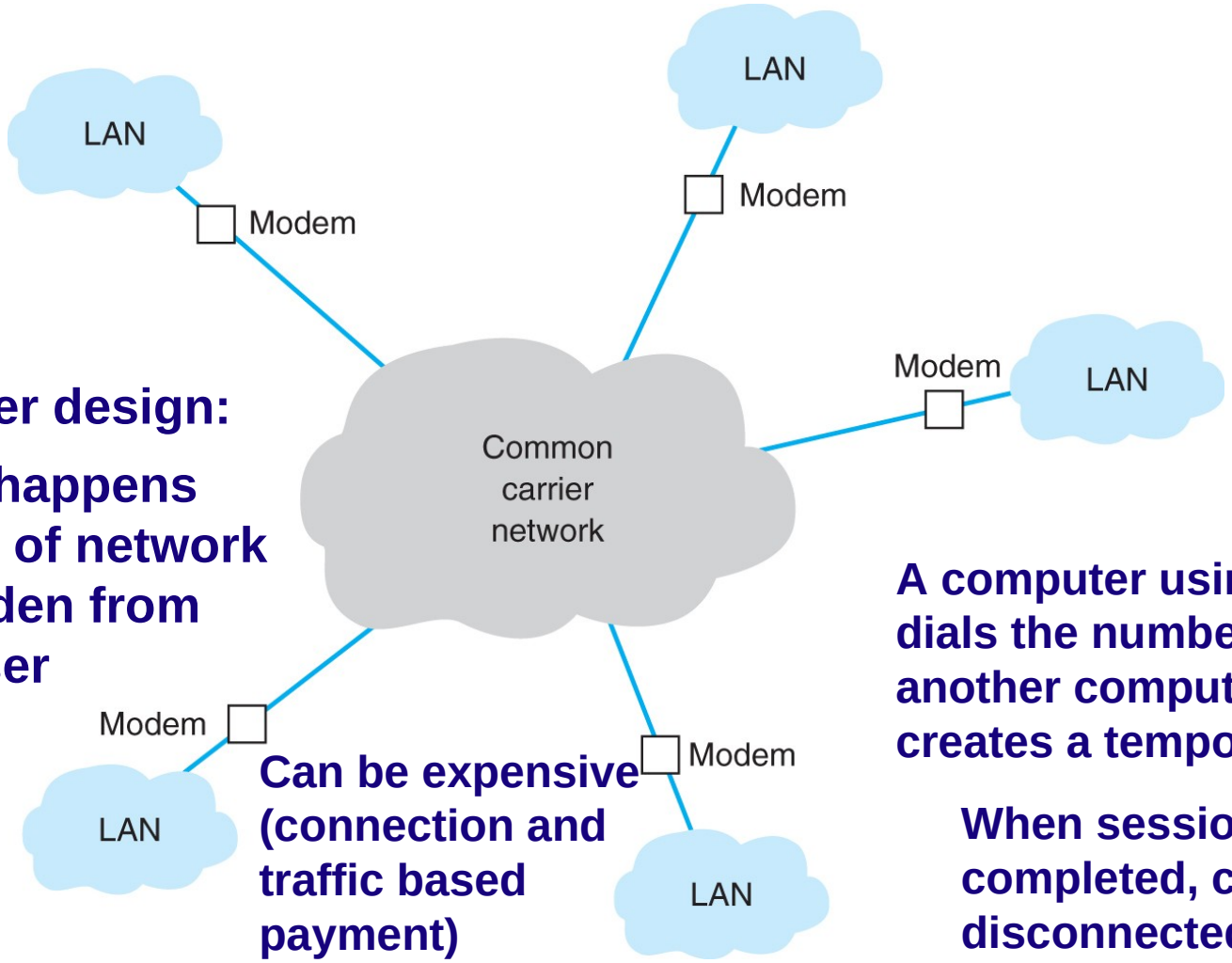
Basic Architecture of Circuit Switched Services



Simpler design:

What happens inside of network is hidden from the user

Can be expensive (connection and traffic based payment)

A computer using modem dials the number of a another computer and creates a temporary circuit

When session is completed, circuit is disconnected.

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POTS based Circuit Switched Services

- **Use regular dial-up phone lines and a modem**
  - **Modem used to call another modem**
  - **Once a connection is made, data transfer begins**
- **Used to connect to the Internet by calling an ISP's access point**

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ISDN based Circuit Switched Services

- **Combines voice, video, and data over the same digital circuit**
- **Sometimes called narrowband ISDN**
- **Provides digital dial-up lines (each requires):**
  - **An "ISDN modem" which sends digital transmissions is used**
    - **Also called: Terminal Adapter (TA)**
  - **An ISDN Network Terminator (NT-1 or NT-2) (echo cancellation)**
    - **Each NT needs a unique Service Profile Identifier (SPID)**
- **Acceptance has been slow**
  - **Lack of standardization, different interpretations. and relatively high cost**
  - **ISDN: I Still Don't Know, I Still Don't Need it**

Types of ISDN Services

- **Basic rate interface (BRI)**
  - **Basic access service or 2B+D**
    - **Two 64 Kbps bearer ‘B’ channels (for voice or data)**
    - **One 16 Kbps control signaling ‘D’ channel**
  - **Requires BRI specific end connections**
- **Primary rate interface (PRI)**
  - **Primary access service or 23B+D**
    - **Twenty three 64 Kbps ‘B’ channels**
    - **One 64 Kbps ‘D’ channel (basically T-1 service)**
  - **Requires T1 like special circuit**

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Circuit Switched Services

- **Simple, flexible, and inexpensive**
  - **When not used intensively**
- **Main problems**
  - **Need to make separate connection each time**
  - **Low Data transmission rates**
    - **Up to 56 Kbps for POTS, and up to 1.5 Mbps for ISDN**
- **An alternative**
  - **Use a private dedicated circuit**
    - **Leased from a common carrier for the user's exclusive use 24 hrs/day, 7 days/week**

