INTRODUCTION

Over the past few years, several significant technological developments and social phenomena have affected network design. PCs have proliferated, local area networks (LANs) have become commonplace in the working environment, and, of course, the Internet has evolved from a networking facility for government and academic institutions into an all-pervasive technology available to anyone with a PC and a modem.

At the same time, networks within organizations have proliferated, with annual growth rates ranging from 100 to 200% in numbers of workstations per network. The rapid and sometimes instantaneous growth of businesses through mergers and acquisitions has resulted in a dramatic increase in the requirement to interconnect—often among widely dispersed geographical areas.

Global, heterogeneous wide area networks (WANs) are thus becoming commonplace. Composed of many different components—operating systems, hardware, and software—these networks provide a vast array of digital links interconnecting organizations throughout the world. Reliable interconnectivity among both local and wide area networks comprising heterogeneous elements is therefore a fundamental requirement of most network installations today.

PLANNING

Protocols and Standards

In any networking environment, the reliability, stability, and robustness of a network are directly related to the protocols and standards to which the individual network elements are configured.

The International Standards Organization's (ISO) open systems interconnection (OSI) reference model...
for internetworking has become a de facto worldwide standard. This high-level protocol for designers of network products and systems defines the computer communications function in terms of seven distinct layers (see Exhibit 1). As part of its aim to enable open systems to communicate with one another, the model defines open systems as those that comply with protocols for communication with other open systems (protocols that are common to both systems).

Interconnectivity and Transmission Technologies
LAN-WAN interconnectivity and the type of transmission facility required for a particular application are key design issues in interconnecting networks and essential components in determining network performance.

Once the functional goals for the internetwork are defined, they can be used as a statement of objectives. The primary features to be considered in designing a reliable, heterogeneous LAN-WAN internetwork are similar to those for a LAN. They are:

- Performance
- Robustness
- Reliability
- Maintenance and support
- Cost
- Redundancy

Robustness is defined as the capability of a network to handle peak loads and heavy network usage, without degradation. This characteristic is especially critical to the LAN-WAN integration because a robust integration architecture enables the internetwork to handle periods of peak activity and high usage levels among LANs in the wide-area networked environment.

Analysis of Network Traffic
The internetwork traffic that flows among various network locations and the performance levels required (e.g., data volumes and response times) are design criteria. These parameters determine which transmission medium will be used in the network, as well as the hardware components and network operating systems that will make up the system components.

In addition to designing for current traffic requirements, it is important to incorporate traffic forecasts for the next year, 3 years, and 5 years. These forecasts ensure that network capacity and network components can handle the increased traffic occurring as the network matures.
IMPLEMENTATION
Identifying and Selecting Network Components

In a heterogeneous LAN-WAN environment, the LAN-WAN interconnection requires hardware and software components at every location. A choice of LAN architecture (i.e., Ethernet, Token Ring, Fast Ethernet, FDDI, ATM, or combinations of these standard network protocols) needs to be determined. Appropriate selection of components also ensures that the LAN-WAN internetwork provides a seamless interface and meets the defined network criteria.

The LAN operating system in existence at each location, whether Novell NetWare, Microsoft NT (Microsoft New Technology) operating system, Banyan VINES, or 3COM 3 + Open, is another important consideration in the LAN-WAN interconnection process; it is much easier to interconnect operating systems with a degree of commonality in hardware or software, even if they have different architectures and protocols.

Internetworking Hardware and Software

The five different types of hardware devices used in networking design should be considered in a LAN-WAN internetwork. They are:

- Routers
- Repeaters
- Bridges
- Brouters
- Gateways

These devices provide options that enable networks to handle a variety of different forms of network configurations, as well as a range of different types of network traffic from pure data to multimedia communications.

**Routers.** Routers are used in networks to separate network traffic based on the network layer protocol (see Exhibit 1) and are a common component in internetwork communications. They control network traffic by filtering according to protocol, dividing networks logically instead of physically. Routers can divide networks into various subnets, so that only traffic destined for particular addresses passes between segments.

