Chapter Eleven

Voice and Data Delivery Networks

Data Communications and Computer Networks: A Business User's Approach

Eighth Edition

After reading this chapter, you should be able to:

- Identify the basic elements of a telephone system and discuss the limitations of telephone signals
- Describe the composition of the telephone industry before and after the 1984 Modified Final Judgment and explain the differences
- Describe the difference between a local exchange carrier and an interexchange carrier and list the services each offers
- Differentiate between the roles of the local telephone company before and after the Telecommunications Act of 1996

After reading this chapter, you should be able to (continued):

- Identify the main characteristics of digital subscriber line, and recognize the difference between a symmetric system and an asymmetric system
- Identify the main characteristics of a cable modem
- List the basic characteristics of frame relay, such as permanent virtual circuits, committed information rate, and switched virtual circuits

After reading this chapter, you should be able to (continued):

- Identify the main characteristics of Asynchronous Transfer Mode, including the roles of the virtual path connection and the virtual channel connection, the importance of the classes of service available, and ATM's advantages and disadvantages
- Describe the concept of convergence, and identify several examples of it in the networking industry

Introduction

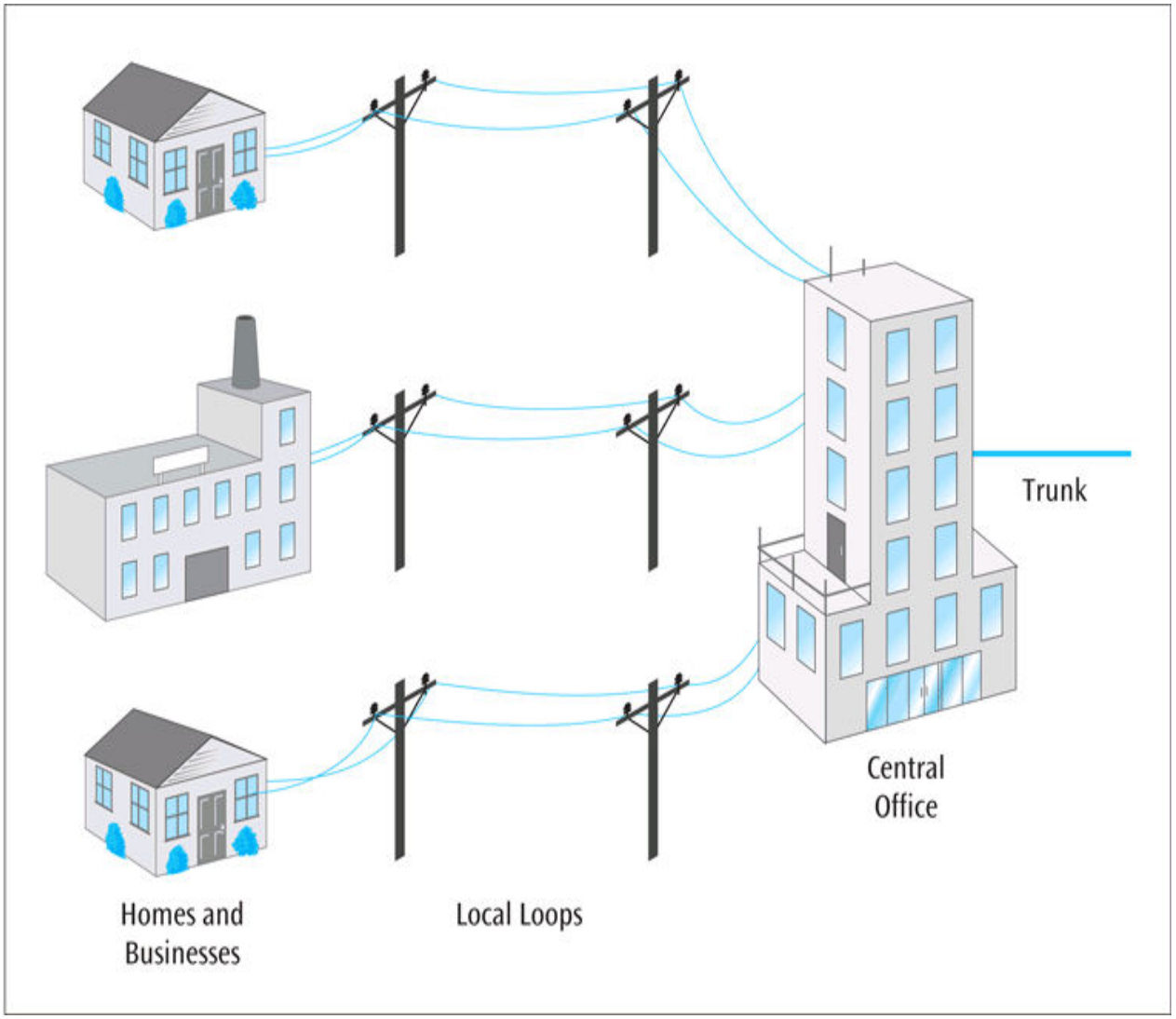
- Students used to go into either data communications or voice communications
- Today, the two fields have merged
- Or should we say that voice networks have given way to data networks and now data networks support both data and voice
- Anyone studying the field of data communications and networks must learn some basic telecommunications too

Telephone Lines, Trunks, and Numbers

- The local loop is the telephone line that runs from the telephone company's central office to your home or business
  - Central office – building that houses the telephone company's switching equipment and provides a local dial tone on your telephone
- If you place a long-distance call, the central office passes your telephone call off to a long-distance provider

Telephone Lines, Trunks, and Numbers

Figure 11-1
The local loop as it connects your house to the telephone company's central office



Telephone Lines, Trunks, and Numbers (continued)

- The country is divided into a few hundred local access transport areas (LATAs)
  - If your call goes from one LATA to another, it is a long-distance call and is handled by a long-distance telephone company
  - If your call stays within a LATA, it is a local call and is handled by a local telephone company

Telephone Lines, Trunks, and Numbers (continued)

- Trunk – special telephone line that runs between central offices and other telephone switching centers
  - Usually digital, high-speed, and carries multiple telephone circuits
  - Typically a 4-wire circuit, while a telephone line is a 2-wire circuit

Telephone Lines, Trunks, and Numbers (continued)

- A trunk is not associated with a single telephone number like a line is
- A telephone number consists of an area code, an exchange, and a subscriber extension
  - The area code and exchange must start with the digits 2-9 to separate them from long distance and operator services
  - How long until we have to make the telephone number larger?

