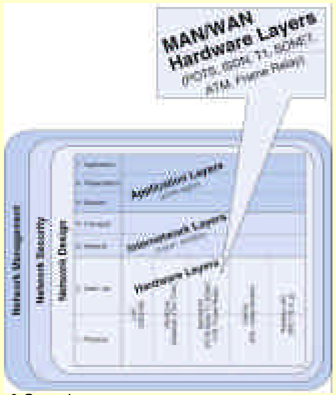
Chapter 6
Hardware Layers: Metropolitan and Wide Area Networks



Networking in the Internet Age

by Alan Dennis

2

Chapter 6. Learning Objectives

- Understand circuit-switched services and topologies
- Understand dedicated-circuit services and topologies
- Understand packet-switched services and topologies
- Be familiar with virtual private network services and topologies
- Understand the best practice recommendations for MAN/WAN design

3

Chapter 6. Outline

- **Introduction**
- **The Public Switched Telephone Network**
  - PSTN Architecture, Analog Transmission, Digital Transmission of Analog Voice Data, Multiplexing
- **Circuit Switched Networks**
  - Topology, POTS, ISDN
- **Dedicated Circuit Networks**
  - Topology, T-Carriers, SONET
- **Packet Switched Networks**
  - Topology, X.25, ATM, Frame Relay, SMDS, Ethernet/IP Packet Networks
- **Virtual Private Networks**
  - Topology, VPN Types
- **The Best Practice MAN/WAN Design**

4

Introduction

5

Introduction

- Metropolitan area networks (MANs) typically span from 3 to 30 miles and connect backbone networks (BNs), and LANs.
- Wide area networks (WANs) connect BNs and MANs across longer distances, often hundreds of miles or more.
- Most organizations cannot afford to build their own MANs and WANs, so they rent or lease circuits from ***common carriers*** such as AT&T, BellSouth or Ameritech.
- The combination of their networks is referred to as the ***public switched telephone network (PSTN).***

6

The Public Switched Telephone Network

7

The Telephone Network

- Many countries have government agencies that regulate data and voice communications.
- The United States agency is the ***Federal Communications Commission (FCC).*** Each US state also has its own ***public utilities commission (PUC)*** to regulate communications within its borders.
- A ***common carriers*** are private companies that sell or lease communications services and facilities to the public.
- Those providing local telephone services are called ***local exchange carriers (LECs),*** while those providing long distance services are called ***interexchange carriers (IXCs).***
- As telecommunications services are being deregulated, the differences between these two are disappearing.

8

PSTN Architecture (Figure 6-1)

- Unlike LANs and other data networks, the PSTN is circuit switched.
- During the set up portion of a telephone call, a special circuit is created, which is then torn down when the call is completed.
- Originally, the entire telephone network was analog, but it is now mostly digital.
- The digital parts include the switches and backbone lines between them (called trunk lines).
- The connection between the customer premises equipment and the first telephone switch, called the local loop, is still analog.

9

Figure 6-1 Public switched telephone network 10

Sound Waves (Figure 6-2)

- Sound is converted into electricity by a telephone and then transmitted as an analog signal.
- These waves have 3 fundamental characteristics:
  - ***Amplitude***, meaning the height (intensity) of the wave
  - ***Frequency***, which is the number of waves that pass in a single second and is measured in Hertz (cycles/second) (***wavelength***, the length of the wave from crest to crest, is related to frequency.).
  - ***Phase*** is a third characteristic that describes the point in the wave's cycle at which a wave begins and is measured in degrees. (For example, changing a wave's cycle from crest to trough corresponds to a 180 degree phase shift).

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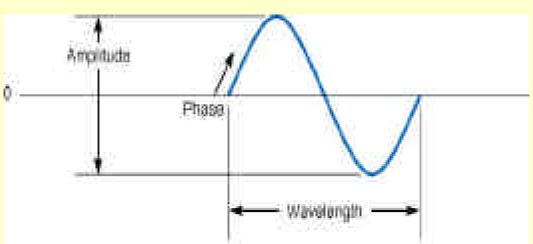

Figure 6-2 Sound wave

12

Modulation

- ***Modulating*** a wave means changing one or more of its fundamental characteristics to encode information.
- The unmodulated wave used for this is called a carrier wave.
- There are three basic ways to modulate a carrier wave:
  - Amplitude Modulation
  - Frequency Modulation
  - Phase Modulation

13

Amplitude Modulation

- ***Amplitude Modulation*** (AM), also called Amplitude Shift Keying (ASK), means changing the height of the wave to encode data.
- Figure 6-3a shows a simple case of amplitude modulation in which one bit is encoded for each carrier wave change.
  - A high amplitude means a bit value of 1
  - Zero amplitude means a bit value of 0

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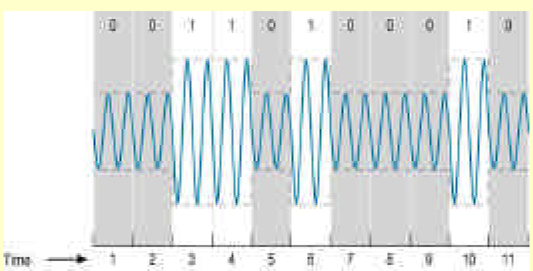

Figure 6-3a Amplitude modulation

15

Sending Multiple Bits Symbol

- Each modification of the carrier wave to encode information is called a ***symbol***
- By using a more complicated information coding system, it is possible to encode more than 1 bit/symbol.
- Figure 6-3b gives an example of amplitude modulation using 4 amplitude levels, corresponding to 2 bits/symbol.
- Increasing the possible number of symbols from 4 to 8 corresponds with encoding 3 bits/symbol, 16 levels to 4 bits, and so on.