One drawback of the router is that its intelligent forwarding and filtering capability usually results in reduced network speed. The process takes more time than that required by a switch or bridge, which only performs an access function to the shared transmission medium.

**Repeaters.** Repeaters are the building blocks of complex networks. They are important elements in LAN-WAN internetworks, extending the
physical length of a transmission medium by amplifying signals and allowing additional workstations to be connected in each network segment.

For example, in a thin Ethernet/IEEE 802.3 LAN, 30 devices can be supported for each 185-meter segment. Repeaters can be inserted to accommodate more devices per segment or an increase in the length of a segment. All network architectures have constraints that dictate how many devices can be attached per segment. Exhibit 2 illustrates these constraints for a typical Ethernet architecture. Other architectures (i.e., ARCNET, Token Ring, and FDDI, or fiber distributed data interface) have similar limitations on number of devices and distance between network segments.

In addition to extending the reach of a network, repeaters also monitor all network segments to ensure that the basic characteristics are present for the network to meet specified performance requirements. For example, when a break occurs, all segments in a network may become inoperable. Repeaters limit the effect of problems in a faulty section by segmenting the network, disconnecting the problem segment, and allowing unaffected segments to function normally.

**Bridges.** A bridge is akin to a traffic manager used to divide the network into logical subsets. Most bridges are multiport devices that connect one network to another, using store-and-forward filtering techniques and handling potential bridging loops between networks. Bridges enable redundancy to be built into a network by providing multiple pathways between network segments.

**Brouters.** Brouters are hybrids of the bridge and router, and are often referred to as routing bridges. They provide the processing speed of a bridge with the internetworking capabilities of a router. They are proto-

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**EXHIBIT 1—The Open Systems Interconnection (OSI) Reference Model**

![OSI Reference Model Diagram](image-url)
col-independent devices that direct traffic based on the OSI data link access referenced in Exhibit 1.

The sophisticated design of these devices enables them to logically segment the network based on the routing algorithm, higher layer protocol, or the WAN architecture that has been implemented.

**Gateways.** Gateways are devices that handle specific applications such as the interconnection between different classes of hardware and network architectures, such as mainframes, Token Rings, workstations, or midrange systems. They may operate at all seven OSI layers and are often used to interconnect incompatible E-mail systems, convert and transfer files from one system to another, or facilitate interoperability between dissimilar operating systems.

**Building Networked Communities**

Over the past 10 or more years, network vendors, such as Novell, have played a leading role in perfecting the foundation technology resulting in the implementation of networked communities of PC users and business workgroups. Workgroup networks enable individuals to share documents and expensive hardware resources such as printers and disk drives, often on an enterprisewide basis.

These workgroup networks can be expanded to support communication and collaboration in enterprisewide WANs, leading to a variety of
LAN-WAN interconnection options. Novell, along with other significant players in the networking systems marketplace, such as Microsoft and Banyan, foresaw the potential of the original concept of building communities of PC users by connecting workgroups into enterprise networks. NetWare, Novell’s network operating system, provides a range of distributed services for networking enterprisewide WANs. Because NetWare products now run on more than 2.5 million networks, a sound knowledge of Novell’s networking products is important for network design.

**Principles of LAN-WAN Internetworking**

Novell’s strategy for forging the future of networking provides a guideline for network design. It rests on the following three basic principles:

1. Smart networks
2. Anytime, anywhere access
3. Network heterogeneity

**The Smart Network.** The first principle maintains that making networks smarter relieves users of the arcane world of operating systems, applications, and tools. Without a smart network that identifies the user and knows what information is required and how to provide it, connections to a global network are a difficult task.

**Anytime, Anywhere Access.** This principle is based on the premise that a simple, single log-in procedure enables access to smart networks anytime, from anywhere, by anyone. Such access would, among other things, transform work from a place into an activity. The concept of the virtual office already exists in many organizations, and with it comes enormous new demands for accessing information, resources, and other people.