Telephone Lines, Trunks, and Numbers (continued)

- When telephone company installs a line, it must not proceed any further than 12 inches into the building
  - This point is the demarcation point, or demarc
- Modular connectors, such as the RJ-11, are commonly used to interconnect telephone lines and the telephone handset to the base
- When handset is lifted off base (off-hook), an off-hook signal is sent to the central office

Telephone Lines, Trunks, and Numbers (continued)

- When off-hook signal arrives at central office, a dial tone is generated and returned to telephone
- When user hears the dial tone, they dial (or press) number
- The central office equipment collects dialed digits, and proceeds to place appropriate call

Telephone Lines, Trunks, and Numbers (continued)

- POTS – plain old telephone service – the landline telephone system we know today
- Private Branch Exchange (PBX) – common internal phone switching system for medium- to large-sized businesses
- Centrex (central office exchange service) is like having a PBX but the PBX resides at the local telephone company
- Private lines are leased, permanent telephone circuits; opposite of dial-up lines

The Telephone Network Before and After 1984

- In 1984, U.S. government broke up AT&T
- Before then, AT&T owned large majority of all local telephone circuits and all the long-distance service
- With Modified Final Judgment (MFJ) of 1984, AT&T had to split off local telephone companies from long-distance company
  - The local telephone companies formed seven Regional Bell Operating Companies
    - Today, there are only 3 left: AT&T (Southwestern Bell, Bell South, Ameritech, Pacific Telesis), CenturyLink (US West), and Verizon (Bell Atlantic, NYNEX)

The Telephone Network Before and After 1984 (continued)

Figure 11-2
The original 23 Bell companies and the newer 7 regional telephone companies

The Telephone Network Before and After 1984 (continued)

- Another result of the Modified Judgment was creation of LATA (local access and transport area)
- Local telephone companies became known as local exchange carriers (LECs), and long distance telephone companies became known as interexchange carriers (IEC, or IXC)
- Calls that remain within LATA are intra-LATA, or local calls
- Calls that pass from one LATA to another are inter-LATA, or long distance

The Telephone Network Before and After 1984 (continued)

- Before 1984, telephone networks in the U.S. resembled a large hierarchical tree, with Class 5 offices at the bottom and Class 1 offices at the top
  - Users were connected to Class 5 offices
  - The longer the distance of a telephone call, the further up the tree the call progressed
- Today's telephone structure is a collection of LECs, POPs, and IECs

Summary – Results of MFJ

- AT&T could not control everything
- Difference between local distance and long distance clearly defined
- Users could select their own long distance carrier
- AT&T had to allow other long distance phone companies access to their switching centers

Telecomm Act of 1996

- Another landmark ruling affecting the telephone industry was the Telecommunications Act of 1996
  - Opened up local telephone market to competitors
- Now cable TV companies (cable telephony), long-distance telephone companies, or anyone that wants to start a local telephone company can offer local telephone service
- Local phone companies that existed before the Act are known as incumbent local exchange carriers (ILEC) while the new companies are competitive local exchange carriers (CLEC)

Telecomm Act of 1996 (continued)

- LECs are supposed to allow CLECs access to all local loops and switching centers / central offices
- If a local loop is damaged, the LEC is responsible for repair
- The LEC is also supposed to provide the CLEC with a discount to the dial tone (17-20%)
- LECs can also provide long-distance service if they can show there is sufficient competition at the local service level

Results of Telecomm Act of 1996

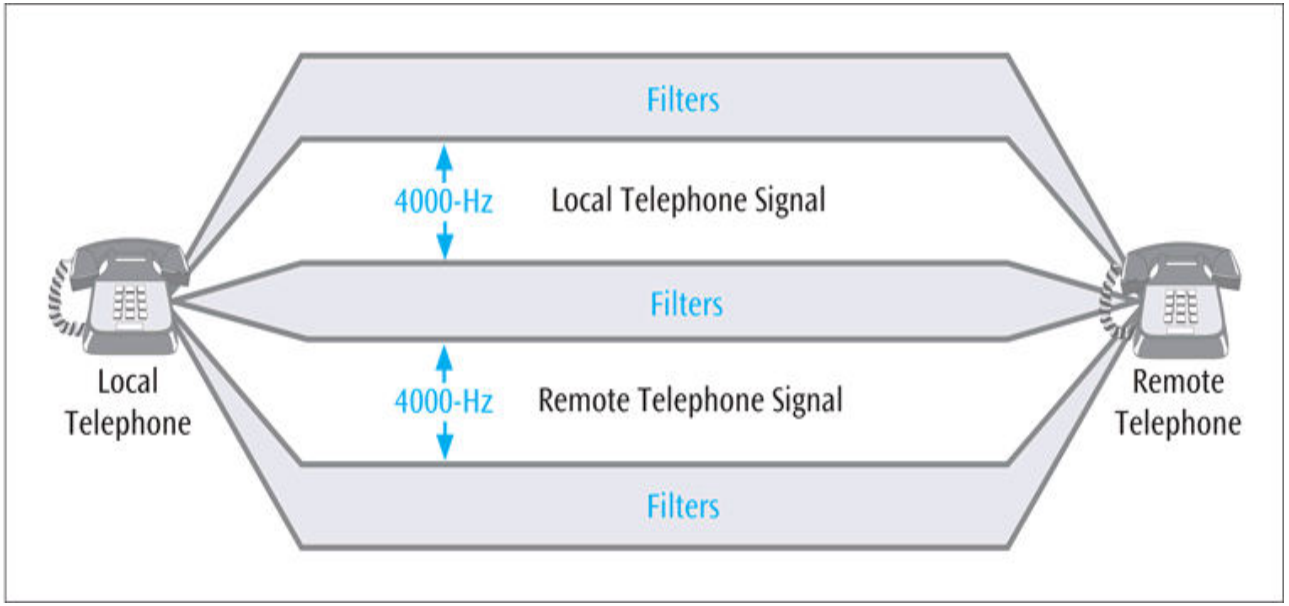
- Users now have a “choice” of local telephone providers, but this didn’t work as well as MFJ
- Choices include original provider (like AT&T), cable television company, VoIP over Internet, or none at all (many drop land line in favor of cellular service only)
- Mega-phone companies (like AT&T) are coming back

Limitations of Telephone Signals

- POTS lines were designed to transmit the human voice, which has a bandwidth less than 4000 Hz
- A telephone conversation requires two channels, each occupying 4000 Hz

Limitations of Telephone Signals (continued)

Figure 11-3
The various telephone channels and their assignment of frequencies



Limitations of Telephone Signals (continued)

- A 4000 Hz analog signal can only carry about 33,600 bits per second of information while a 4000 Hz digital signal can carry about 56,000 bits per second
- If you want to send information faster, you need a signal with a higher frequency or you need to incorporate more advanced modulation techniques