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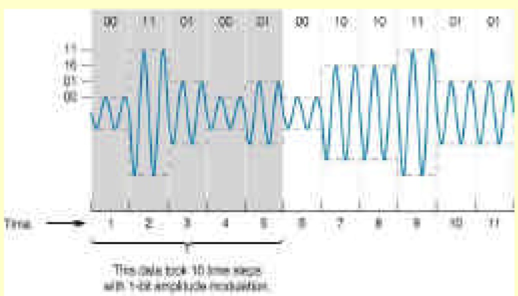

Figure 6-3b Two-bit amplitude modulation

17

Frequency Modulation

- ***Frequency Modulation*** (FM), also called Frequency Shift Keying (FSK), means changing the frequency of the carrier wave to encode data.
- Figure 6-4 shows a simple case of frequency modulation in which one bit is encoded for each carrier wave change.
  - Changing the carrier wave to a higher frequency encodes a bit value of 1
  - No change in the carrier wave frequency means a bit value of 0

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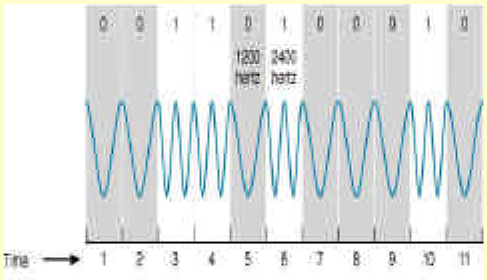

Figure 6-4 Frequency Modulation

19

Phase Modulation

- ***Phase*** refers to the point in each wave cycle at which the wave begins. ***Phase Modulation*** (PM) or Phase Shift Keying (PSK) means changing the carrier wave's phase to carry data.
- Figure 6-5 shows a simple case of phase modulation in which one bit is encoded for each carrier wave change.
  - A 180° phase shift corresponds to a bit value of 1
  - No phase shift means a bit value of 0
- Two bits per symbol could be encoded using phase modulation using 4 phase shifts such as 0°, 90°, 180° and 270°.

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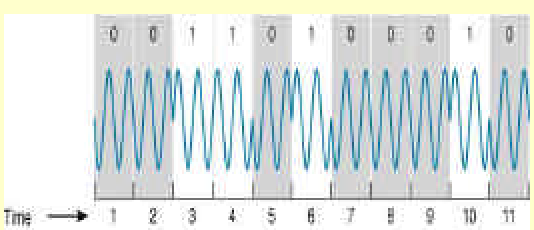

Figure 6-5 Phase Modulation

21

Quadrature Amplitude Modulation (QAM)

- ***QAM*** is a widely used encoding schemes that encodes multiple bits per symbol by combining amplitude and phase modulation.
- Symbols are also chosen to minimize the chance they might be mistaken for another one.
- For example, two symbols with similar phase shifts and the same amplitude could be mistaken for one another.
- ***Trellis coded modulation (TCM)*** takes this idea further by adding increasing the number of bits per symbol, then restricting the use of symbols that might be mistaken for one another, greatly reducing the error rate created by noise.

22

Digital Transmission of Analog Voice

- The analog voice signal created by the sender's telephone is converted a digital signal using a ***codec*** (**co**der/**dec**oder).
- A second codec later converts the digital signal back to an analog one at the receiver's end.
- The codec converts the incoming analog signal to a digital signal by taking repeated samples of the analog signal (see Figure 6-6).
- Each sample is then rounded off to a whole number and then encoded as a binary number.
- The resulting stream of binary values is sent as a digital transmission over the telephone network.

23

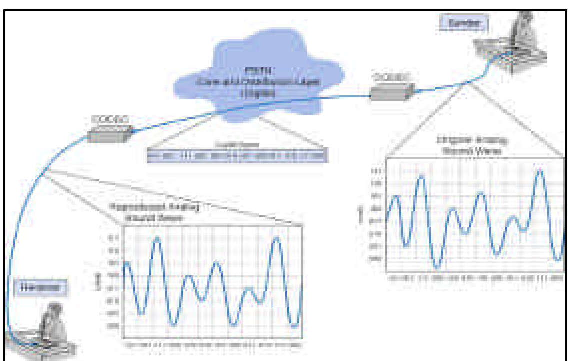

Figure 6-6 Pulse amplitude modulation (PAM)

24

How Telephones Transmit Voice

- The telephone network uses a digitization technique called ***Pulse Code Modulation (PCM).***
- PCM samples the incoming analog signal 8000 samples/second using 8 bit samples.
- The resulting 64,000 bits per second signal, called a DS-0, that is used throughout the telephone network to send digital transmissions of voice transmissions.

