**Designing Remote Connectivity**

Connectivity to remote locations such as the Internet, branches, offices, and teleworkers is provided through enterprise edge technologies and the enterprise WAN architecture. Infrastructure support is provided at the remote locations with enterprise branch architectures.

To connect to remote locations, WAN technologies and WAN transport media must be utilized when considering ownership, reliability, and backup issues. In addition, WAN remote access choices include cable and DSL technologies that are used with Virtual Private Networks (VPN). The enterprise branch is a remote location that is smaller than an enterprise campus and can use a simpler architecture.

## Identifying WAN Technology Considerations

The enterprise edge connects campus resources to remote enterprise locations. It can include the WAN, Internet connectivity, remote access, and VPN modules. Many WAN technologies exist today, and new technologies are constantly emerging. The following sections explain the role of a WAN and the requirements necessary for achieving a reliable and efficient WAN design. They also describe the characteristics of the WAN technologies that are currently available.

### Review of WAN Features

A WAN is a communications network that covers a relatively broad geographic area. Most often, a WAN uses the transmission facilities that are provided by service providers (carriers) such as telephone companies. WANs generally carry various traffic types, such as voice, data, and video. A network provider often charges user fees called tariffs for the services that are provided by the WAN. Therefore, WAN communication is often known as a service; some considerations include

* **Service-level agreements (SLA):** Networks carry application information between computers. If the applications are not available to network users, the network is failing to achieve its design objectives. Organizations need to define what level of service, such as bandwidth or allowed latency and loss, is acceptable for the applications that run across the WAN.
* **Cost of investment and usage:** WAN designs are always subject to budget limitations. Selecting the right type of WAN technology is critical in providing reliable services for end-user applications in a cost-effective and efficient manner.

The following are the objectives of an effective WAN design:

* A well-designed WAN must reflect the goals, characteristics, and policies of an organization.
* The selected technology should be sufficient for current and (to some extent) future application requirements.
* The associated costs of investment and usage should stay within the budget limitations.

[Figure 5-1](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390501.jpg')) illustrates ways that WAN technologies connect the enterprise network modules.

[Figure 5-1](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390501.jpg'))

[**Figure 5-1**](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390501.jpg')) Types of WAN Interconnections

Typically, the intent is to provide these results:

* Connectivity between the enterprise edge modules and ISPs
* Connectivity between enterprise sites across the service provider and public switched telephone network (PSTN) carrier network
* Connectivity between enterprise sites across the ISP network

WAN connections can be point-to-point between two locations or a connection to a multipoint WAN service offering, such as a Frame Relay or Multiprotocol Label Switching (MPLS) network. An alternative to WAN connections is a service provider IP network that links the remote sites of an enterprise network. Complete cooperation at the IP layer between the enterprise edge and service provider network is required for this type of connection. DSL and cable are technologies that are frequently used for ISP access for teleworkers and very small offices. This type of network service provides no guarantee of the quality of sessions and is considered a "best effort."

### Comparison of WAN Transport Technologies

Table 5-1 reviews WAN technologies that are based on the main factors that influence technology selection. The table provides baseline information to help compare the performance and features that different technologies offer. The options that service providers offer usually limit technology decisions.

#### Table 5-1. WAN Transport Technology Comparison

| **Technology** | **Bandwidth** | **Latency and Jitter** | **Connect Time** | **Tariff** | **Initial Cost** | **Reliability** |
| --- | --- | --- | --- | --- | --- | --- |
| TDM | M | L[\*](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ch05tn01.html')) | L | M | M | M |
| ISDN | L | M/H | M | M | L | M |
| Frame Relay | L | L | L | M | M | M |
| ATM | M/H | L | L | M | M | H |
| MPLS | M/H | L | L | M | M | H |
| Metro Ethernet | M/H | L | L | M | M | H |
| DSL | L/M[\*\*](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ch05tn02.html')) | M/H | L | L | L | M |
| Cable Modem | L/M[\*\*](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ch05tn03.html')) | M/H | L | L | M | L |
| Wireless | L/M | M/H | L | L | M | L |
| SONET/SDH | H | L | L | M | H | H |
| DWDM | H | L | L | M | H | H |
| Dark Fiber | H | L | L | M | H | H |