Dial-Up Internet Service

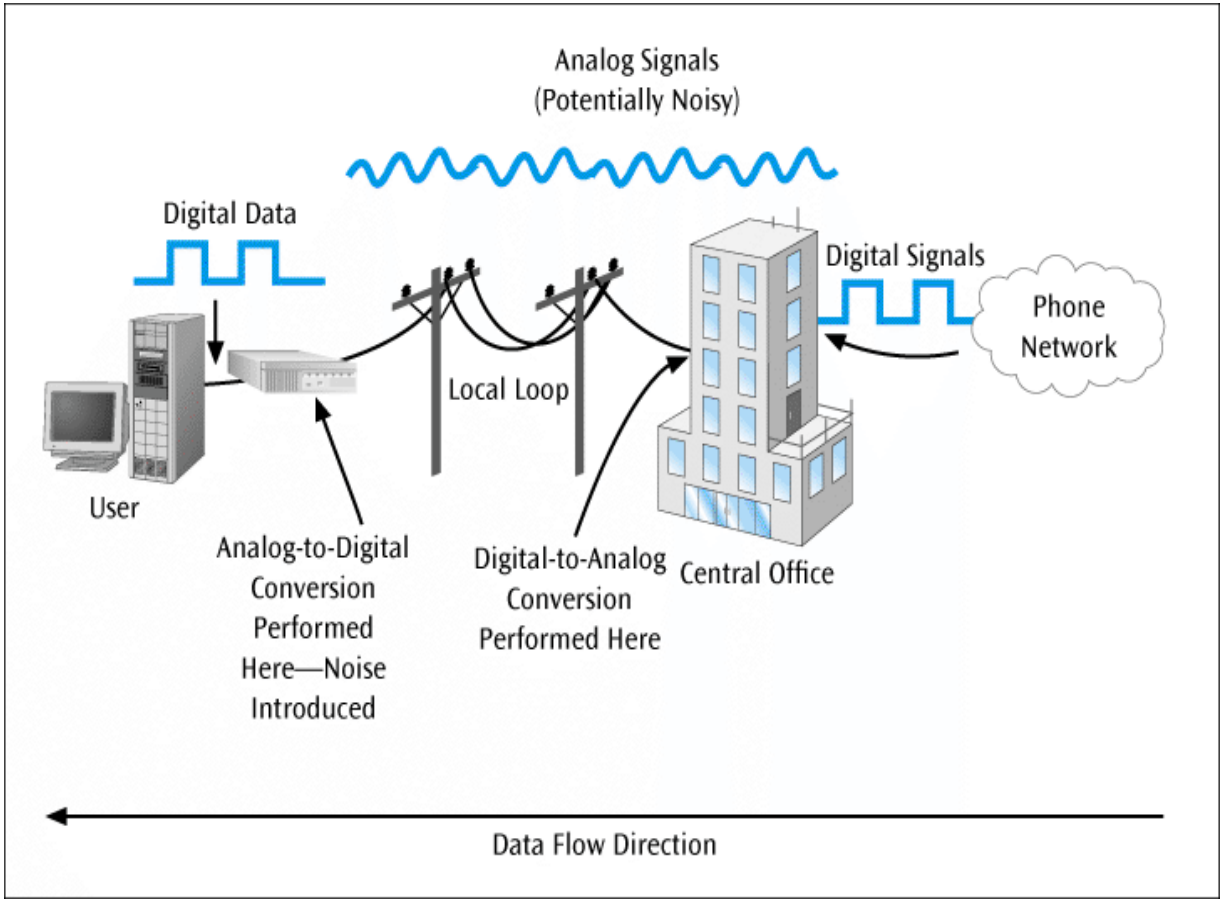
- Once upon a time most Internet users used a dial-up service, such as a 56k modem
- A 56k modem (56,000 bps) achieves this speed by combining digital signaling with analog signaling

Dial-Up Internet Service (continued)

- Would actually achieve 64k except:
  - Local loop is still analog, thus analog signaling
  - Analog to digital conversion at the local modem introduces noise/error
  - Combined, these shortcomings drop the speed to at best 56k
- Doesn't even reach 56k due to line noise and other factors

Dial-Up Internet Service (continued)

Figure 11-4
The analog and digital forms of a telephone connection between a home and the central office



Dial-Up Internet Service (continued)

- Based upon one of two standards:
  - V.90
    - Upstream speed is maximum 33,600 bps
  - V.92
    - Newer standard
    - Allows maximum upstream speed of 48 kbps (under ideal conditions)
    - Can place a data connection on hold if the telephone service accepts call waiting and a voice telephone call arrives

Digital Subscriber Line

- 56k dial-up modems are disappearing (too slow!)
- What is replacing 56k for in home Internet access?
  - DSL can provide very high data transfer rates over standard telephone lines
  - Cable modems (but let's look at DSL first)

DSL Basics

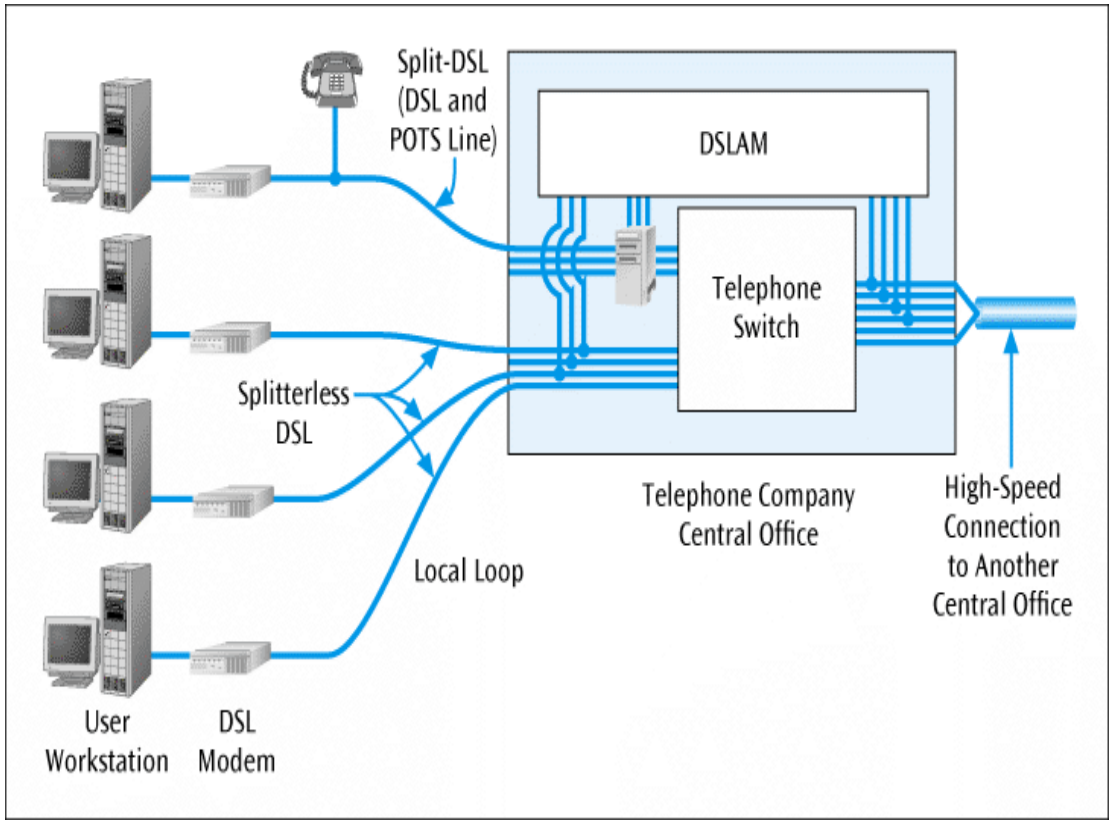
- DSL, depending on the type of service, is capable of transmission speeds from 100s of kilobits into single-digit megabits
- Because DSL is highly dependent upon noise levels, a subscriber cannot be any more than 5.5 kilometers (2-3 miles) from the DSL central office
- DSL service can be:
  - Symmetric – downstream and upstream speeds are identical
  - Asymmetric – downstream speed is faster than the upstream speed