25

How Instant Messenger Transmits Voice (Technical Focus 6-1)

- Instead of PCM, ***Instant Messaging*** uses an alternative technique called ***ADPCM***, adaptive differential pulse code modulation.
- ADPCM encodes the differences between samples. Instead of 8 bits/sample, ADPCM uses only 4 bits/sample, generally at 8000 samples/second. This allows a voice signal to be sent at 32 kbps, which makes it possible to for IM to send voice signals as digital signals using POTS-based analog phone lines.
- ADPCM can sample at lower rates of 8 or 16 kbps, but these produce lower quality voice signals.

26

Multiplexing (Figure 6-7)

- Multiplexing combining several lower speed circuits into a higher speed one.
- The advantage to is that multiplexing is cheaper since fewer network circuits are needed.
- ***Inverse Multiplexing,*** is works in the opposite way, and breaks up a higher speed circuit into two or more lower speed ones (see Figure 6-7).
- There are four categories of multiplexing:
  - ***Frequency division multiplexing*** (**FDM**)
  - ***Time division multiplexing*** (**TDM**)
  - ***Statistical time division multiplexing*** (**STDM**)
  - ***Wavelength division multiplexing*** (**WDM**)

27

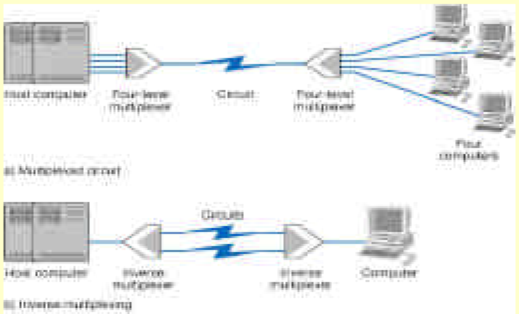

Figure 6-7 Multiplexed circuit and inverse multiplexing

28

Frequency Division Multiplexing (FDM)

- FDM works by making a number of smaller channels from a larger frequency band. FDM is sometimes referred to as dividing the circuit "horizontally".
- In order to prevent interference between channels, unused frequency bands called ***guardbands*** are used to separate the channels. Because of the use of guardbands, there is also significant wasted capacity on an FDM circuit.
- CATV uses FDM. FDM was also commonly used to multiplex telephone signals before digital transmission became common and is still used on some older transmission lines.

29

Time Division Multiplexing (TDM)

- TDM allows multiple channels to be used by allowing the channels to send data by taking turns. TDM is sometimes referred to as dividing the circuit "vertically."
- With TDM, time on the circuit is shared equally with each channel getting a specified time slot, whether or not it has any data to send.
- TDM is more efficient than FDM, since TDM doesn't use guardbands, so the entire capacity can be divided up between the data channels.

30

Statistical Time Division Multiplexing (STDM)

- STDM is designed to make use of the idle time created when terminals are not using the multiplexed circuit.
- Like regular TDM, STDM uses time slots, but the time slots are not fixed. Instead, they are used as needed by the different terminals on the multiplexed circuit.
- Since the source of a data sample is not identified by the time slot it occupies, additional addressing information must be added to each sample.
- If all terminals try to use the multiplexed circuit intensively, response time delays can occur. The multiplexer also needs to contain memory to store data in case more data samples come in than its outgoing circuit capacity can handle.

31

Wavelength Division Multiplexing (WDM)

- With ***Wavelength Division Multiplexing (WDM),*** data is transmitted at several different frequencies over the same optical fiber, typical transmitted at 622 Mbps.
- A new version of WDM, ***Dense WDM*** or ***DWDM*** permits up to 40 circuits, with each transmitting at a rate of 10 Gbps, making single fiber aggregate data rates of 400 Gbps possible.
- Recently, a new version of DWDM has been announced capable of carrying 128 circuits at 10 Gbps, or an aggregate transmission rates of 1.28 Terabits per second.

32

Circuit-Switched Networks

33

Circuit-Switched Networks

- The oldest and simplest MAN/WAN approach.
- Circuits provided by common carriers like AT&T and Ameritech using the PSTN.
- An example of a switched circuit is using a modem to dial-up and connect to an ISP.
- Two basic types in use today are: POTS and ISDN.

34

Circuit-Switched Network Topology

- Uses a cloud architecture, meaning that users connect to a network and what happens inside of the network "cloud" is hidden from the user (see Figure 6-8).
- A user using a computer and a modem dials the number of a another computer and creates a temporary circuit between the two.
- When the communications session is completed, the circuit is disconnected.