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8.3 Dedicated Circuits

- **Leased full duplex circuits from common carriers**
- **Used to create point to point links between organizational locations**
  - **Routers and switches used to connect these locations together to form a network**
- **Billed at a flat fee per month (with unlimited use of the circuit)**
- **Require more care in network design**
- **Basic dedicated circuit architectures**
  - **Ring, star, and mesh**
- **Dedicated Circuit Services**
  - **T carrier services**
  - **Synchronous Optical Network (SONET) services**

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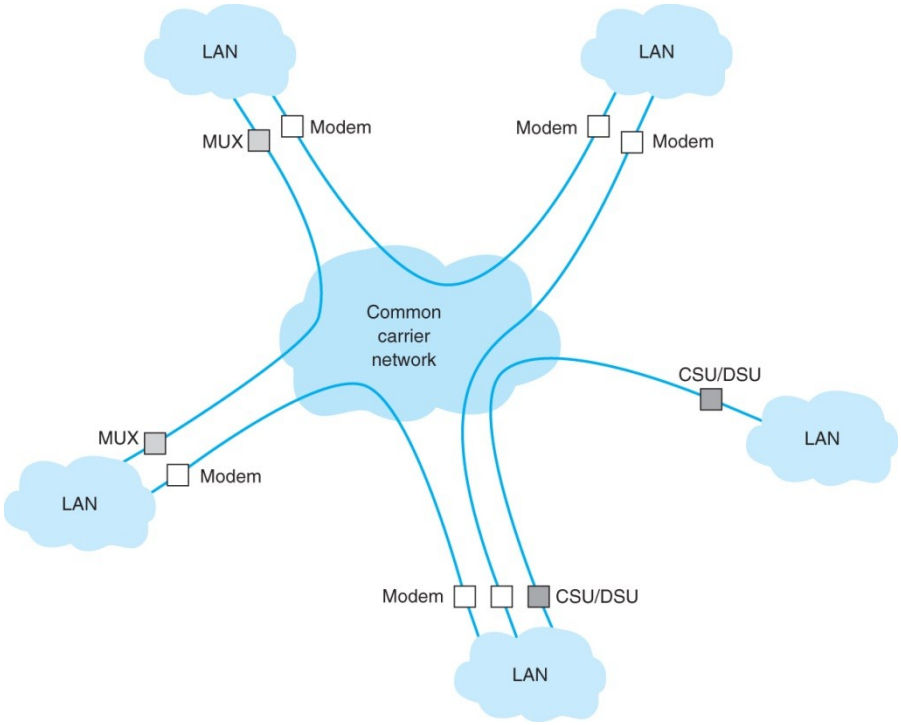
Dedicated Circuit Services



Equipment installed at the end of dedicated circuits

- **CSU/DSU: Channel Service Unit / Data Service Unit**
- **WAN equivalent of a NIC in a LAN**
- **May also include multiplexers**

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Ring Architecture

- **Reliability**
  - **Data can flow in both directions (full-duplex circuits)**
    - **With the expense of dramatically reduced performance**
- **Performance**
  - **Messages travel through many nodes before reaching destination**



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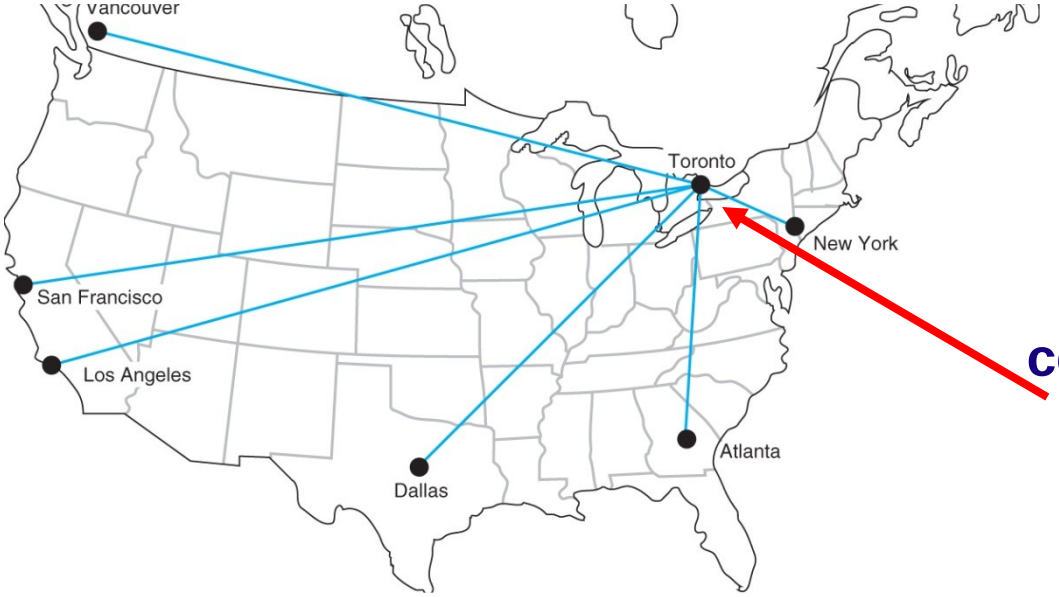
Star Architecture

- **Easy to manage**
  - **Central computer routes all messages in the network**
- **Reliability**
  - **Failure of central computer brings the network down**
  - **Failure of any circuit or computer affects one site only**
- **Performance**
  - **Central computer becomes a bottleneck under high traffic**



central routing computer

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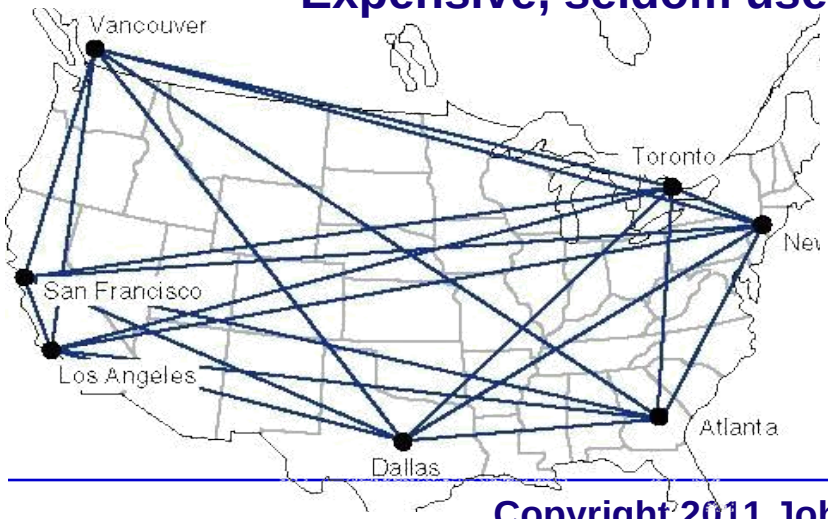
Mesh Architectures