DSL Basics (continued)

- DSL service
  - Often connects a user to the Internet
  - Can also provide a regular telephone service (POTS)
- The DSL provider uses a DSL access multiplexer (DSLAM) to split off the individual DSL lines into homes and businesses
  - A user then needs a splitter to separate the POTS line from the DSL line, and then a DSL modem to convert the DSL signals into a form recognized by the computer

DSL Basics (continued)

Figure 11-5
The four necessary components of a DSL connection



DSL Formats

- A DSL service comes in many different forms:
  - ADSL (Asymmetric DSL)
  - DSL Lite
    - Slower form than ADSL
  - VDSL2 (Very high data rate DSL2)
  - RADSL (Rate-adaptive DSL)
    - Speed varies depending on noise level

Cable Modems

- Allow high-speed access to wide area networks such as the Internet
- Most are external devices that connect to the personal computer through a common Ethernet card
- Can provide data transfer speeds between 500 kbps and 25 Mbps

Cable Modems (continued)

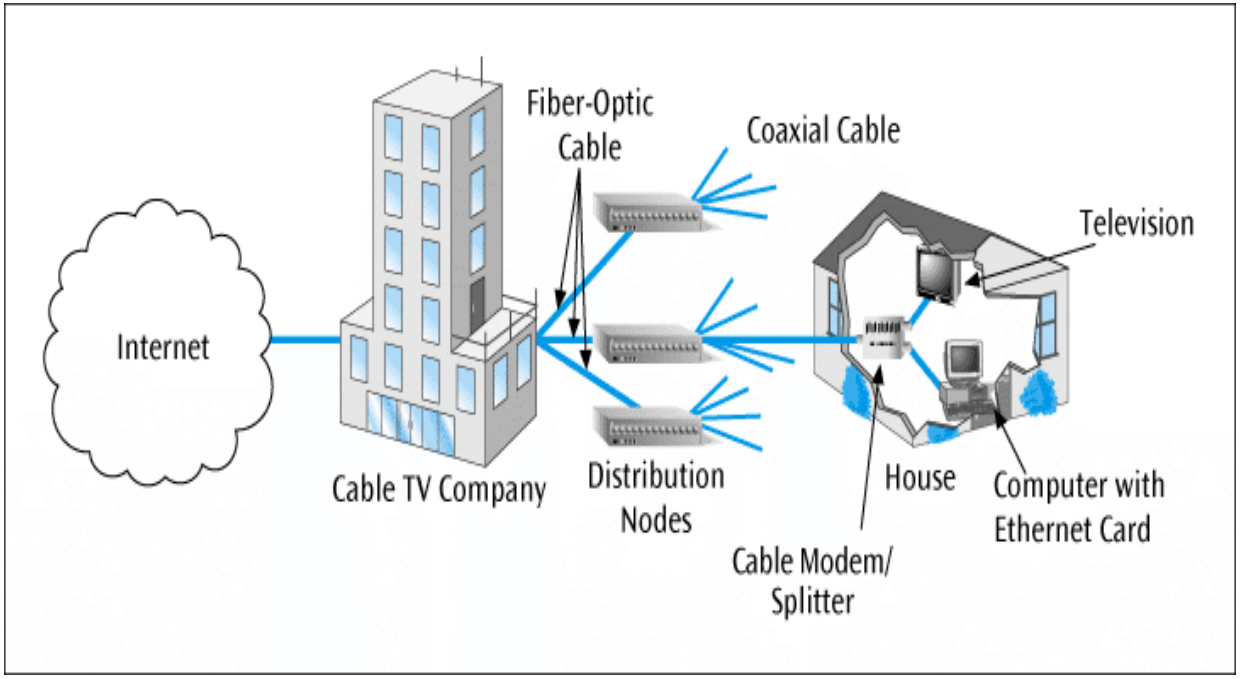
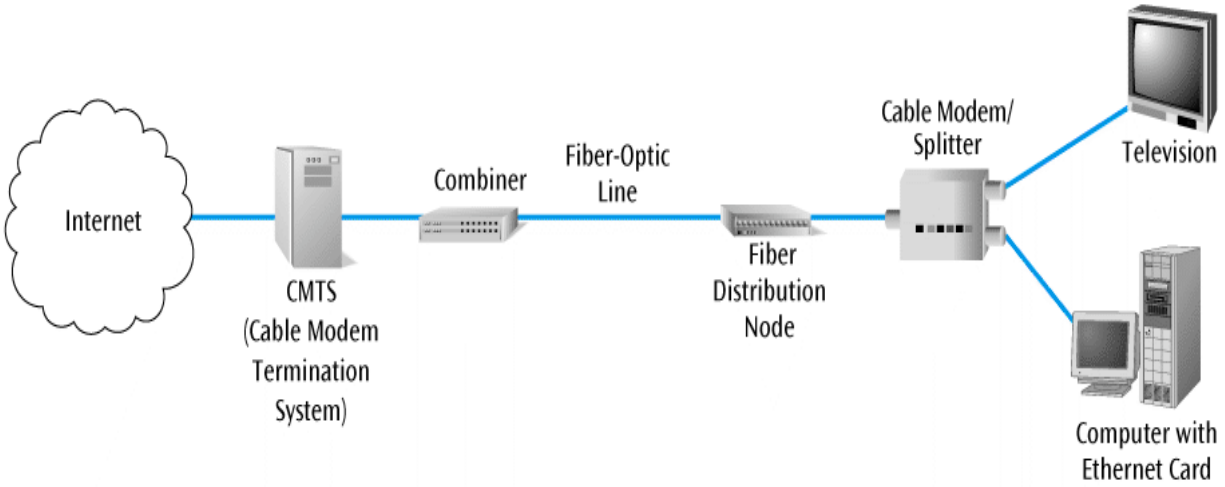