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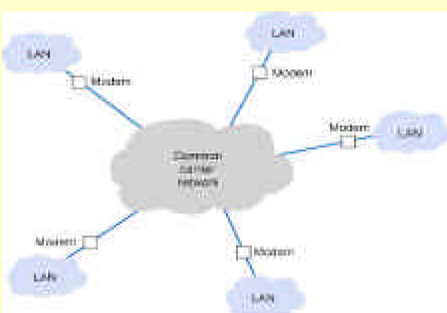

Figure 6-8 Circuit-switched service

36

Advantages and Disadvantages of Circuit-Switched Networking

- The advantages of circuit switched networks are that they are simple, flexible, and inexpensive when not used extensively.
- There are two main problems with dialed circuits.
  - Each connection goes through the regular telephone network on a different circuit, which vary in quality.
  - Data transmission rates are low, from 28.8 to 56 Kbps.
- An alternative is to use a private dedicated circuit, which is leased from a common carrier for the user's exclusive use 24 hrs/day, 7 days/week.

37

Plain Old Telephone Service (POTS)

- ***POTS***-based data communications just uses regular dial-up phone lines and a modem.
- The modem is used to call another modem. Once a connection is made, data transfer can begin.
- POTS is most commonly used today to connect to the Internet by calling an ISP's access point.
- The most commonly used data link layer protocol for POTS is ***Point-to-Point Protocol (PPP)*** developed in the early 1990s for data transfer over a POTS line.

38

Point-to-Point Protocol (PPP)

- PPP uses a half duplex stop media access control protocol.
- The modem waits for the other modem to stop transmitting before trying to transmit itself.
- Continuous ARQ is the error control method.
- Frame structure (see Figure 6-9):
  - The frame begins and ends with a flag (01111110)
  - The address and control fields are fixed
  - The protocol field specifies the network layer protocol (e.g., IP, IPX)
  - The message field can be up to 1,500 bytes in length
  - CRC-16 is used for the error detection value

39

Flag (1 byte)	Address (1 byte)	Control (1 byte)	Protocol (2 bytes)	Message (variable)	CRC-16 (2 bytes)	Flag (1 byte)

Figure 6-9 Point-to-Point Protocol (PPP).
CRC = cyclic redundancy check.

40

Modem Transmission of Data

- As previously discussed, modems convert digital data from a computer into analog data for transmission over the analog local loop.
- The V-series of modem standards are those approved by the ITU-T standards group.
  - V.22, an early standard, had a 2400 bps bit rate
  - V.34, one of the robust V standards, includes multiple data rates (up to 28.8 kbps) and a ***handshaking*** sequence that tests the circuit and determines the optimum data rate. V.34+ increases the max. to 33.6 kbps

41

V.90 and V.92 Modems

- "56K" modems, the fastest possible on voice grade lines, use the V.90 and V.92 standards.
- Downstream transmissions (from phone switch to the user's computer) use a technique based on recognizing PCM's 8-bit digital symbols instead of carrier wave modulation.
- With the V.90 standard, upstream transmissions are still based on the V.34+ standard. The V.92 standard uses this PCM symbol recognition technique for both up and downstream channels.
- The technique is very sensitive to noise and both V.90 and V.92 modems often must use lower data rates. The max. V.92 upstream rate is 48 kbps.

42

Data Compression

- ***Data compression*** works by encoding redundancies in the outgoing data stream in a simpler form, then decoding them at the receiving end of the transmission.
- The V.42bis and V.44 use Lempel-Ziv compression. Lempel-Ziv encoding compresses creates a dictionary of 2-4 byte patterns, then transmits short codes for those patterns.
- The usually results in from 4:1 to 6:1 compression.
- With modest errors and reasonable compression, a V.90 modem at 56 kbps can have an effective data rate between 200-300 kbps using V.42bis or V.44.

43

Integrated Services Digital Network (ISDN)

- Narrowband ISDN, combines voice, video, and data over the same digital circuit. Acceptance has been slow due to a lack of standardization and relatively high costs.
- ISDN operates over digital dial-up lines that work much like analog lines. An "ISDN modem" is used which transmits digital signals.
- Narrowband ISDN offers two types of service:
  - Basic rate interface (BRI, basic access service or 2B+D) provides two 64 Kbps bearer 'B' channels and one 16 Kbps control signaling 'D' channel. One advantage of BRI is it can be installed over existing telephones lines (if less than 3.5 miles).
  - Primary rate interface (PRI, primary access service or 23B+D) provides 23 64 Kbps 'B' channels and one 64 Kbps 'D' channel (basically T-1 service).

44

Broadband ISDN

- Broadband ISDN (B-ISDN) is a circuit-switched service that uses ATM to move data.
- B-ISDN is backwardly compatible with ISDN.
- Three B-ISDN services are currently offered:
  - Full duplex channel at 155.2 Mbps
  - Full duplex channel at 622.08 Mbps
  - Asymmetrical service with two simplex channels (Upstream: 155.2 Mbps, downstream: 622.08 Mbps)

45

Dedicated-Circuit Networks

46

Dedicated-Circuit Networks (Fig. 6-11)

- Dedicated-circuits involve leasing circuits from common carriers to create point to point links between organizational locations.
- These points are then connected together using special equipment such as routers and switches.
- Dedicated-circuits are billed at a flat fee per month for which the user has unlimited use of the circuit.
- Dedicated-circuits therefore require more care in network design than dialed circuits.
- The three basic dedicated circuit architectures are ***ring***, ***star***, and ***mesh*** architectures.