- **Combine performance benefits of ring and star networks**
- **Use decentralized routing, with each computer performing its own routing**
- **Impact of losing a circuit is minimal (because of the alternate routes)**
- **More expensive than setting up a star or ring network.**

Full mesh

- **Expensive, seldom used**



Partial mesh

- **More practical**



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T-Carrier Services

- **Most commonly used dedicated digital circuits in North America**
- **Units of the T-hierarchy**
  - **DS-0 (64 Kbps); Basic unit of T-1, bound into groups of 24**
  - **T-1, also called DS-1 (1.544 Mbps)**
    - **Allows 24 simultaneous 64 Kbps channels which transport data or voice messages using PCM**
  - **T-2 (6.312 Mbps) multiplexes 4 T-1 circuits**
  - **T-3 (44.376 Mbps); 28 T-1 capacity**
  - **T-4 (274.176 Mbps); 178 T-1 capacity (672 DS-0 channels)**
  - **Fractional T-1, (FT-1) offers a portion of a T-1**

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T-Carrier Digital Hierarchy

T Carrier Designation	DS Designation	Speed
FT1	DS0	64 Kbps
T1	DS1	1.544 Mbps
T2	DS2	6.312 Mbps
T3	DS3	44.376 Mbps
T4	DS4	274.176 Mbps

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Synchronous Optical Network (SONET)

- **ANSI standard for optical fiber transmission in Gbps range**
  - **Similar to ITU-T which is a sector International Telecommunication Union; (The Study Groups of ITU's Telecommunication Standardization Sector (ITU-T)) , synchronous digital hierarchy (SDH)**
  - **SDH and SONET can be easily interconnected**
- **SONET hierarchy**
  - **Begins with OC-1 (optical carrier level 1) at 51.84 Mbps**
  - **Each succeeding SONET hierarchy rate is defined as a multiple of OC-1**

SONET Digital Hierarchy

SONET Designation	SDH Designation	Speed
OC-1		51.84 Mbps
OC-3	STM-1	155.52 Mbps
OC-12	STM-4	622.08 Mbps
OC-24	STM-8	1.244 Gbps
OC-48	STM-16	2.488 Gbps
OC-192	STM-24	9.953 Gbps
OC-768	STM-256	39.813 Gbps
OC-3072	STM-1024	159.25 Gbps

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8.4 Packet Switched Services

- **In both circuit switched and dedicated services**
  - **A circuit is established between two computers**
    - **Solely dedicated or assigned for use only between these two computers**

- **Packet switched services**
  - **Enable multiple connections to exist simultaneously between computers over the same physical circuits**
  - **User pays a fixed fee for the connection to the network plus charges for packets transmitted**

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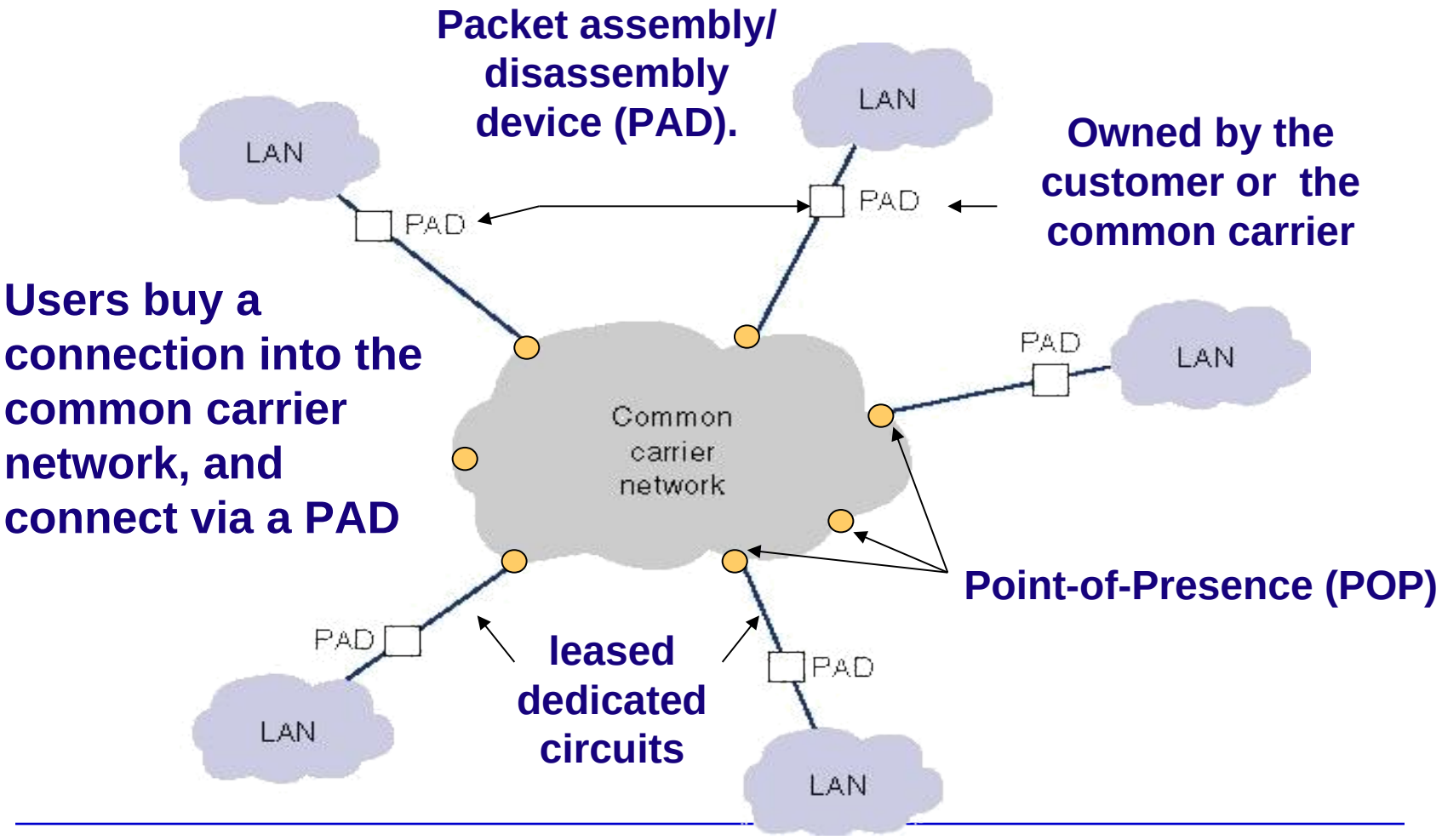
Basic Architecture of Packet Switched Services