#### Time-Division Multiplexing

Time-division multiplexing (TDM) reserves point-to-point connection bandwidth for transmissions indefinitely, rather than using bandwidth only as required. TDM is a type of digital multiplexing in which two or more channels are derived from a given data stream by interleaving pulses representing bits from different channels. For example, a North American T1 circuit is made up of 24 channels that run at 64 kbps, for a total of 1.536 Mbps. When framing overhead is included, the total reaches 1.544 Mbps. A T3 circuit is made up of 28 T1s or 672 channels; including overhead, a T3 circuit provides 44.736 Mbps. Corresponding European standards are the E1 standard, which supports 32 64-kbps channels for a total of 2.04 Mbps, and the E3 standard, which supports 480 64-kbps channels that provides 34.368 Mbps. A carrier can establish a connection in the TDM network by dedicating a channel with the use of TDM. By contrast, packet-switched networks traditionally offer the service provider more flexibility and use network bandwidth more efficiently than TDM networks because the network resources are shared dynamically. Subscribers using TDM are charged an amount based on their guaranteed use of the network.

#### ISDN Connectivity

Integrated Services Digital Network (ISDN) is a system of digital phone connections that has been available as a communications standard since 1984. This system allows voice and data to be transmitted simultaneously across the world using end-to-end digital connectivity. Connectivity over ISDN offers increased bandwidth, reduced call setup time, reduced latency, and lower signal-to-noise ratios than analog dialup. However, the industry is moving from broadband technologies such as DSL, cable, and public wireless to IP Security (IPsec) VPNs. ISDN presents an effective solution solely for remote-user applications, where broadband technologies are not available.

Analog modern dialup or plain old telephone service (POTS) provides data connectivity over the PSTN using analog modems. Dialup supports relatively low-speed connections, while broadband technologies such as DSL, cable, and public wireless are faster. Dialup point-to-point service is typically no longer a cost-effective solution for WAN connectivity. It is only cost-effective as a backup access solution for Internet connectivity in teleworker environments.

#### Frame Relay

Frame Relay is an example of a packet-switched technology for connecting devices on a WAN. Frame Relay has been deployed since the late 1980s. Frame Relay networks transfer data using one of two connection types:

* Permanent virtual circuits (PVC), which are permanent connections
* Switched virtual circuits (SVC), which are temporary connections that are created for each data transfer and are then terminated when the data transfer is complete (not a widely used connection)

#### Multiprotocol Label Switching

MPLS is a switching mechanism that uses labels (numbers) to forward packets. In a normal routed environment, frames pass from a source to a destination on a hop-by-hop basis. Transit routers evaluate the Layer 3 header of each frame and perform a route table lookup to determine the next hop toward the destination. However, MPLS enables devices to specify paths through the network. This is performed by using labels that are based on initial route lookup and classification of quality of service (QoS), as well as bandwidth needs of the applications, while taking into account Layer 2 attributes. MPLS labels can correspond to parameters such as a QoS value, a source address, or a Layer 2 circuit identifier. After a path has been established, packets that are destined to the same endpoint with the same requirements can be forwarded based on these labels, without a routing decision at every hop. Labels usually correspond to a Layer 3 destination address, which makes MPLS equal to destination-based routing. Label switching occurs regardless of the Layer 3 protocol. One of the strengths of MPLS is that it can be used to carry many kinds of traffic, including IP packets, as well as native ATM, SONET, and Ethernet frames. A designer's main objective is to minimize routing decisions and maximize switching use.

#### Metro Ethernet

Metro Ethernet uses Ethernet technology to deliver cost-effective, high-speed connectivity for metropolitan-area network (MAN) and WAN applications. Service providers have started to offer Metro Ethernet services to deliver converged voice, video, and data networking. Metro Ethernet provides a data-optimized connectivity solution for the MAN and WAN based on technology that is widely deployed within the enterprise LAN. Metro Ethernet supports high-performance networks in the metropolitan area, meeting the increasing need for faster data speeds and more stringent QoS requirements. Where traditional TDM access is rigid, complex, and costly to provision, Metro Ethernet services provide scalable bandwidth in flexible increments, simplified management, and faster, lower-cost provisioning. This simple, easy-to-use technology appeals to customers who are already using Ethernet throughout their LANs.

