The Application of Undersea Cable Systems in Global Networking

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Undersea fiber-optic systems have greatly expanded the capacity and capabilities of the global telecommunications network. These systems facilitated the exceptional growth of new services, which in turn contributed to the rise of multinational corporations and the development of a global economy. As they branch out, these corporations require the same variety and quality of services that are available in their home markets. Thus, the global demand for fiber-optic connectivity is increasing rapidly. This paper discusses the evolution and organization of the global undersea network and some of the key factors that are driving the technology's progress.

Introduction

In the few years since the installation of the first major, transoceanic, undersea fiber-optic systems in the late 1980's, such systems have greatly expanded the capacity and capabilities of the global telecommunications network. By providing an unmatched combination of transmission quality, reliability, and capacity, these systems facilitated an "explosion" of growth in new telecommunication services. This growth has contributed greatly to the rise of multinational corporations and the realization of a global economy.

As these corporations expand their domains, they expect to receive the same, wide array of services available in their home markets, along with the high-quality transmission characteristics made possible by fiber-optic technology. The result is a global demand for fiber-optic connectivity, even from the most remote areas.

Today, we are entering an era in which all the coastal countries of the world will be connected in a vast, global network of undersea fiber-optic cable. This discussion focuses on the network's background and evolution, and it highlights some of the elements influencing the development and installation of undersea transmission systems.

First-Generation Global Network

In 1988, undersea fiber-optic technology reached a historic milestone with the deployment of TAT-8, a trans-Atlantic fiber-optic cable linking the United States, the United Kingdom, and France (see Figure 1). The technology was made possible by a first-generation AT&T SSI undersea cable system known as SL280. This was not only the first transoceanic fiber-optic system; it was also the longest, continuous, digital-transmission span ever created.

The performance of this new system proved to be exceptional. In a test by an international team of engineers, the six fibers within the cable were connected together, and their combined length equaled the circumference of the globe. A signal was then transmitted along the fiber, at a rate of 280 Mbits/s, with virtually error-free performance. This was the first, conclusive demonstration of the feasibility of constructing high-capacity networks on a worldwide scale.

Soon after, the same technology was used to link the United States and Japan. For the first time, this fiber-optic connection provided the prospect of "seamless," high-capacity, digital networking among the world's three largest markets—the United States, Europe, and Japan. The reaction from the business community was overwhelmingly positive. The unprecedented growth in international communication, which included voice and data traffic, resulted in TAT-8 reaching its capacity within 18 months of installation. The
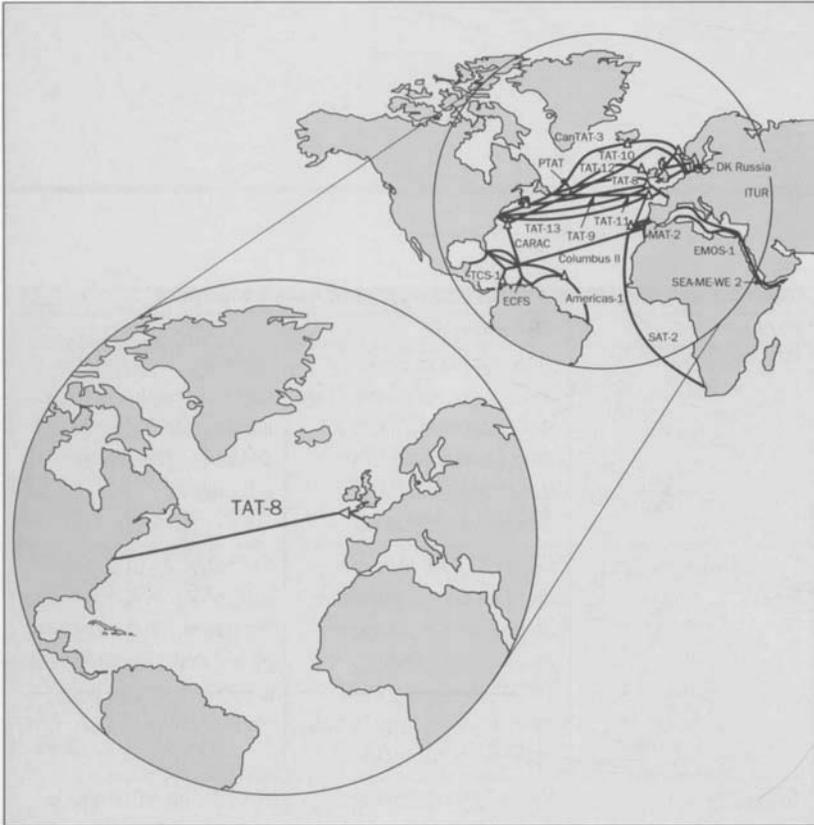
Figure 1. In 1988, a historic milestone was reached with the deployment of TAT-8, a trans-Atlantic fiber-optic cable linking the United States, the United Kingdom, and France. In a test, the cable's six fibers were connected together, and a signal was transmitted along the fiber at a rate of 280 Mbits/s, with virtually error-free performance. This was the first, conclusive demonstration of the feasibility of constructing high-capacity networks on a worldwide scale.