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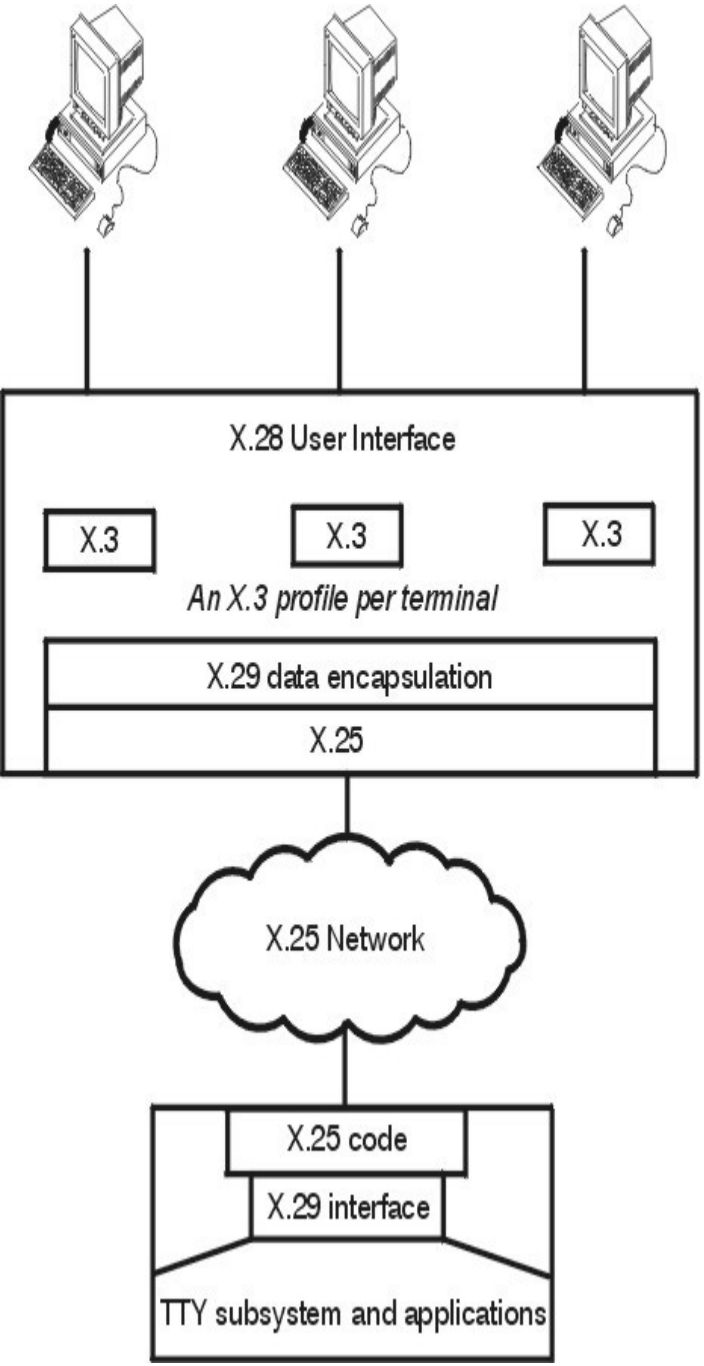
PAD example



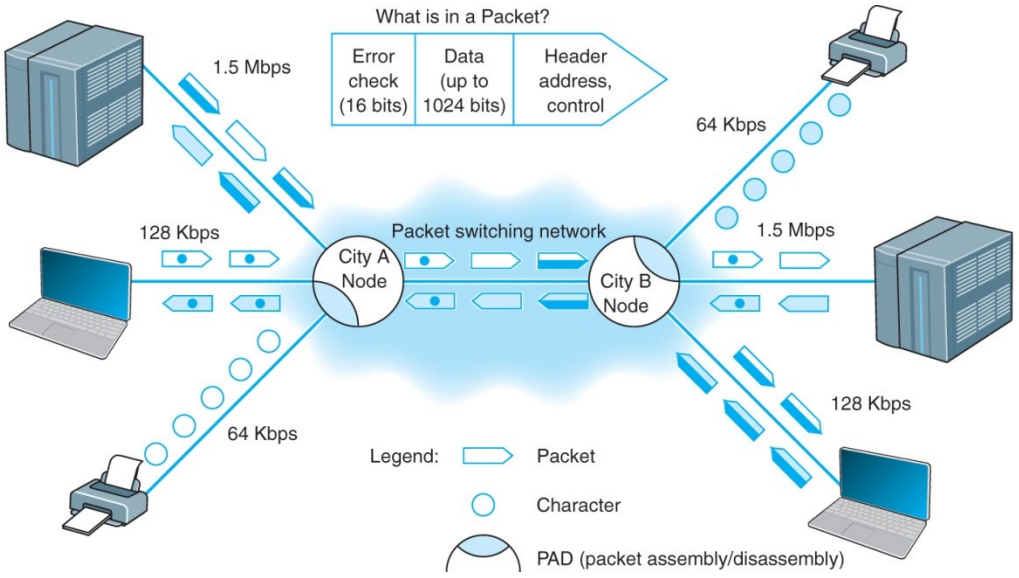
X.3 X.3 Defines a set of parameters that the PAD uses to identify and control the attached terminals. A complete set of parameters is called a *profile*, and each DTE-C (Data Terminal Equipment-Character) has its own profile selected or set for use with the PAD.