**The Heterogeneous Network.** This final principle recognizes that the network will always be heterogeneous. It has several different operating systems and many different applications and services, is designed with a variety of tools, and is capable of being accessed from a wide variety of intelligent devices.

**Transmission Alternatives in Heterogeneous LAN-WAN Networks**

LAN-WAN interconnection options are wide-ranging. Although previous services usually offered minimal bandwidth and were unreliable and overpriced, they did the job. WAN services available today are cheaper, offer greater bandwidth, and are far more reliable.
Depending on the particular needs of the network, a variety of transmission media forms are available: standard telephone lines, digital communications lines, switched or permanent links, and packet or circuit-switched connections.

A typical, logical design process involves selecting the WAN transmission medium once the LAN specifications have been determined. The following considerations are important for determining which medium to select:

- Will the network connections be used for LAN connections and to connect telecommuters to the corporate information system?
- What level of traffic will the WAN handle and how often?
- What are the forecasted traffic patterns for the LAN-WAN internet-work? Do they include constant bit-rate video, file transfer, or multimedia?
- Will traffic cross regional, national, or global boundaries, requiring special considerations for regulatory provisions?
- What level of reliability is needed? Is a backup required?
- What level of service will WAN communications require? Around-the-clock? Intermittent?

The answers to these questions provide the direction needed to determine which of the following transmission technologies will fit the specification for the LAN-WAN interconnection:

- POTS (plain old telephone system)
- ISDN (integrated services digital network)
- Leased lines
- X.25
- Frame relay
- ATM (asynchronous transfer mode)

**POTS.** The plain old telephone system, or POTS, has faded as a transmission facility because it cannot meet the high-level performance requirements of modern networks. However, it is useful in situations in which only a limited amount of bandwidth (up to 28.8K bps) is required for periodic connections.

Two applications fall into this category: telecommuting and WAN links requiring low-level backup. In these situations, the analog connection provided by the POTS has the bandwidth to handle the transmission requirements.

The key to this media is to understand its limitations in terms of long-distance reliability and use it mainly for local connections to minimize the costs incurred by distance-sensitive pricing.
**ISDN.** ISDN (integrated services digital network) is a transmission medium that has gained prominence over the past few years and will prove useful in many LAN-WAN internetworks. This technology is an evolution of POTS that enables faster, more reliable digital connections on existing telephony infrastructures.

Increased speed, low latency, and high reliability make ISDN useful for constant bit-rate applications such as videoconferencing. Its higher speed connections (between 128K bps and 2.048M bps) mean that it can be used for direct or backup LAN-to-LAN connectivity. Owing to its distance and usage-sensitive tariffs, ISDN is most cost effective for intermittent local transmissions.

**Leased Lines.** Leased lines are the foundation of corporate internetworks in North America, although their permanence limits their use to LAN-to-LAN connections. They provide suitable network solutions for corporate communications because they offer a range of speeds from 19.2K bps to T3 and provide 99.99% uptime (in North America). Because they are dedicated permanent links, they are more secure than other WAN alternatives and suitable for a variety of different types of network traffic (including video).

Because pricing is distance sensitive, leased-line connections are costly. This is an important consideration when evaluating leased lines in terms of other equivalent-bandwidth alternatives.

**X.25.** X.25 is a packet-switched network and the most advanced, established, international protocol. As an alternative to direct connections, packet-switched networks provide a communications link that is a virtual connection (i.e., it does not exist physically).

One advantage of X.25 services is that they are available on a universal basis, offering bandwidths ranging from 9.2K bps to 256K bps. This protocol is so well established that it supports several of the other access technologies, including POTS, ISDN, and leased-line connections. This capability makes X.25 ideally suited for global LAN-WAN heterogenous internetworks involving a variety of different architectures, protocols, and operating systems. A drawback to X.25 is that it does not support high-bandwidth applications (such as video), which cannot tolerate the latency introduced by a packet-switched network.