Figure 11-6
Cable modem connecting a personal computer to the Internet via a cable television connection

Cable Modems (continued)

Figure 11-7
Basic architecture and components of a cable modem system



T-1 Leased Line Service

- DSL and cable modems are great for home users and small commercial users. But what else is there for commercial users?
- T-1 – digital service offered by the telephone companies that can transfer data as fast as 1.544 Mbps (both voice and computer data)
- To support a T-1 service, a channel service unit / data service unit (CSU/DSU) is required at the end of the connection

T-1 Leased Line Service (continued)

- A T-1 service
  - Is a digital, synchronous TDM stream used by businesses and telephone companies
  - Is always on and always transmitting
  - Can support up to 24 simultaneous channels
    - These channels can be either voice or data (PBX support)
  - Can also be provisioned as a single channel delivering 1.544 Mbps of data (LAN to ISP connection)

T-1 Leased Line Service (continued)

- A T-1 service (continued)
  - Requires 4 wires, as opposed to a 2-wire telephone line
  - Can be either intra-LATA (local) which costs roughly $350-$400 per month, or inter-LATA (long distance) which can cost thousands of dollars per month (usually based on distance)
    - A customer may also be able to order a 1/4 T-1 or a 1/2 T-1 (fractional T-1)

T-1 Leased Line Service (continued)

- Constantly transmits frames (8000 frames per second)
  - Each frame consists of one byte from each of the 24 channels, plus 1 sync bit (8 * 24 + 1 = 193 bits)
    - 8000 frames per second * 193 bits per frame = 1.544 Mbps
  - If a channel is used for voice, each byte is one byte of PCM-encoded voice
  - If a channel is used for data, each byte contains 7 bits of data and 1 bit of control information (7 * 8000 = 56 kbps)

T-1 Alternatives

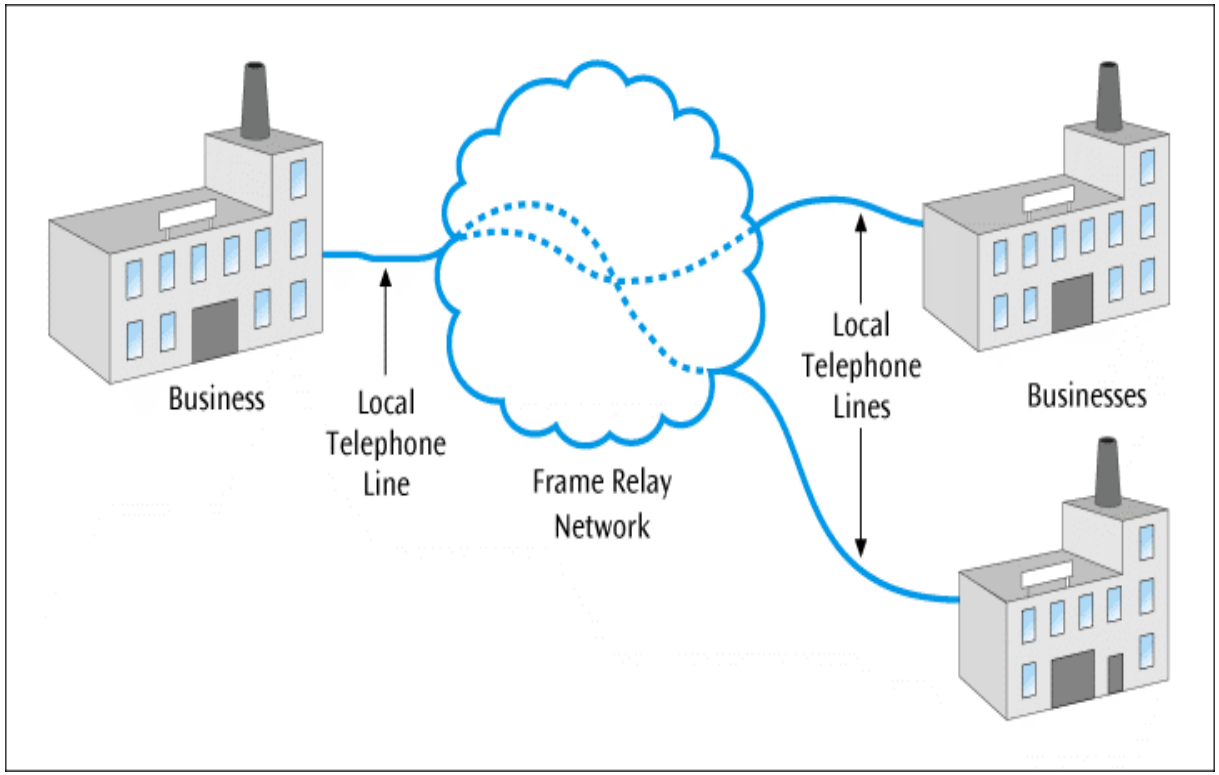
- There are a number of alternatives to using the often costly T-1 lines, especially for long distances
- Let's take a look at frame relay, asynchronous transfer mode, and MPLS/VPN

Frame Relay

- Leased service that can provide a high-speed connection for data transfer between two points either locally or over long distances
- A business only has to connect itself to local frame relay port
  - Hopefully this connection is a local telephone call
  - Once data reaches local frame relay port, the frame relay network, or cloud, transmits the data to the other side

Frame Relay (continued)

Figure 11-8
Three businesses connected to the frame relay cloud via local connections



Frame Relay (continued)

- Permanent virtual circuit (PVC) – connection between two endpoints
  - Created by the provider of the frame relay service
- The user uses a high-speed telephone line to connect its company to a port, which is the entryway to the frame relay network
- The high-speed line, the port, and the PVC should all be chosen to support a desired transmission speed

Frame Relay (continued)