X.28 X.28 defines how a terminal user can control the X.3 PAD parameters. It specifies the command and response formats, and the status indicators.

X.29 X.29 Defines the way in which a PAD and a remote DTE (or another PAD) exchange control messages on an X.25 virtual circuit.

Packet Switching

- **Interleave packets from separate messages for transmission**
  - **Most data communications consists of short burst of data**
  - **Packet switching takes advantage of this burstiness**
    - **Interleaving bursts from many users to maximize the use of the shared network**



Packet Routing Methods

- **Describe which intermediate devices the data is routed through**
- **Connectionless (Datagram)**
  - **Adds a destination and sequence number to each packet**
  - **Individual packets can follow different routes through the network**
  - **Packets reassembled at destination**
- **Connection Oriented (Virtual Circuit (VC))**
  - **Establishes an end-to-end circuit between the sender and receiver**
  - **All packets for that transmission take the same route over the virtual circuit established**
  - **Same physical circuit can carry many VCs**

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Types of Virtual Circuits

- **Permanent Virtual Circuit (PVCs)**
  - **Established for long duration (days or weeks)**
  - **Changed only by the network manager**
  - **More commonly used**
  - **Packet switched networks using PVCs behave like a dedicated circuit networks**
- **Switched Virtual Circuit (SVC)**
  - **Established dynamically on a per call basis**
  - **Disconnected when the call ends**

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Data Rates of Virtual Circuits

- **Users specify the rates per each Permanent Virtual Circuit (PVC) via negotiations**
  - **Committed information rate (CIR)**
    - **Guaranteed by the service provider**
    - **Packets sent at rates exceeding the CIR are marked discard eligible (DE)**
      - **discarded if the network becomes overloaded**
  - **Maximum allowable rate (MAR)**
    - **Sends data only when the extra capacity is available**

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Packet Switched Service Protocols

- **Asynchronous Transfer Mode (ATM)**
- **Frame Relay**
- **IP/MPLS**
- **Ethernet Services**

- **Some carriers stopped offering all but Ethernet and Internet services**

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Asynchronous Transfer Mode (ATM)

- **Provides packet switching service**
- **Operating characteristics**
  - **Performs encapsulation (no translation) of packets**
  - **Provides no error control (an unreliable packet protocol)**
  - **Provides extensive QoS information**
  - **Scalable (easy to multiplex ATM circuits onto much faster ones)**
  - **Typically uses SONET at layer 2**
- **Data Rates**
  - **Same rates as SONET: 51.8, 466.5, 622.08 Mpbs**
  - **New versions: T1 ATM (1.5 Mbps), T3 ATM (45 Mbps)**

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Frame Relay

- **Another standardized technology**
- **Slower than ATM**
- **Encapsulates packets**
  - **Packets delivered unchanged through the network**
- **Unreliable, like ATM**
  - **Up to the end-points to control the errors**
- **NO QoS support (under development)**
- **Common (Committed Information Rate) CIR speeds:**
  - **56, 128, 256, 384 Kbps, 1.5, 2, and 45 Mbps**

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Ethernet Services

- **Most organizations use Ethernet and IP in the LAN and BN.**
- **Currently offer CIR speeds from 1 to 40 Gbps at a lower cost than traditional services**
- **No need to translate LAN protocol (Ethernet/IP) to the protocol used in WAN services**
  - **ATM and Frame Relay use different protocols requiring translation from/to LAN protocols**
- **Emerging technology; expect changes**

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Multi Protocol Label Switching (MPLS)

- **relatively new WAN technology**
- **designed to work with a variety of commonly used layer 2 protocols**

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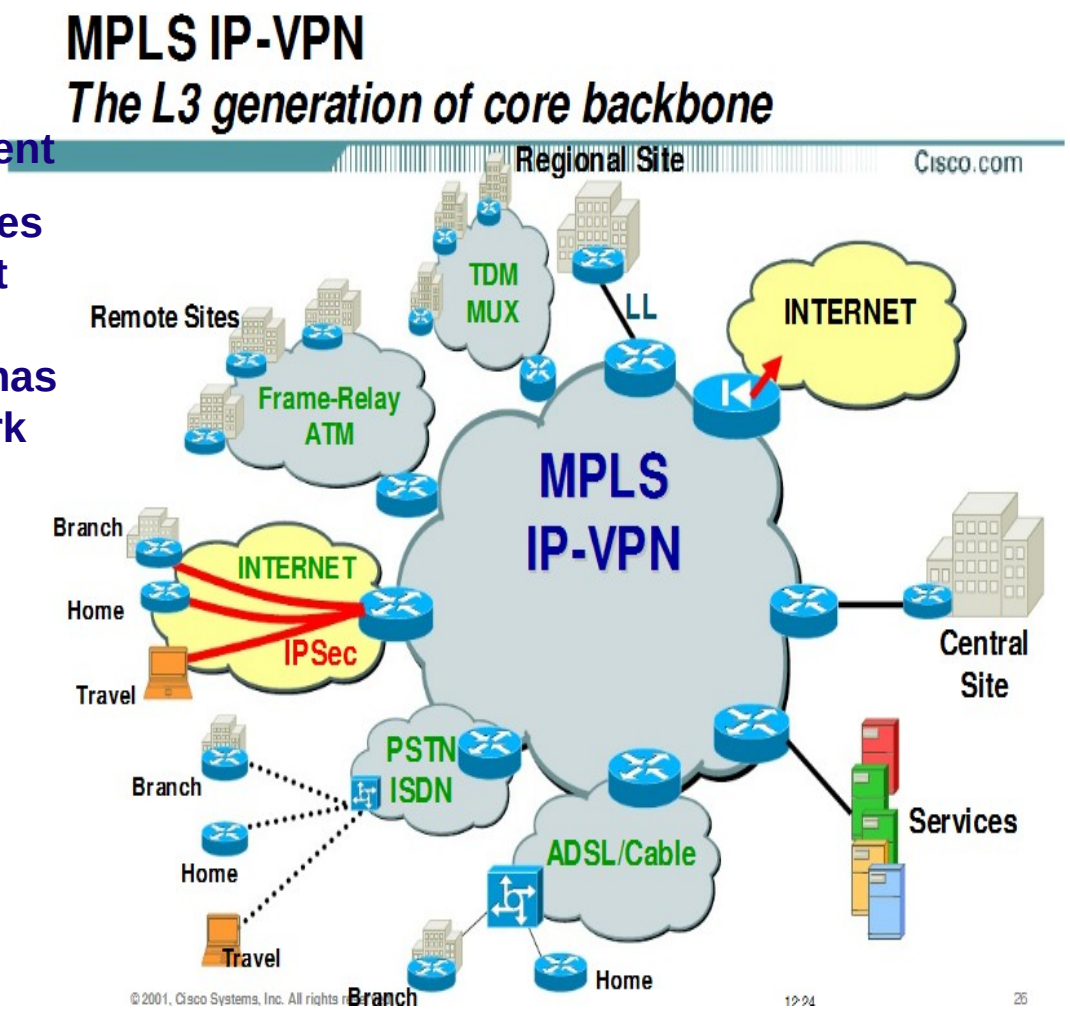
MPLS – How It Works