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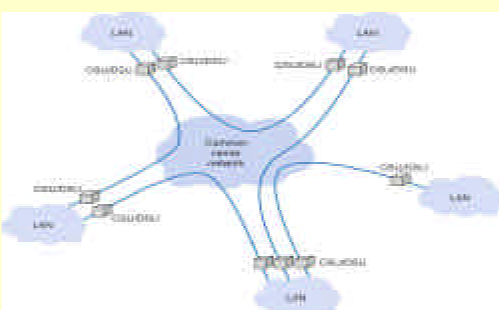

Figure 6-11 Dedicated-circuit services. CSU = channel service unit; DSU = data service unit 48

Ring Topology (Figure 6-12)

- In a ring topology, computers are in a closed loop, with each computer linked to the next.
- Since dedicated circuits are full duplex, data can flow in both directions.
- One disadvantage of a ring topology is that messages need to travel through many nodes before reaching their destination.
- Failure of any part of the ring does not stop the ring from functioning, since messages can be rerouted around the failed link. This can, however, dramatically reduce network performance.

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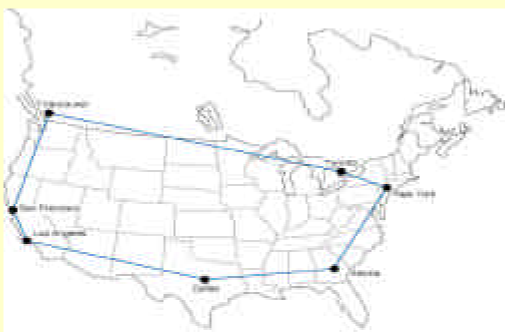

Figure 6-12 Ring-based design

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Star Topology (Figure 6-13)

- A star-based WAN design connects all computers to a central routing computer that relays messages to their destination, usually using a series of point-to-point dedicated circuits.
- The star is easy to manage since the central computer receives and routes all messages in the networks.
- The need for the central computer to route all messages means it can also become a bottleneck under high traffic conditions.
- The failure of any one circuit or computer generally only affects the computer on that circuit.

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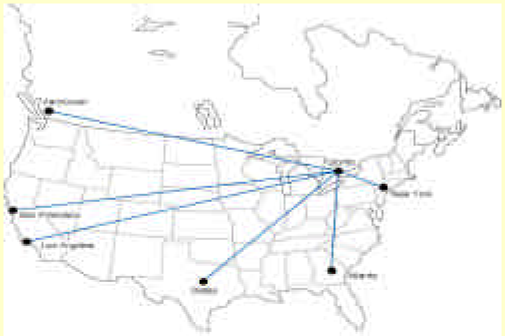

Figure 6-13 Star-based design

52

Mesh Topology (Figure 6-14)

- Mesh architectures can use either a full or partial mesh.
- Because creating a full mesh network is so expensive, generally speaking, only partial mesh networks are set up. As long as there are alternative routes on the network, the impact of losing a circuit on the mesh is minimal.
- Mesh networks combine the performance benefits of both ring and star networks and use decentralized routing, with each computer performing its own routing.
- Setting up the many alternate routes between computers on a mesh network means that creating a mesh architecture is more expensive than setting up a star or ring network.

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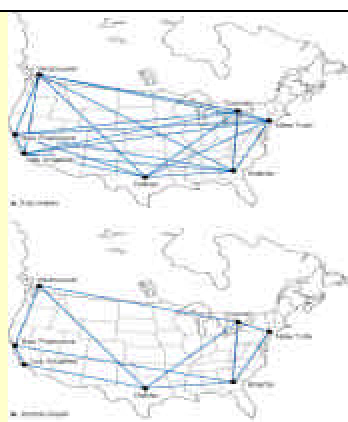

Figure 6-14
Mesh Designs

T-Carrier Services

- T-Carrier circuits are the most common dedicated digital circuits used in North America today.
- The basic unit of the T-hierarchy is the 64 kbps DS-0 created by digitizing an analog voice channel using PCM.
- T-carriers are created by combining a number of DS-0 signals using time division multiplexing along with some overhead information to create a higher speed data stream.

55

The T-1 Carrier

- The lowest level of the T-carrier hierarchy is the T-1, created by combining 24 DS-0 signals.
- A T1 multiplexer combines the 8-bit samples from 24 DS-0 channels along with one framing bit to create the 193 bit T1 frame (see Figure 6-15).
- This frame is then transmitted 8000 time per second, resulting in a nominal data rate of 193 x 8000 = 1.544 Mbps for a T1 carrier.