#### DSL Technology

Digital subscriber line (DSL) is a technology that delivers high bandwidth over traditional telephone copper lines. The term xDSL covers a number of similar yet competing forms of DSL. Asymmetric DSL (ADSL) is the most common form of DSL, which utilizes frequencies that normally are not used by a voice telephone call—in particular, frequencies higher than normal human hearing. ADSL can be used only over short distances, typically less than 18,000 ft. The distinguishing characteristic of ADSL over other forms of DSL is that the volume of data flow is greater in one direction than the other; that is, it is asymmetric.

[Figure 5-2](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390502.jpg')) illustrates a typical ADSL service architecture.

[Figure 5-2](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390502.jpg'))

[**Figure 5-2**](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390502.jpg')) ADSL Implementation Example

The network consists of customer premises equipment (CPE), the network access provider (NAP), and the network service provider (NSP):

* The CPE refers to an end-user workstation, such as a PC, together with an ADSL modem or an ADSL transmission unit-remote (ATU-R).
* The NAP provides ADSL line termination by using DSL access multiplexers (DSLAM).
* The DSLAM forwards traffic to the local access concentrator, the NSP, which is used for Layer 3 termination.

An ADSL circuit connects an ADSL modem on each end of a twisted-pair telephone line. This setup creates three information channels:

* Medium-speed downstream channel
* Low-speed upstream channel
* Basic telephone service channel

Filters (splitters) split off the basic telephone service channel from the digital modem. This feature guarantees uninterrupted basic telephone service, even if ADSL fails.

#### Cable Technology

Cable is a technology for data transport that uses coaxial cable media over cable distribution systems. This technology is a good option for environments where cable television is widely deployed.

The Universal Broadband Router (uBR), also referred to as the cable modem termination system (CMTS), provides high-speed data connectivity and is deployed at the cable company head end. The uBR forwards data upstream to connect with either the PSTN or the Internet. The cable modem (also referred to as the cable access router) at the remote location supports voice, modem, and fax calls over the TCP/IP cable network. The uBR is designed to be installed at the head-end facility or distribution hub of a cable operator and to function as the CMTS for subscriber end devices. In general, cable operators install cable modems at the customer premises to support small businesses, branch offices, and corporate telecommuters.

**NOTE**

The Data–over–Cable Service Interface Specifications (DOCSIS) protocol describes data-over-cable procedures that the equipment must support.

#### Wireless Technology

The term wireless describes telecommunications in which electromagnetic waves carry the signal. Common examples of wireless equipment include cellular phones, Global Positioning Systems (GPS), cordless computer peripherals, satellite television, and wireless LANs.

Wireless implementations include the following:

* **Bridged wireless:** Designed to connect two or more networks, typically located in different buildings at high data rates for data-intensive, line-of-sight applications. Building-to-building wireless connects two or more networks that are located in different buildings. A series of wireless bridges or routers can connect discrete distant sites into a single LAN and thus interconnect hard-to-wire sites, discontiguous floors, satellite offices, school or corporate campus settings, temporary networks, and warehouses.
* **Mobile wireless:** Includes cellular applications and others. Mobile cellular wireless technologies are migrating to digital services on wireless. Second- and third-generation mobile phones are migrating to digital services that offer connectivity and higher speeds. There are three widely deployed mobile wireless technologies:
  + **Global System for Mobile Communications (GSM):** A GSM is a digital mobile radio that uses the Time Division Multiple Access (TDMA) technology, which allows eight simultaneous calls on the same RF in three bands: 900, 1800, and 1900 MHz. The transfer data rate is 9.6 kbps. A unique benefit of GSM is its international coverage, allowing the use of a GSM phones almost transparently while traveling abroad, without the need to change any settings or configuration parameters.
  + **General Packet Radio Service (GPRS):** A GPRS extends the capability of GSM speed and supports intermittent and bursty data transfer. Speeds that are offered the client are in the range of ISDN speeds (64 to 128 kbps).
  + **Universal Mobile Telecommunications Service (UMTS):** Also called third-generation (3G) broadband, UMTS provides packet-based transmission of text, digitized voice, video, and multimedia at data rates of up to 2 Mbps. UMTS offers a consistent set of services to mobile computer and phone users, no matter where they are located in the world.
* **Wireless LAN:** Developed to meet the demand for LAN connections over the air. It is often used in intrabuilding connections. Wireless LANs have developed to cover a growing range of applications, such as guest access and voice over wireless. They support services such as advanced security and location of wireless devices.