Customer connects to the carrier's network using any common layer 2 service (e.g., T carrier, SONET, ATM, frame relay, Ethernet)

The carrier's switch at the network entry point examines the incoming frame and converts the incoming layer 2 or layer 3 address into an MPLS address label

The carrier can use the same layer 2 protocol inside its network as the customer, or it can use something different

When delivered, the MPLS switch removes the MPLS header and delivers the packet into the customer's network using whatever layer 2 protocol the customer has used to connect into the carrier's network at this point (e.g., frame, T1).



MPLS Advantages

1.) operates faster than traditional routing

2.) common carriers in the U.S. and Canada typically have a different way of charging for MPLS services than for other packet services, so it is common to use a full mesh design in which every location is connected to every other location. Packets take fewer hops and thus less time to reach their destinations

8.5 Virtual Private Networks

- **Provides equivalent of a private packet switched network over public Internet**
  - **Use Permanent Virtual Circuits (*tunnels*) that run over the public Internet, yet appear to the user as private networks**
  - **Encapsulate the packets sent over these tunnels using special protocols that also encrypt the IP packets**
- **Provides low cost and flexibility**
- **Disadvantages of VPNs:**
  - **Unpredictability of Internet traffic**
  - **Lack of standards for Internet-based VPNs, so that not all vendor equipment and services are compatible**

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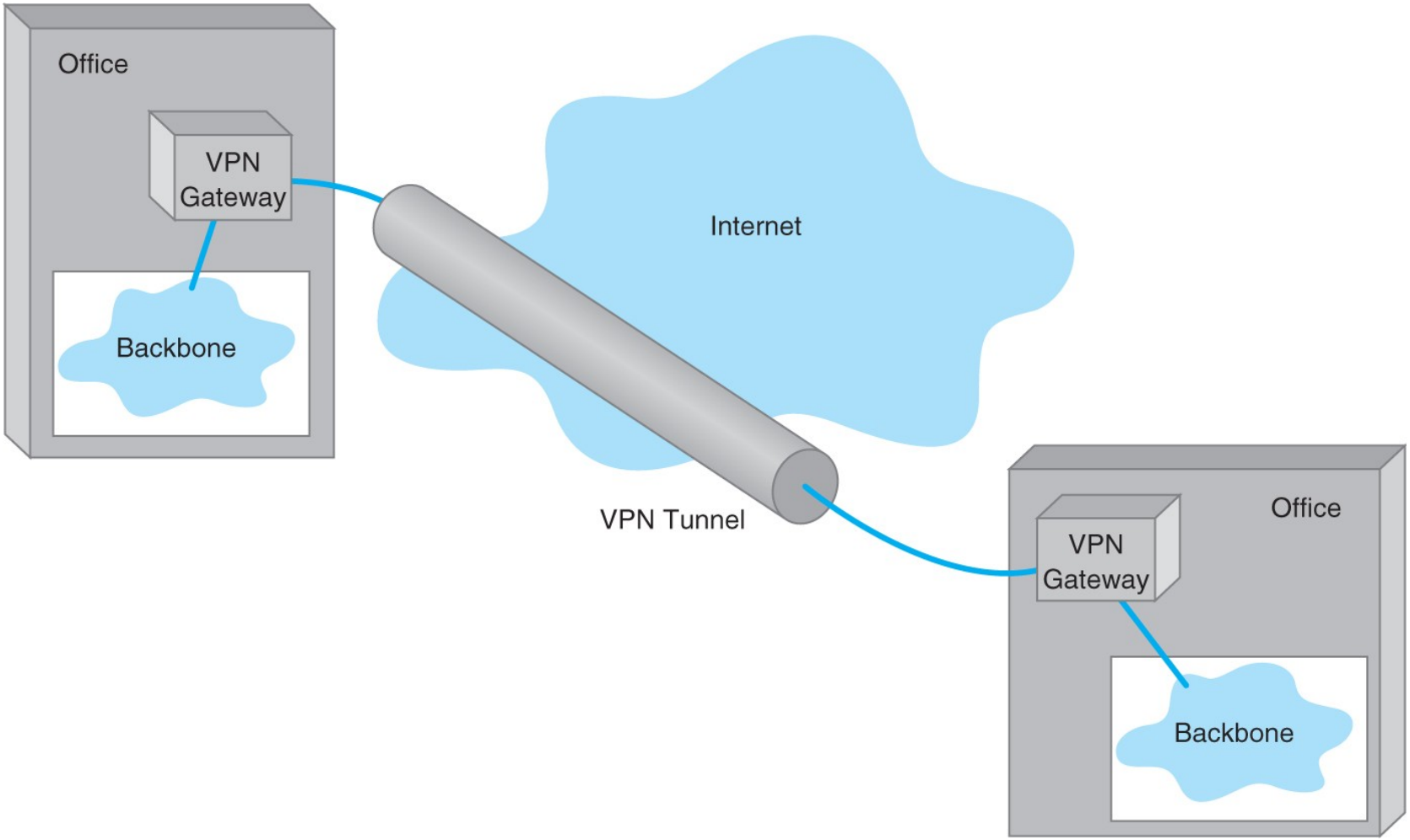
VPN Architecture