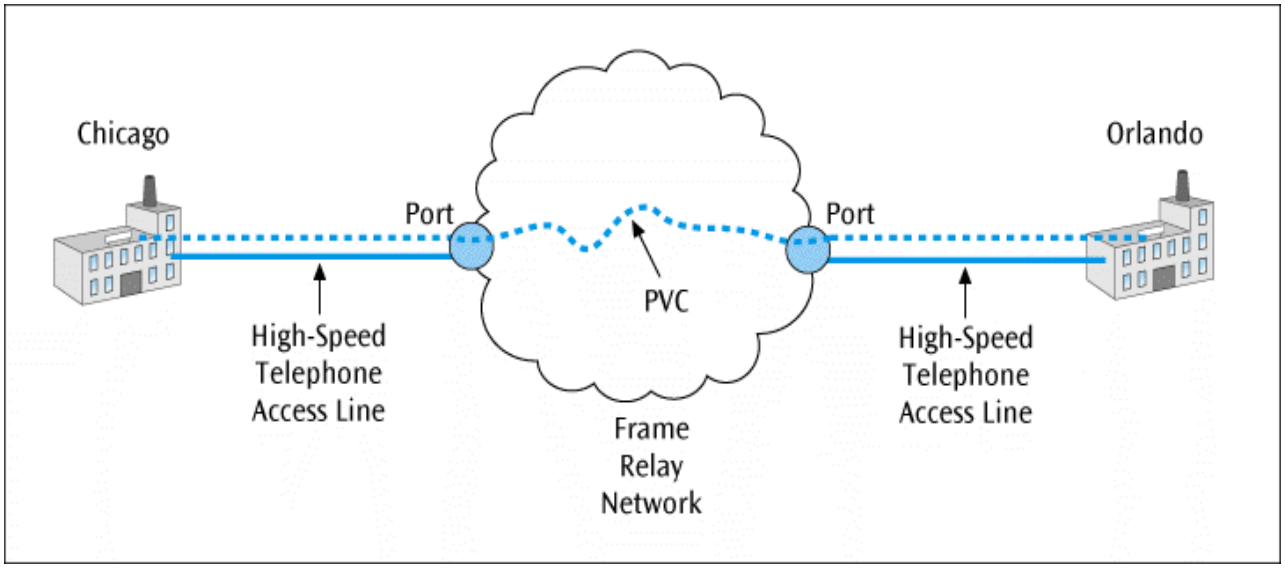


Figure 11-9
A frame relay connection between Chicago and Orlando, showing access lines, ports, and PVC

Committed Information Rate (CIR)

- The user and frame relay service would agree upon a committed information rate (CIR)
- The CIR states that if the customer stays within a specified data rate (standard rate plus a burst rate) the frame relay provider will guarantee delivery of 99.99% of the frames
- The burst rate cannot be exceeded for longer than 2 seconds

Committed Information Rate (CIR) (continued)

- Example – if a company agrees to a CIR of 512 kbps with a burst rate of 256 kbps, the company must stay at or below 512 kbps, with an occasional burst up to 768 kbps, as long as the burst does not last longer than 2 seconds
  - If the company maintains their end of the agreement, the carrier will provide something like 99.99% throughput and a network delay of no longer than 20 ms
  - If the customer exceeds its CIR, and the network becomes congested, the customer's frames may be discarded

Asynchronous Transfer Mode (ATM)

- Asynchronous Transfer Mode (ATM) – very high-speed packet-switched service, similar in a number of ways to frame relay
- Both send packets of data over high-speed lines
- Both require a user to create a circuit with a provider
- One noticeable difference between ATM and frame relay is speed
  - ATM is capable of speeds up to 622 Mbps while frame relay's maximum is typically 45 Mbps

Asynchronous Transfer Mode (ATM) (continued)

- Similar to frame relay, data travels over a connection called a virtual channel connection (VCC)
- To better manage VCCs, a VCC must travel over a virtual path connection (VPC)
- One of ATM's strengths (besides its high speeds) is its ability to offer various classes of service

ATM Classes of Service

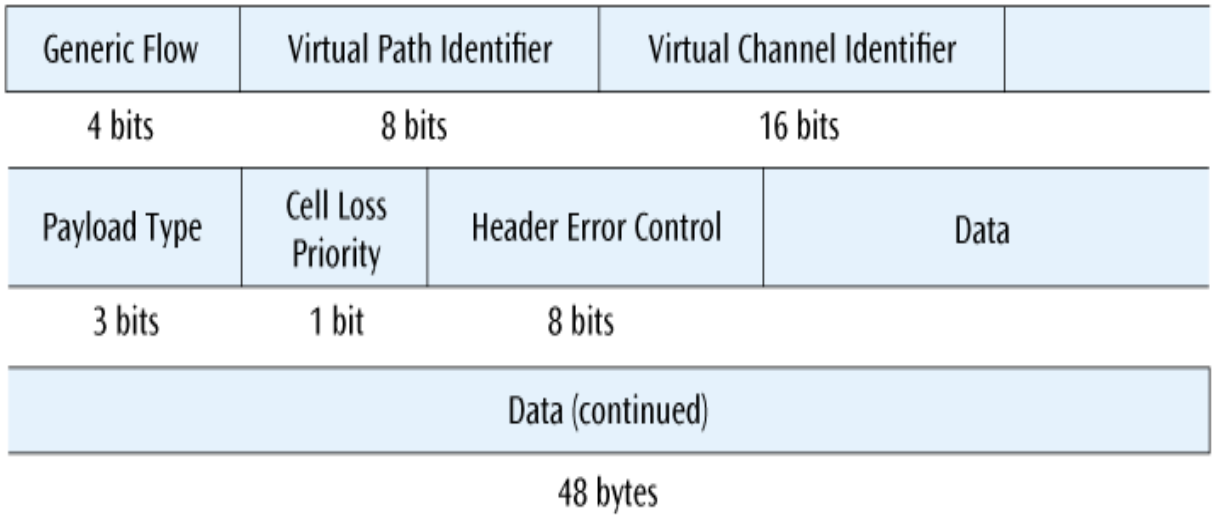
- If a company requires a high-speed, continuous connection, they might consider a constant bit rate service (CBR). CBR customers get first access to ATM “pipe”.
- A less demanding service is variable bit rate (VBR). VBR customers are allowed on the ATM “pipe” right after CBR customers
  - VBR can also support real-time applications (rt-VBR), as well as non-real-time applications (nrt-VBR), but do not demand a constant bit stream

ATM Classes of Service (continued)

- Available bit rate (ABR) is used for bursty traffic that does not need to be transmitted immediately
  - ABR traffic may be held up until a transmission opening is available
- Unspecified bit rate (UBR) is for lower rate traffic that may get held up, and may even be discarded part way through transmission if congestion occurs

ATM Cell Composition

Figure 11-10
The 53-byte ATM cell with its individual fields



Advantages and Disadvantages of ATM

- Advantages of ATM include very high speeds and the different classes of service
- Disadvantages include potentially higher costs (both equipment and support) and a higher level of complexity

MPLS and VPNs

- Frame relay and ATM are declining in popularity due to more people using the Internet
- But you can't just send potentially important data over the Internet without doing something first
- One thing businesses are doing is applying MPLS labels to the IP packets
- The use of MPLS routes data packets quickly through the Internet
- And as we have also seen, VPNs (virtual private networks) create secure tunnels