#### SONET and SDH Technology

Circuit-based services architecture is the basis for SONET and Synchronous Digital Hierarchy (SDH). This technology uses TDM and delivers high-value services over an optical infrastructure. SONET or SDH provides high-speed, point-to-point connections that guarantee bandwidth, regardless of actual usage (for example, common bit rates are 155 and 622 Mbps, with a maximum of 10 Gbps). SONET or SDH rings offer proactive performance monitoring and automatic recovery ("self-healing") through an automatic protection switching (APS) mechanism.

[Figure 5-3](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390503.jpg')) illustrates a typical SONET/SDH implementation example.

[Figure 5-3](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390503.jpg'))

[**Figure 5-3**](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390503.jpg')) SONET/SDH Example

SONET or SDH rings support two IP encapsulations for user interfaces: ATM or Packet over SONET/SDH (POS), which sends native IP packets directly over SONET or SDH frames. Optical Carrier (OC) rates are the digital hierarchies of the SONET standard. They support the following speeds:

* OC-1 = 51.85 Mbps
* OC-3 = 155.52 Mbps
* OC-12 = 622.08 Mbps
* OC-24 = 1.244 Gbps
* OC-48 = 2.488 Gbps
* OC-192 = 9.962 Gbps
* OC-255 = 13.21 Gbps

**NOTE**

SONET and SDH represent important differences in terminology. SONET is an ANSI specification. SDH is the SONET-equivalent specification that is proposed by the ITU. European carriers use SDH widely; Asian and Pacific Rim carriers commonly use SONET.

#### DWDM Technology

Dense wavelength division multiplexing (DWDM) improves the utilization of optical fiber. Multichannel signaling on a single strand of fiber increases its available bandwidth to the equivalent of several Gigabit Ethernet links. DWDM is a crucial component of optical networks. It maximizes the use of installed fiber cable and allows service providers to efficiently offer new services over the existing infrastructure. Flexible add-and-drop modules permit service providers to drop and insert individual channels along a route. An open architecture system allows various devices, including SONET terminals, ATM switches, and IP routers, to be connected.

#### Dark Fiber

Dark fiber refers to fiber-optic cables that are leased from the service provider, where the framing is provided by the enterprise. Dark fiber connection allows framing options other than SONET/SDH. The edge devices connect directly over the site-to-site dark fiber using other encapsulations, such as Gigabit Ethernet. To transmit data over long distances, regenerators are inserted into the link to maintain signal integrity and provide appropriate jitter control. Depending on the carrier and location, dark fiber is now available on the wholesale market for both metro and wide-area links at prices that were previously associated with leased-line rentals.

In terms of reliability, SONET/SDH networks offer advanced features over DWDM and dark fiber, such as automatic backup and repair mechanisms to cope with system failure. The failure of a single SONET/SDH link or network element does not lead to failure of the entire network.