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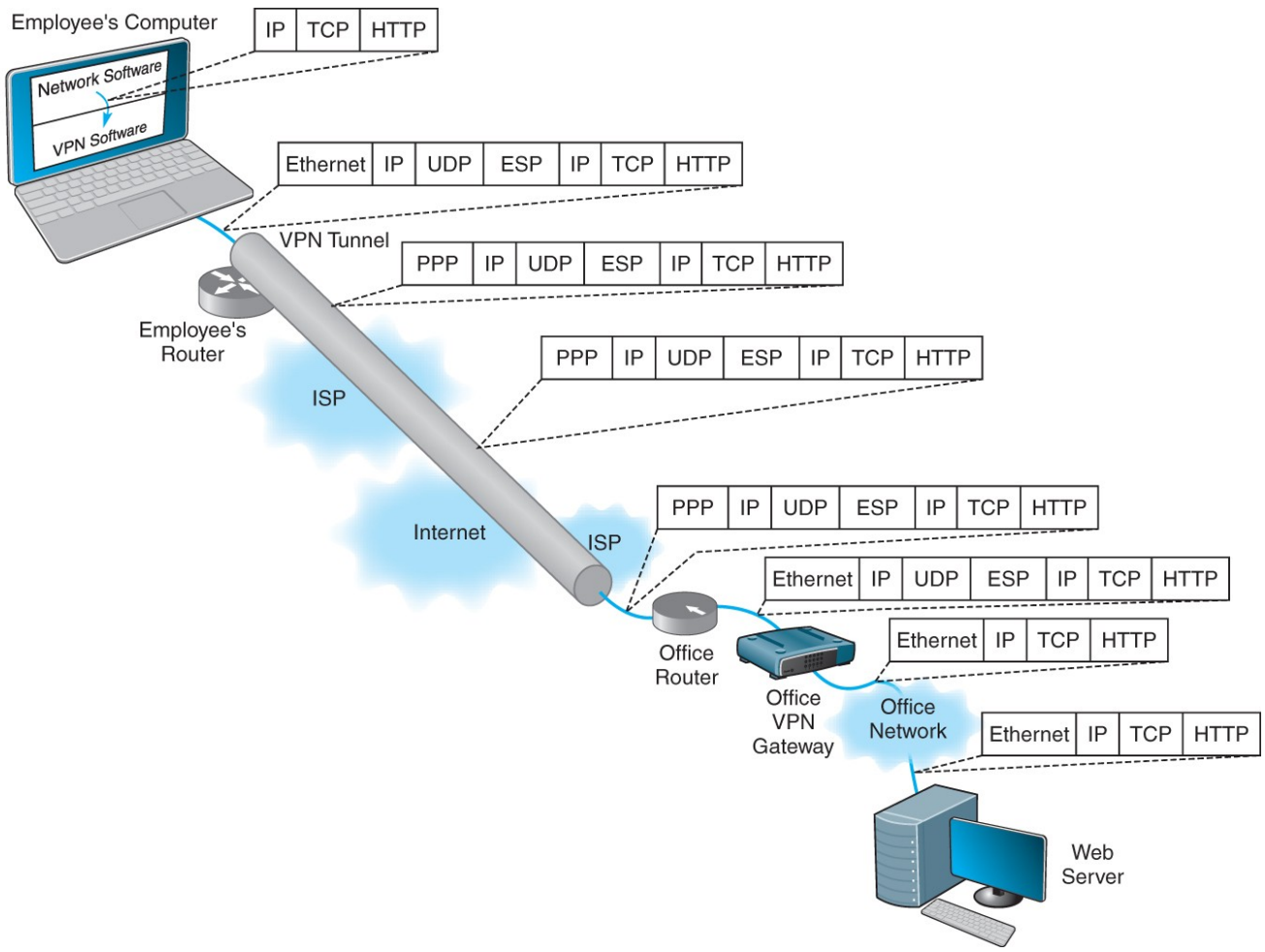
VPN Encapsulation of Packets



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VPN Types

- **Intranet VPN**
  - **Provides virtual circuits between organization offices over the Internet**
- **Extranet VPN**
  - **Same as an intranet VPN except that the VPN connects several different organizations, e.g., customers and suppliers**
- **Access VPN**
  - **Enables employees to access an organization's networks from remote locations**

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8.6 WAN Design Practices

- **Difficult to recommend best practices**
  - **Services, not products, being bought**
  - **Fast changing environment with introduction of new technologies and services from non-traditional companies**
- **Factors used**
  - **Effective data rates and cost**
  - **Reliability**
  - **Network integration**
- **Design Practices**
  - **Start with flexible packet switched service**
  - **Move to dedicated circuit services, once stabilized**
  - **May use both: packet switched services as backup**