56

Figure 6-15 T1 data transfer with multiplexing

57

Inverse Multiplexing with a T-1C Carrier

- A T1C circuit is an inverse multiplexed bundle of two T1 circuits.
- Each T1C circuit provides a nominal data rate of 3.152 Mbps.
- The sending T1C mux transmits the signal by splitting it up between two T1 circuits (see Figure 6-16).
- The receiving mux then recombines the incoming data streams from both T1 circuits.

58

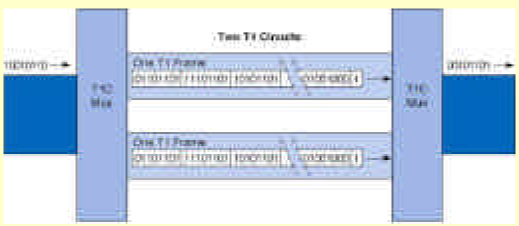

Figure 6-16 T1C data transfer with inverse multiplexing

59

The T-Carrier Hierarchy (Figure 6-17)

- T-Carrier circuits include:
- ***T-1 circuit*** (a.k.a. DS-1) has a data rate of 1.544 Mbps. T-1's allow 24 simultaneous 64 Kbps channels which transport data or voice messages using PCM.
- ***T-2*** (6.312 Mbps) multiplexes four T-1 circuits.
- ***T-3*** (44.376 Mbps) has a 28 T-1 capacity.
- ***T-4*** (274.176 Mbps) has a 178 T-1 capacity.
- ***Fractional T-1***, (FT-1) offers a portion of a T-1.

60

Digital Signal Name	T-Carrier Name	No. of DS-1 Channels	Nominal Data Rate	Effective Data Rate
DS-0			64 kbps	53 kbps
DS-1	T-1	1	1.544 Mbps	1.3 Mbps
DS-1C	T-1C	2	3.152 Mbps	2.6 Mbps
DS-2	T-2	4	6.312 Mbps	5.2 Mbps
DS-3	T-3	28	33.375 Mbps	36 Mbps
DS-4	T-4	168	274.176 Mbps	218 Mbps

Figure 6-17 Types of T-carrier services

61

E-Carrier Name	No. of E-1 Channels	Nominal Data Rate	Effective Data Rate
E-1	1	2.048 Mbps	1.7 Mbps
E-2	4	8.448 Mbps	6.8 Mbps
E-3	16	34.368 Mbps	27 Mbps
E-4	64	139.264 Mbps	109 Mbps
E-5	256	565.148 Mbps	438 Mbps

Figure 6-18 Types of E-carrier services

(Used in place of T-carriers in Europe, South America, Africa and most of Asia).

62

Synchronous Optical Network (SONET) (Figure 6-19)

- The ***synchronous optical network (SONET)*** has recently been accepted by ANSI as the standard for optical fiber transmission for speeds in the gigabit per second range.
- ***Optical carrier 1 (OC-1)*** frames are 810 bytes long and transmitted at 8000 frames/second resulting in a transmission speed of 51.84 Mbps.
- Each succeeding SONET hierarchy rate is defined as a multiple of OC-1.
- Note that even the lowest member of the SONET hierarchy is faster than a T-3 carrier.

63

OC Name	Number of OC-1 Channels	Nominal Data Rate	Effective Data Rate
OC-1	1	51.84 Mbps	48 Mbps
OC-3	3	155.52 Mbps	143 Mbps
OC-12	12	622.08 Mbps	571 Mbps
OC-48	48	2.488 Gbps	2.3 Gbps
OC-192	192	9.953 Gbps	9.1 Gbps
OC-768	798	39.812 Gbps	36.4 Gbps

Figure 6-19 Types of SONET services

64

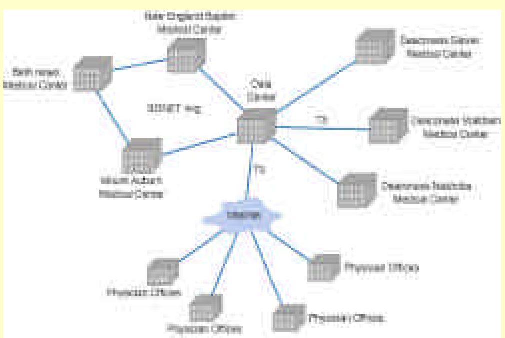

Figure 6-20 CareGroup's MAN & WAN

65

Packet-Switched Networks

66

Packet-Switched Network Topology

- Unlike circuit-switched and dedicated-circuit networks, packet-switched networks enable multiple connections to exist simultaneously between computers.
- A packet-switched user connects to the network using ***packet assembly/ disassembly device (PAD)*** (Fig. 6-21).
- Packets may also become ***interleaved*** with packets from other messages during transmission.
- Organizations usually connect to a packet network by leasing dedicated circuits from their offices to the packet switched network's ***point-of-presence (POP)*** .