Comparison of DSL, Cable Modems, Frame Relay, and ATM

	Typical Maximum Speeds	Cost per Month	Switchable or Fixed	QoS
DSL-consumer	~600 kbps	~$30	Fixed	No
DSL-business	~7 Mbps	$100s	Fixed	No
Cable modem	~1.5 Mbps	~$35	Fixed	No
T-1	1.544 Mbps	$100s (local)	Fixed	No
Frame relay	45 Mbps	$100s–$1000s	Both	No
ATM	622 Mbps	$100s–$1000s	Both	Yes
MPLS/VPN	*	~$100s	Both	Yes

*Depends on connection to Internet

Convergence

- Big issue in the voice and data delivery industry
- Phone companies are buying other phone companies
- Older technologies are falling by the wayside as newer technologies take over a larger share of the market
- Newer devices are incorporating multiple applications
- Computer telephony integration is one large example of convergence

Computer-Telephony Integration (CTI)

- Field that combines more traditional voice networks with modern computer networks
- Consider a system in which a customer calls a customer support number
  - The customer's telephone number appears on the customer support rep's terminal and immediately pulls up the customer's data
  - The rep answers the phone by clicking on an icon on the screen and helps the customer
  - The rep transfers the call by clicking on another icon on the computer screen

Computer-Telephony Integration (CTI) (continued)

- CTI can also integrate voice cabling with data cabling
- The company PBX talks directly to the LAN server
  - The PBX can direct the LAN server to provide a telephone operation to the user through the user's computer
- The telephones may still be connected to the PBX or they may be connected to the LAN via the LAN wiring

Computer-Telephony Integration (CTI) (continued)

- CTI applications could include the following:
  - Unified messaging
  - Interactive voice response
  - Integrated voice recognition and response
  - Fax processing and fax-back
  - Text-to-speech and speech-to-text conversions

Computer-Telephony Integration (CTI) (continued)

- CTI applications could include the following: (continued)
  - Third-party call control
  - PBX graphic user interface
  - Call filtering
  - Customized menuing systems

Unified Communications

- Just as CTI is a convergence of multiple technologies and applications, unified communications is the convergence of real-time and non-real-time communications
- For example, convergence of telephony, instant messaging, video conferencing, voice mail, e-mail, and presence information into one or more applications

Telecommunication Systems In Action: A Company Makes a Service Choice

- Better Box Corporation has offices in Seattle, San Francisco, and Dallas, with headquarters in Chicago
- Better Box wants to connect Chicago to each of the other three offices
- Better Box needs to download 400k byte files in 20 seconds
  - This requires a transmission speed of 160,000 bps

Telecommunication Systems In Action: A Company Makes a Service Choice (continued)

- What could Better Box use for communications?
  - 56kbps dial-up?
  - T-1?
  - Frame relay?
  - ATM?
  - MPLS/VPN over the Internet?

Telecommunication Systems In Action: A Company Makes a Service Choice (continued)

- 56 kbps lines are too slow for our application
- T-1s, frame relay, and ATM appear to be viable choices
- We should be able to create a VPN using MPLS over the Internet

Telecommunication Systems In Action: A Company Makes a Service Choice (continued)

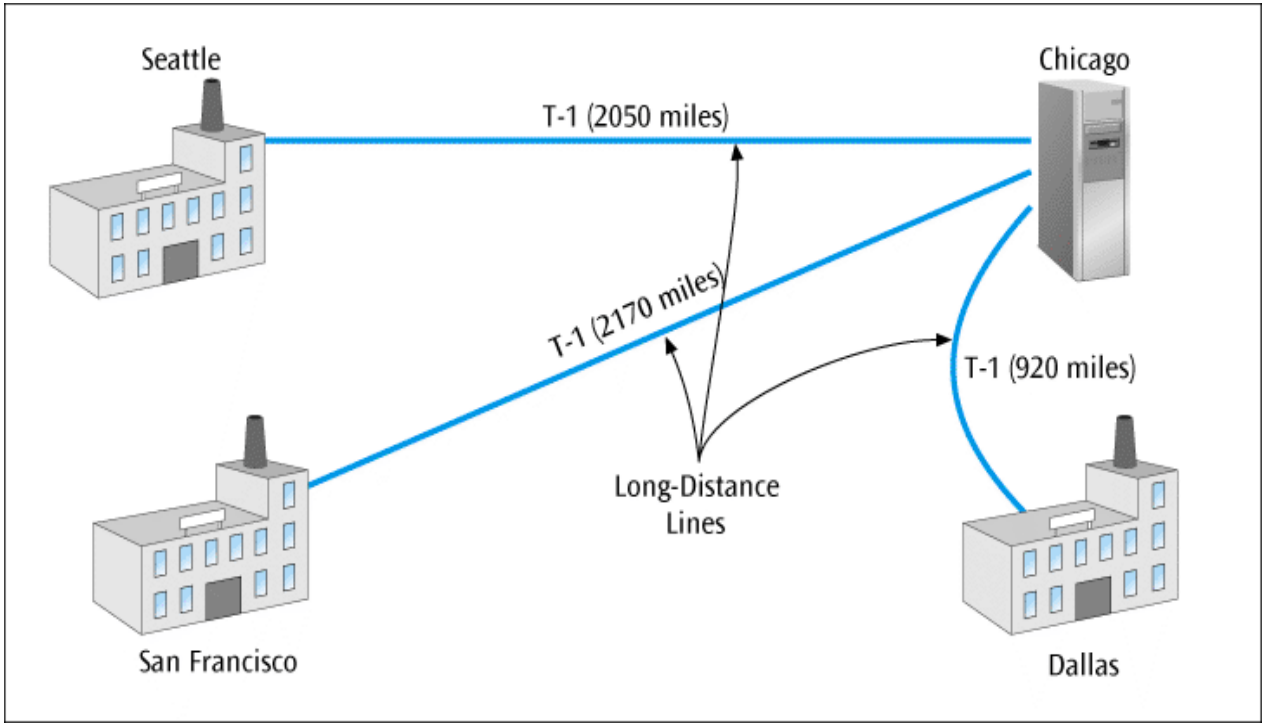


Figure 11-11
Three T-1 lines connecting the three regional offices to Chicago

Telecommunication Systems In Action: A Company Makes a Service Choice (continued)