Panel 1. Abbreviations, Acronyms, and Terms

ADM — add/drop multiplexer

Africa ONE — a proposed, undersea, fiber-optic communication system that will encircle Africa

Pan-American Network — a proposed, undersea, fiber-optic communication system that will traverse the west coasts of North America, Central America, and South America

NPE — network-protection equipment

SDH — synchronous digital hierarchy

SL100 — third-generation, non-repeatered, AT&T undersea cable system

SL280 — first-generation AT&T undersea cable system

SL560 — second-generation AT&T undersea cable system

SL1000, SL2000 — third-generation, repeatered, AT&T undersea cable systems

SSI — the Submarine Systems, Inc. business unit of AT&T

TAT-8 — a trans-Atlantic fiber-optic cable linking the United States, the United Kingdom, and France

WDM — wavelength-division multiplexing

most optimistic forecasts predicted that the system's capacity would not be reached for over ten years. Some planners actually believed that—with its 18,900 virtual voice circuits (after application of the digital-circuit multiplication sys-

tem)—TAT-8 would *never* be filled, and that no other trans-Atlantic cable system would ever be needed.

The Technological Heritage

The success of the first undersea fiber-optic systems was not accidental. The quality and reliability of those systems resulted from two factors that are the foundation of all AT&T Submarine Systems, Inc. (SSI) products and services: *extensive experience* and *technological breadth and depth.*

Long before TAT-8 was completed, AT&T had gained more than 30 years of experience in designing, manufacturing, and placing undersea, analog, coaxial systems, having installed more than 100,000 kilometers of such cable around the world. This broad-based experience was applied directly to the new and emerging fiber-optic digital technology.[1]

Technological breadth and depth, and the success of SSI technologies, grew from AT&T Bell Laboratories' fundamental research in electronics, photonics, and optical-fiber technology. This research is combined with highly specialized, dedicated staff and facilities for the development and manufacture of undersea network products.

The Second Generation

Major, industrialized population centers were connected by the first-generation, SL280 undersea lightwave cable system. It was during the life cycle of the SL560

second-generation product in the early 1990s, however, that the concept of a global, fiber-optic infrastructure really began to take hold. A number of factors—technical, political, and economic—combined to make this so.

Rapid advances in undersea cable-system technology made it possible to transmit signals over long distances—at twice the rate of the first-generation system—using half the number of repeaters. Such advances reversed a historical trend whereby higher-capacity systems always required more repeaters. This trend reversal made the SL560 system a relative bargain in the information-movement market. In addition, the high performance and proven reliability of the first-generation system was so impressive that those who had taken a wait-and-see approach to investing in undersea fiber-optic technology now enthusiastically embraced this second-generation system.

Even more importantly, many nations began to realize the benefits of becoming totally involved with the burgeoning global economy, and that such participation requires a fiber-optic connection to world markets. Involvement with the global economy was further stimulated by the trend—in many countries—toward the privatization and liberalization of the telecommunication sector. These processes gave telecommunication authorities new freedom to invest in global connectivity, which resulted in many countries seeking connection to the global network simultaneously—a trend that continues unabated today.

The Evolving Third Generation

Recent developments in undersea fiber-optic technology provide the most exciting possibilities for global networking. The technology embedded in the latest, third-generation AT&T products, both repeatered (SL2000 and SL1000) and non-repeatered (SL100), makes it practical and affordable—for the first time—to realize a network that extends to every coastal country and to many population centers by means of undersea fiber-

Table I. Comparison of factors in system-design analysis

Factor	Repeatered	Non-Repeatered
Span Distance	Up to 9,000 km. Repeater spacing can vary from 33 km to 120 km or higher as a function of system length, transmission rate, and desired bit-error rate.	Maximum span lengths vary as a function of transmission rate. Typically, distances of 300 km are achievable.
Trunk Cross-Section Size	Currently, four-fiber-pair cross sections are available. In the future, wavelength-division multiplexing (WDM) technology will make multiple virtual trunks available per fiber pair.	Currently, up to 12-fiber-pair cables are available. In the future, WDM technology will make multiple virtual trunks available per fiber pair.
Reliability	Virtually no difference in system reliability of repeatered and non-repeatered systems of equal system length.	Virtually no difference in system reliability of repeatered and non-repeatered systems of equal system length.
Upgradability Path	Constrained by initial design.	Constrained by initial design.
Power-Feed Equipment	Designed to meet system requirements.	Not needed; therefore, no floor space, building power, or operation and maintenance of this equipment are necessary.
System Life	More than 25-years.	More than 25-years.
Cost	Determined on a case-by-case basis.	Determined on a case-by-case basis.