### WAN Link Categories

From the ownership perspective, WAN links are divided into three broad categories:

* **Private WAN:** Uses private transmission systems to connect distant LANs. The owner of a private WAN must buy, configure, and maintain the physical layer connectivity (copper, fiber, wireless, coaxial) and the terminal equipment that is required to connect locations. Thus, private WANs are expensive to build, labor-intensive to maintain, and difficult to reconfigure for constantly changing business needs. The advantages of using a private WAN include higher levels of security and transmission quality.
* **Leased WAN:** Uses dedicated bandwidth that is leased by an enterprise from a service provider with either private or leased terminal equipment. The provider provisions the circuit and is responsible for maintenance. Some examples include TDM and SONET circuits. The enterprise pays for the allocated bandwidth, whether or not it is used, and operating costs tend to be high.
* **Shared WAN:** Shares physical resources with many users. Carriers offer various circuit- or packet-switching transport networks, such as MPLS or Frame Relay, for user traffic. The provider provisions the circuit and is responsible for the maintenance. Linking LANs and private WANs into a shared network involves a compromise among cost, performance, and security.

There are fixed costs in a typical WAN environment:

* Equipment purchases, such as modems, CSUs and DSUs, and router interfaces
* Circuit and service provisioning
* Network management tools and platforms

Recurring costs include the service provider monthly circuit fees and the support and maintenance of the WAN, including any network management center personnel.

### WAN Transport Technology Pricing and Contract Considerations

Historically, WAN transport costs include an access circuit charge and, for TDM, a distance-sensitive rate. Some carriers have dropped or reduced distance-based factors as TDM circuits have become a commodity.

Access circuits generally take 60 days or more to be provisioned by the service provider. The higher the bandwidth, the more lead time it can take. For Metro Ethernet, availability can be spotty and the lead times can be long. Construction fees can be required for the fiber access. Service and pricing options between carriers should be compared to reduce fees, depending on competition in the area.

**NOTE**

The details in this section are specific to the United States; pricing, timing, and contract details differ from country to country.

For Frame Relay and ATM, typical charges include a combination of an access circuit charge (per-PVC) and possibly per-bandwidth (committed information rate [CIR] or minimum information rate [MIR]) charges. Some carriers have simplified these rates by charging based on the access circuit and then setting the CIR or MIR to half that speed. This technique allows bursts to two times the guaranteed rate.

Frame Relay generally has been available at up to T3 speeds. In some cases, T3 is the size of trunks between Frame Relay switches, so the service providers do not want to offer T3 access circuits.

For MPLS VPN service, pricing is generally set to compete with Frame Relay and ATM. Some providers are encouraging customers to move to MPLS VPNs by offering lower prices for bandwidth than for Frame Relay and ATM. Other service providers price MPLS VPNs somewhat higher than Frame Relay or ATM because they are providing a routing service, which has value beyond bandwidth alone.

Tariffed commercial services are typically available at published rates and are subject to certain restrictions. Some carriers are moving toward unpublished rates, allowing more flexibility in options and charges.

In general, for a standard carrier package, the time that is needed to contract a WAN circuit is usually one month. If negotiating a service-level agreement (SLA), six months or more of discussions with the service provider, including the legal department, should be expected. Unless a very large customer is represented, it might not be possible to influence many changes in the SLA.

Contract periods usually last from one to five years. Because the telecommunications industry is changing rapidly, enterprises generally do not want to get locked into a long-term contract. Escape clauses that apply in the case of a merger or poor performance can help mitigate the business risks of long-term contracts.

For dark fiber, contract periods are generally 20 years in length. One key factor is the right of nonreversion, meaning that no matter what happens to the provider, the fiber belongs to the customer for 20 years. This way, the enterprise is protected in the case of situations such as a service provider merger, bankruptcy, and so on. The process to repair fiber cuts needs to be defined in the SLA.

### WAN Design Requirements

When developing the WAN design by using the Prepare, Plan, Design, Implement, Operate, and Optimize (PPDIOO) methodology, continue the process of designing the topology and network solutions. This should be accomplished after taking the earlier steps of analyzing organizational requirements and characterizing the existing network.

To develop the WAN topology, consider the projected traffic patterns, technology performance constraints, and network reliability. The design document should describe a set of discrete functions that the enterprise edge modules perform. The document should also describe the expected level of service that is provided by each selected technology, based on the services that a service provider offers.