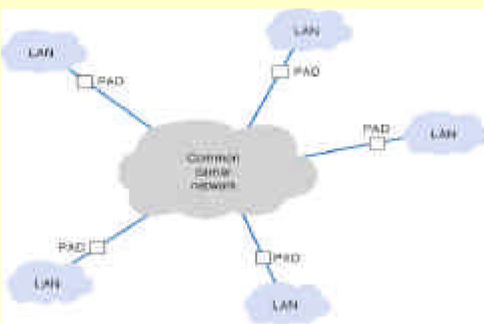

Figure 6-21 Packet-switched services

Packet Routing Methods

- There are two methods for routing packets:
  - A ***datagram*** is a connectionless service which adds a destination and sequence number to each packet, in addition to information about the data stream to which the packet belongs. Individual packets can follow different routes before being reassembled on the destination host.
  - In a ***virtual circuit*** the packet switched network establishes an end-to-end circuit between the sender and receiver. All packets for that transmission take the same route over the virtual circuit that has been set up for that transmission.

Permanent and Switched Virtual Circuits

- Two types of virtual circuits, permanent (PVCs) and switched (SVC), are available from common carriers. PVCs are far more common.
- Although established using software, setting up or taking down a PVC takes days or weeks to do.
- Each PVC has two data rates: a ***committed information rate (CIR)***, which is guaranteed and a ***maximum allowable rate (MAR)***, which sends data only when the extra capacity is available.
- Packets sent at rates exceeding the CIR are marked ***discard eligible (DE)***, and discarded if the network becomes overloaded, in which case they may need to be retransmitted.

70

Packet-Switched Service Protocols

- There are five protocols in use for packet-switched services:
  - X.25
  - Asynchronous Transfer Mode (ATM)
  - Frame Relay
  - Switched Multimegabit Data Service (SMDS)
  - Ethernet/IP packet networks

71

X.25

- The oldest packet switched service is ***X.25***, a standard developed by ITU-T.
- X.25 offers datagram, switched virtual circuit, and permanent virtual circuit services.
- X.25 is a ***reliable protocol***, meaning it performs error control and retransmits bad packets (shown in Figure 6-22).
- Although widely used in Europe, X.25 is not in widespread use in North America. The primary reason is the low transmission speed, now 2.048 Mbps (up from 64 Kbps).

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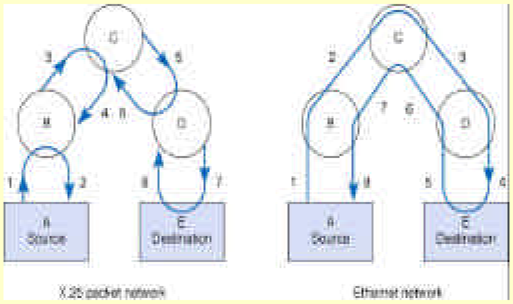

Figure 6-22 Ethernet compared with X.25 packet switching

73

Asynchronous Transfer Mode (ATM)

- Asynchronous transfer mode (ATM) is a newer technology than X. 25.
- ATM for the MAN/WAN environment operates in a similar way to its operation over backbone networks discussed in the last chapter.

74

Asynchronous Transfer Mode (ATM)

- Four differences between ATM and X.25 are:
  - ATM performs encapsulation of packets, so they are delivered unchanged across the network.
  - ATM is ***unreliable***; i.e., it provides no error control, so error control must be handled at another layer (typically by TCP).
  - ATM provides ***quality of service*** information enabling priority setting for different transmissions types (e.g., high for voice, lower for e-mail).
  - ATM is ***scaleable***, since basic ATM circuits are easily multiplexed onto much faster ones.

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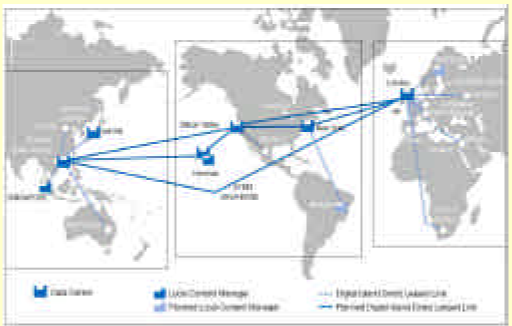

Figure 6-23 Digital Island's WAN

76

Frame Relay

- ***Frame relay*** is a packet switching technology that transmits data faster than X.25 but slower than ATM.
- Like ATM, Frame relay encapsulates packets, so packets are delivered unchanged through the network.
- Also like ATM, Frame relay networks are unreliable (although they are capable of doing error checking, this is not enough to make Frame relay reliable).
- Common carriers offer frame relay with different transmission speeds: 56 Kbps to 45 Mbps.

77

Switched Multimegabit Data Service (SMDS)

- ***Switched multimegabit data service (SMDS)*** is another unreliable packet service like ATM and frame relay.
- Most, but not all, RBOCs offer SMDS at a variety of transmission rates, ranging from 56 Kbps up to 45 Mbps.
- SMDS is not standardized and offers no clear advantages over frame relay.
- For this reason, it is not a widely accepted protocol and offers no advantages over frame relay. Its future is uncertain.