optic cables.[2-3] These cables integrate "seamlessly" with other technologies to reach inland areas. The enabling elements—optical amplifiers, low-loss and dispersion-shifted fibers, synchronous digital hierarchy (SDH) terminals, forward error correction, and so forth—as well as the specific product families that embody them, are detailed elsewhere in this issue.[1,4-6]

Research indicates that these third-generation products will be the most ubiquitous undersea systems yet. The sections that follow discuss how these products are combined to implement the global network.

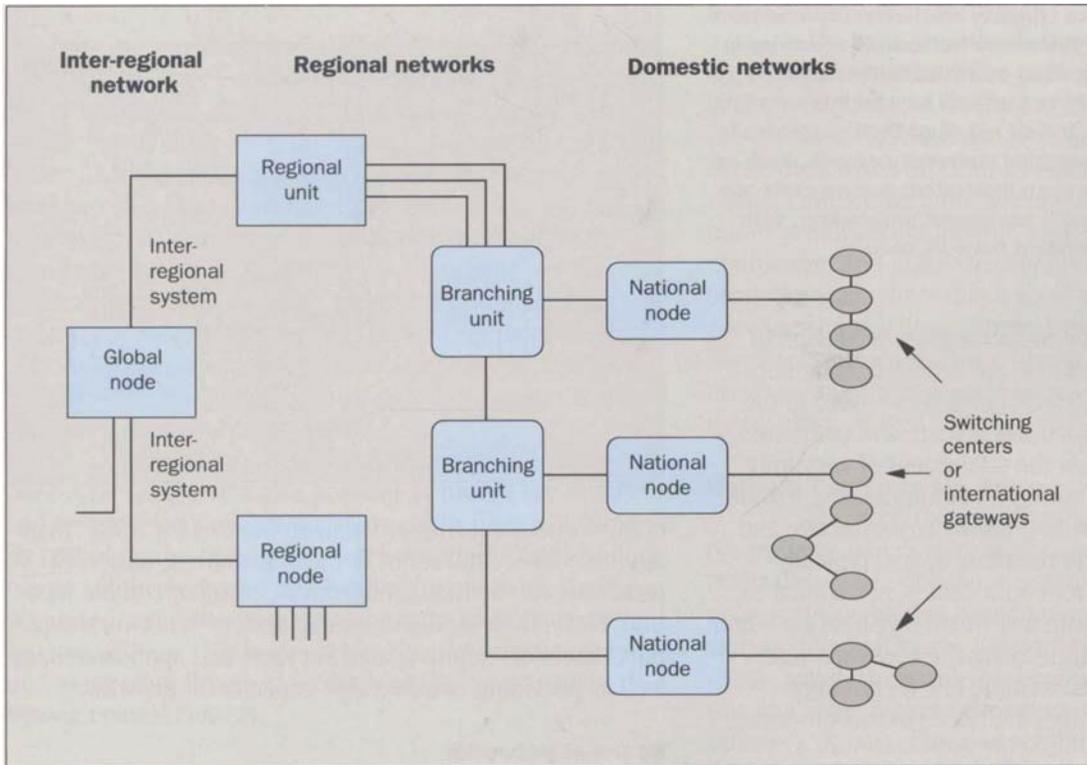The technology-platform enablers that differenti-

Figure 2. A global network can be viewed as a four-tiered architecture. Domestic tiers connect either population centers within a country, islands in a group, or islands near a country's mainland. Regional tiers connect countries in a geographic region to one another. Inter-regional tiers connect worldwide geographic regions. Special-application tiers (not shown) are represented by networks procured by governments, or by industry for dedicated, private applications.

ate third-generation from second-generation products were stated earlier. Subsequent papers in this issue describe these enablers in detail, as well as their unique applications and combinations when applied to the undersea communications environment.[1-6] As noted later in this paper, the decision of whether a non-repeatered or repeatered system should be installed, based on either technical or economic reasons, or both, is becoming less distinct. In fact, it is now more the rule rather than the exception that hybrid systems—those having both repeatered and non-repeatered segments—are being deployed. A brief comparison of selected items, cited as factors in system-design analysis, is provided in Table I.