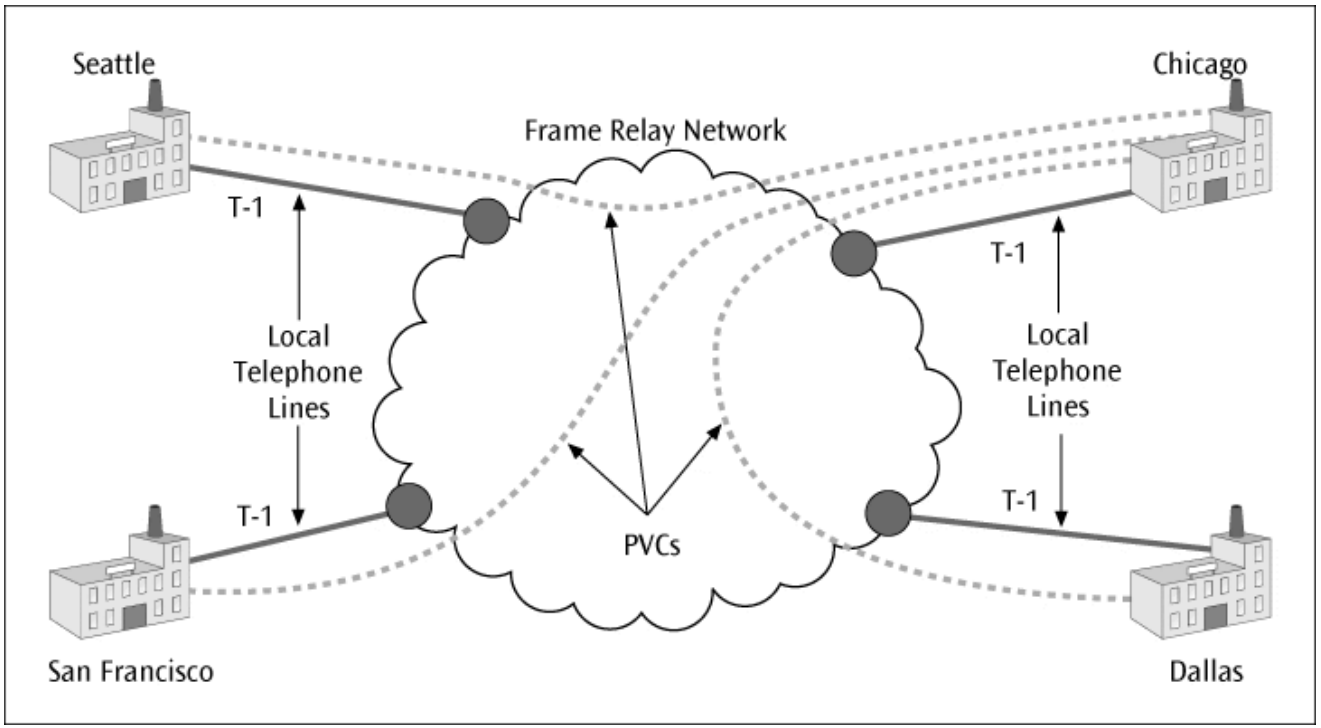


Figure 11-12
Four cities connected to the frame relay cloud

Telecommunication Systems In Action: A Company Makes a Service Choice (continued)

- Typical various prices for these services are shown on the next table

Telecommunication Systems In Action: A Company Makes a Service Choice

Type of Service	Speed	Per-Month Cost (Approximate)
POTS	~53 kbps	$20
T-1 (local-distance)	1.544 Mbps	$350
T-1 (long-distance)	1.544 Mbps	$1200 + $2.50 per mile
Frame Relay port	56 kbps	$220
	128 kbps	$400
	256 kbps	$495
	512 kbps	$920
	768 kbps	$1240
	1.544 Mbps	$1620
Frame Relay PVC	56 kbps	$60
	128 kbps	$110
	256 kbps	$230
	512 kbps	$410
	1024 kbps	$1010
	1.544 Mbps	$1410
ATM CBR port	1.544 Mbps	$2750
	3 Mbps	$3400
ATM ABR port	1.544 Mbps	$1750
	3 Mbps	$2400
ATM PVC path		$2 per mile
ATM PVC channel		$250 per channel (no mileage charge)
MPLS/VPN	Depends on link to ISP	$1000 initial hardware per port plus $375 per month ISP charge

Telecommunication Systems In Action: A Company Makes a Service Choice (continued)

- To provide T-1 service to all four offices:
  - Seattle to Chicago: $6325 ($1200 + $2.50 per mile)
  - San Francisco to Chicago: $6625
  - Dallas to Chicago: $3500
  - Total interLATA T-1 costs = $16,450 / month

Telecommunication Systems In Action: A Company Makes a Service Choice (continued)

- To provide frame relay service:
  - Three ports at 256K = 3 x $495
  - One port in Chicago at 512K = $920
  - Three 256K PVCs = 3 x $230
  - Four intraLATA T-1s = 4 x $350
  - Total charge = $4495 / month

Telecommunication Systems In Action: A Company Makes a Service Choice (continued)

- To provide asynchronous transfer mode service:
  - Four ports at 1.544 Mbps ABR = 4 x $1750
  - Three channels = 3 x $250
  - Three paths = $2 per mile x 5140 miles = $10,280
  - Four intraLATA T-1s = 4 x $350
  - Total ATM charges = $19,430 / month

Telecommunication Systems In Action: A Company Makes a Service Choice (continued)

- To provide MPLS/VPN solution:
  - Initial VPN cost of $1000 per gateway per port = 4 x $1000
  - Monthly charge of ISP connection at each port = 4 x $375
  - Monthly charge of local-distance T-1 at each location = 4 x $350
  - Monthly charge of $2900 per month after initial $4000 fee

Summary

- The basic telephone system that covers the U.S. is called plain old telephone service (POTS) and is a mix of analog and digital circuits
- Divestiture of AT&T in 1984 opened the long-distance telephone market to other long-distance providers, forced AT&T to sell off its local telephone companies, and divided the country into local access transport areas (LATAs)
- A PBX is an on-premise computerized telephone switch that handles all internal and outgoing telephone calls and offers a number of telephone services

Summary (continued)

- A Centrex offers same services as PBX, but equipment resides on telephone company's property, and business leases the service
- Telecommunications Act of 1996 opened local telephone service to new competitors and required existing local telephone companies to provide these competitors with access to local telephone lines
- Leased lines are established by communications service provider and serve as permanent, private connections between two locations
- Data rate of dial-up modems using voice-grade telephone lines has peaked a little less than 56,000 bits per second.

Summary (continued)

- Technologies such as digital subscriber line (DSL) and cable modems have improved data transfer rates available between homes and businesses and Internet service providers
- T-1 service provides a digital connection of 1.544 Mbps between a company and a service provider
- Frame relay is service that provides digital data transfer over long distances and at high data transfer rates (<45 Mbps)
- Asynchronous Transfer Mode (ATM) is also a packet-switched service, but it supports all types of traffic and can operate at speeds faster than either T-1 or frame relay
- Computer-telephony integration and unified communications are examples of convergence of data communications networks and voice systems