A network design should be adaptable to future technologies and should not include any design elements that limit the adoption of new technologies as they become available. This consideration needs to be balanced with the issue of cost-effectiveness throughout a network design and implementation. For example, many new internetworks are rapidly adopting VoIP. Network designs should support future VoIP without requiring a substantial upgrade by provisioning hardware and software that have options for expansion and upgradability.

Most users seek application availability in their networks. The chief components of application availability are response time, throughput, and reliability. Applications such as voice and video are negatively impacted by jitter and latency. Table 5-2 shows some examples of applications and their requirements.

#### Table 5-2. Identifying Application Requirements

| **Requirement** | **Data File Transfer** | **Data-Interactive Application** | **Real-Time Voice** | **Real-Time Video** |
| --- | --- | --- | --- | --- |
| Response time | Reasonable | Within a second | Round trip of less than 250 ms of delay with low jitter | Minimum delay and jitter |
| Throughput and packet loss tolerance | High/Medium | Low/Low | Low/Low | High/Medium |
| Downtime (high reliability has low downtime) | Reasonable; zero downtime for mission-critical applications | Low; zero downtime for mission-critical applications | Low; zero downtime for mission-critical applications | Minimum; zero downtime for mission-critical applications |

#### Response Time

Response time is the time between a user request and a response from the host system. Users accept response times up to a certain limit, at which point user satisfaction declines. Applications in which a fast response time is considered critical include interactive online services, such as point-of-sale machines.

Response time is also a measure of usability for end users. They perceive the communication experience in terms of how quickly a screen updates or how much delay is present on a phone call. They view the network in terms of response time, not link utilization.

**NOTE**

Voice and video applications use the terms delay and jitter to express the responsiveness of the line and the variation of the delays.

#### Throughput

In data transmission, throughput is the amount of data that is moved successfully from one place to another in a given time period. Applications that put high-volume traffic onto the network have a high impact on throughput. In general, throughput-intensive applications involve file-transfer activities. Usually, throughput-intensive applications do not require short response times, so they can be scheduled when response time–sensitive traffic is low (for example, after normal work hours).

**NOTE**

Wireless throughput will be significantly less than the maximum data rate because of the half-duplex nature of RF technology.

[Figure 5-4](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390504.jpg')) illustrates response time and link utilization.

[Figure 5-4](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390504.jpg'))

[**Figure 5-4**](javascript:popUp('/content/images/chap5_9781587204241/elementLinks/ds390504.jpg')) Utilization/Throughput Correlation

The response time increases with the offered traffic until it becomes unacceptable to the end user. Similarly, the link utilization increases with the offered traffic until the link becomes saturated. The goal of the designer is to determine the maximum offered traffic that is acceptable to both the end user and the network manager. Planning for a WAN capacity increase should begin early, usually when link utilization reaches 50 percent. Additional bandwidth purchases should start at 60 percent utilization. A link utilization of 75 percent typically means that increased WAN capacity is already urgently needed.

#### Packet Loss

BER is usually expressed as 10 to a negative power. For example, a transmission might have a BER of 10 to the minus 6 (10–6), meaning that 1 out of 1,000,000 bits transmitted was in error. The BER indicates how frequently a packet or other data unit must be retransmitted because of an error. A BER that is too high might indicate that a slower data rate could improve the overall transmission time for a given amount of transmitted data. In other words, a slower data rate can reduce the BER, thereby lowering the number of packets that must be resent.

**NOTE**

In telecommunication transmission, packet loss is expressed as a bit error rate (BER), which is the percentage of bits that have errors relative to the total number of bits received in a transmission.

#### Reliability

Although reliability is always important, some applications have requirements that exceed typical needs. Some organizations that require nearly 100 percent uptime for critical applications are

* Financial services
* Securities exchanges
* Emergency
* Police
* Military operations

These organizations require a high level of hardware and topological redundancy. Determining the cost of any downtime is essential to identify the relative importance of the reliability of the network.

Assignment:

Discuss the WAN link categories

Explain SONET and SDH Technology

### Compare different WAN Transport Technologies

Name & discuss a packet-switched technology for connecting devices on a WAN.