**Frame Relay.** Frame relay is another packet-switched service that can replace leased lines. It is a simplified version of the X.25 protocol, without the error-correction facilities that guarantee reliable data delivery.

Because frame relay is a digital protocol, it is only available where digital communications facilities are in place. The cost of frame relay is usually less than an equivalent-bandwidth leased line, with the price differential growing as the distance between sites increases. Because this
protocol supports dial-up access through POTS and ISDN, it is a practical transmission medium for remote users in many network environments.

**ATM.** Asynchronous transfer mode (ATM) is one of the latest, most advanced, and sophisticated network protocols. Defined in the OSI reference model, it is rapidly becoming the medium of choice in many network applications.

ATM is a cell-switching, multiplexing technology that combines the features of circuit switching (i.e., constant transmission delay and guaranteed capacity) with those of packet switching (i.e., flexibility and efficiency for intermittent traffic). It is particularly suitable for the simultaneous transmission of multimedia information (i.e., voice, video, or data).

ATM defines packets or cells with a fixed byte. The cells consist of payload and header information. The header contains virtual circuit address information used by the ATM switch for multiplexing and switching, as well as other networking functions.

Dividing data frames into ATM cells is called segmentation, and re- building data frames from ATM cells is called reassembly. Standard chipsets that provide both segmentation and reassembly are now available. The rules of segmentation and reassembly are dictated by the ATM adaptation layer protocols illustrated in Exhibit 1.

The basic transmission unit in ATM is defined to be a fixed-length cell, providing the following characteristics:

- Switching is performed in silicon, providing much lower switch latency values and much higher switch throughputs.
- Fixed-length cells allow the switch to operate isochronously with fixed and predictable delays.

Because it is carried electronically on a synchronous transport system, ATM is asynchronous in nature (i.e., there is no fixed arrival rates of cells) and operates in a constant bit rate mode for video or voice applications.

For LAN-WAN internetworking, ATM protocol applications are now being used to:

- Replace broadcast LAN media, such as Ethernet, Token Ring, and FDDI.
- Function as a LAN backbone technology in a campus or metropolitan area environment.
- Operate as a WAN aggregate link technology.

The characteristics of ATM require that a network administrator do significant network configuration analysis to perform simple network modifications, such as adding a new user to an ATM LAN.
In a LAN backbone configuration, ATM is considered to be more effective than an FDDI architecture. ATM backbones scale well because the technology is nonbroadcast, providing dedicated, nonblocking, 155M-bps, bidirectional, point-to-point virtual circuits between routers. This means that there is no contention for bandwidth as there is in FDDI, allowing for more devices to be added to the backbone without compromising effective throughput of existing devices. This important characteristic of ATM makes it a key transmission architecture for LAN-WAN internetworks where it meets other network specifications.

ATM was developed as a WAN technology for broadband ISDN. Using ATM as a WAN link extends the use of ATM as a backbone in a campus environment and to larger LAN-WAN environments, where design decisions are influenced by the progress of tariffs and service rollouts by carriers.

Industry analysts forecast that ATM, the most advanced transmission technology, will not become a practical option for solving many networking problems for at least the next 3 years. One reason for this forecast is that ATM standards are frozen until the end of 1997, and the announcement of the next set of standards will undoubtedly be followed by a 6-month frenzy of new product design and a further year-long process of working out the bugs.

One rationale for migrating to ATM is to create a high-speed platform for research and development. Most standard networking needs can be met by the more cost effective and reliable solutions existing today.

CONCLUSION
The technologies available for interconnecting LANs and WANs—hardware, software, network operating systems, and transmission media—are rapidly changing. It is important that the LAN-WAN network design allow for flexibility within the network architecture, so that new, proven technologies that enhance network performance can be leveraged.

On the other hand, most organizations requiring reliability in their networks should focus on tried-and-true network architectures and transmission technologies and wait both for vendors to stabilize their offerings and for newer transmission technologies to be proven.

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