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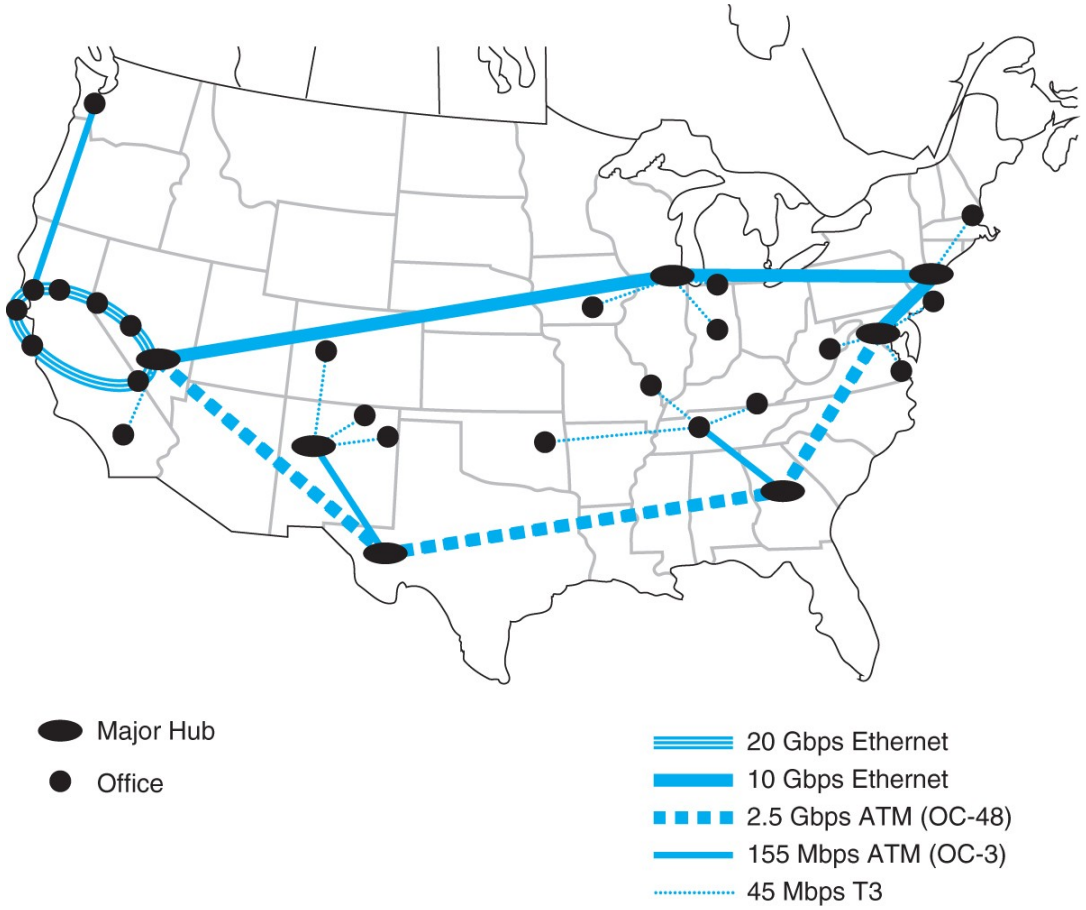
WAN Services



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Comparison of Services

Type of Service	Nominal Data Rates	Relative Cost	Network Integration
Circuit-Switched Services			
POTS	33.6 Kbps to 56 Kbps	Low	Difficult
ISDN	128 Kbps to 1.5 Mbps	Moderate	Difficult
Dedicated-Circuit Services			
T Carrier	64 Kbps to 274 Mbps	Moderate	Moderate
SONET	50 Mbps to 10 Gbps	High	Moderate
Packet-Switched Services			
ATM	52 Mbps to 10 Gbps	High	Moderate
Frame Relay	56 Kbps to 45 Mbps	Moderate	Moderate
Ethernet	1 Mbps to 40 Gbps	Moderate	Simple
MPLS	64 kbps to 155 Mbps	Moderate	Moderate
VPN Services			
VPN	56 Kbps to 40 Gbps	Low	Moderate

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Recommendations for the Best WAN Practices

Network Needs	Recommendation
Low Traffic Needs (64 Kbps or less)	VPN if reliability is less important Frame relay otherwise
Moderate Traffic Needs (64 Kbps to 2 Mbps)	VPN if reliability is less important T1 or fractional T1 if network volume is stable and predictable Frame relay or MPLS otherwise
High Traffic Needs (2 Mbps to 45 Mbps)	Ethernet or MPLS if available T3 if network volume is stable and predictable Frame relay otherwise
Very High Traffic Needs (45 Mbps to 10 Gbps)	Ethernet or MPLS if available SONET if network volume is stable and predictable ATM otherwise

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8.7 Improving WAN Performance

- **Handled in the same way as improving LAN performance**
  - **Improve device performance**
  - **Improve circuit capacity**
  - **Reduce network demand**

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Improving Device Performance

- **Upgrade the devices (routers) and computers that connect backbones to the WAN**
  - **Select devices with lower "latency"**
    - **Time it takes in converting input packets to output packets**
- **Examine the routing protocol (static or dynamic)**
  - **Dynamic routing**
    - **Increases performance in networks with many possible routes from one computer to another**
    - **Better suited for "bursty" traffic**
    - **Imposes an overhead cost (additional traffic)**
      - **Reduces overall network capacity**

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Improving Circuit Capacity

- **Analyze the traffic to find the circuits approaching capacity**
  - **Upgrade overused circuits**
  - **Downgrade underused circuits to save cost**
- **Examine why circuits are overused**
  - **Caused by traffic between certain locations**
    - **Add additional circuits between these locations**
  - **Capacity okay generally, but not meeting peak demand**
    - **Add a circuit switched or packet switched service that is only used when demand exceeds capacity**
  - **Caused by a faulty circuit somewhere in the network**
    - **Replace and/or repair the circuit**
- **Make sure that circuits are operating properly**

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Reducing Network Demand

- **Determine impact on network**
  - **Require a network impact statement for all new application software**
- **Use data compression of all data in the network**
- **Shift network usage**
  - **From peak or high cost times to lower demand or lower cost times**
  - **e.g., transmit reports from retail stores to headquarters after the stores close**
- **Redesign the network**
  - **Move data closer to applications and people who use them**
  - **Use distributed databases to spread traffic across**

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8.8 Implications for Management

- **Changing role of networking and telecomm managers**
  - **Increased and mostly digitized data transmission causing the merger of these positions**
- **Changing technology**
  - **Within 5 years, ATM will possibly disappear**
  - **Increasing dominance of Ethernet and MPLS**
  - **Decreasing cost of setting up WANs**
- **Changing vendor profiles**
  - **From telecomm vendors to vendors with Ethernet and Internet experiences**

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