78

Ethernet/IP Packet Networks

- Recently, Internet startups began offering Ethernet/IP services over MAN/WAN networks.
- All other MAN/WAN services; X.25, ATM, Frame Relay and SMDS use different protocols from Ethernet, so data must be translated or encapsulated before it is sent over these networks.
- Companies offering Ethernet/IP have set up their own gigabit Ethernet fiber optic networks in some large cities, bypassing common carrier networks.
- Ethernet/IP packet network services currently offer CIR speeds from 1 Mbps to 1 Gbps at 1/4 the cost of more traditional services.

79

Virtual Private Networks

80

Virtual Private Networks

- *Virtual Private Networks* (VPNs) use PVCs that run over the Internet but appear to the user as private networks (see Figure 6-24).
- Packets sent over these PVCs, called ***tunnels***, are encapsulated using special protocols that also encrypt the IP packets they enclose.
- The growing popularity of VPNs is based on their low cost and flexibility.
- There are two important disadvantages of VPNs:
  - the unpredictability of Internet traffic
  - the lack of standards for Internet-based VPNs, so that not all vendor equipment and services are compatible.

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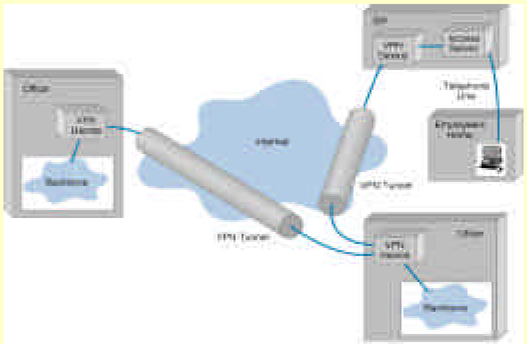

Figure 6-24 A virtual private network (VPN) 82

Basic VPN Architecture (Figure 6-25)

- Each location connected to a VPN is first connected to the ISP providing the VPN service using a leased circuit, such as T-1 line which connects to the ISP's PVCs at ISP access points.
- Outgoing packets from the VPN are sent through specially designed routers or switches.
- The sending VPN device encapsulates the outgoing packet with a protocol used to move it through the tunnel to the VPN device on the other side.
- The VPN device at the receiver, strips off the VPN packet and delivers the packet to the destination network.
- The VPN is transparent to the users, ISP, and the Internet as a whole; it appears to be simply a stream of packets moving across the Internet.

83

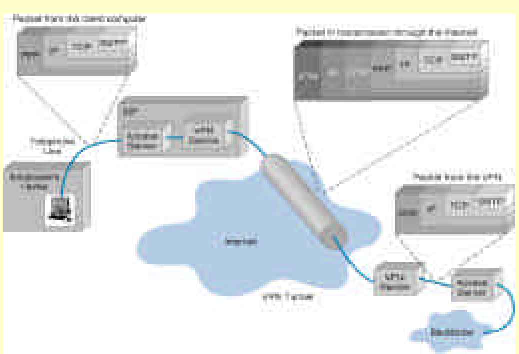

Figure 6-25 VPN encapsulation of packets 84

VPN Types

- Three types of VPN are in common use: intranet VPNs, extranet VPNs and access VPNs.
  - An ***intranet VPN*** provides virtual circuits between organization offices over the Internet.
  - An ***extranet VPN*** is the same as an intranet VPN except that the VPN connects several different organizations, e.g., customers and suppliers, over the Internet.
  - An ***access VPN*** enables employees to access an organization's networks from a remote location.

85

The Best Practice MAN/WAN Design

86

MAN/WAN Recommendations

- For small networks, POTS may still be reasonable alternative
- For moderate volume networks, several choices are popular:
  - VPNs are a good choice when cost is important and reliability is less of an issue.
  - Frame relay is used when demand is unpredictable
  - T-Carriers are used if network demand is predictable
- For high volume networks Ethernet/IP packet networks are becoming the dominant choice.
- Some organizations also may prefer SONET and ATM protocols for their high volume networks.

87

TYPE OF SERVICE	DATA RATES	REL. COST	RELIABILITY	NETWORK INTEGRATION
Circuit Switching				
POTS	33.6-56 kbps	Low	High	Difficult
ISDN	128-1.5Mbps	Moderate	Moderate	Difficult
B-ISDN	155-622 Mbps	High	Low	Difficult
Dedicate Circuit				
T-Carrier	64k-274 Mbps	Moderate	High	Moderate
SONET	50M-10 Gbps	High	High	Moderate
Packet Switching				
X.25	56k-2Mbps	Moderate	High	Difficult
Frame Relay	56k-45Mbps	Moderate	Moderate	Moderate
SMDS	56k-45Mbps	Moderate	Low	Difficult
Ethernet/IP	1M-10Gbps	Low	High	Simple
ATM	52M-10Gbps	High	Moderate	Moderate
VPNs	56k-2Mbps	Very Low	Low	Moderate

Figure 6-26. MAN/WAN services

88

End of Chapter 6

89