Some of these factors are detailed in the papers about repeatered and non-repeatered product technology appearing in this issue.[2-3]

Global Network Architecture

A global network can be viewed as a four-tiered architecture. The first three tiers, as shown in Figure 2, are defined as *domestic*, *regional*, and *inter-regional*.[7] The fourth tier is referred to as *special applications*.

Domestic tiers connect either population centers within a country, islands in a group, or islands near a country's mainland. The domestic network distributes traffic within the country and aggregates outbound traffic to other countries.

Regional tiers connect countries in a geographic region to one another, distributing traffic within the region and aggregating outbound traffic to other regions.

Inter-regional tiers connect geographic regions throughout the world by spanning the oceans that separate them. For this reason, they are often referred to as *global* or *transoceanic tiers*.

The fourth tier, special applications, is somewhat unique when compared with the others. It is typically represented by networks procured by governments, or by industry for dedicated, private applications.

Domestic Networks

Third-generation technologies play a large part in undersea cable installations as applied to any nation's
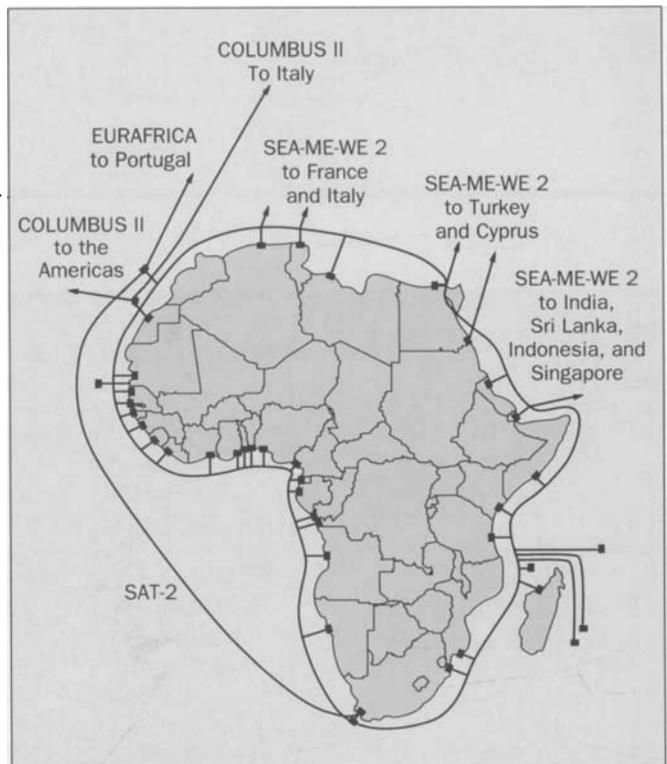
Figure 3. Regional networks typically link several countries, and much of the outbound telephone traffic from countries in a region is directed toward other countries in the same region. Most countries want to maintain sovereignty over their own traffic, however, and do not want their neighbors to have access to it. A well-designed undersea network, such as the proposed Africa ONE system illustrated, resolves this sovereignty issue by placing most equipment underwater, with each country having independent network access.

domestic (intra-country) communication networks. In many cases, these applications are satisfied using non-repeatered technology. Optical amplifiers—used in the *transmit* and *receive* segments of a span, and combined with low-loss fibers—allow the attainment of very long transmission distances (hundreds of kilometers) without undersea repeaters, providing highly cost-effective and versatile cable routes. The resulting spans, typically constructed with high-fiber-count cables, are similar to terrestrial installations from a network-engineering standpoint. The architecture underlying the Hawaiian Inter-island Cable System is an example of a technology application designed to meet the needs of this emerging and evolving market.

Non-repeatered systems can use the same standard transmission formats and network-management interfaces as terrestrial facilities. Undersea spans are used, therefore, to provide alternative routing for existing terrestrial facilities, as well as to extend connectivity to places too difficult for overland cabling. Such alternative routing could be used:

- Where customers are separated by rough terrain;
- In unsettled areas that lack a supporting infrastructure;
- Where ongoing construction activity makes disruption likely;
- In locations too distant to be reached with standard terrestrial technology; and
- In urban areas in which a right-of-way is prohibitive (that is, existing cable ducts are full, requiring the construction of new ducts, but it is too costly or duct installation would disrupt city streets too much).

Undersea spans are an efficient way for developing nations—having a desire for rapid network growth—to build a high-capacity backbone system linking coastal population centers. In some cases, these spans are merged with inland fiber links of comparable capacity to create redundant ring or mesh structures for traffic management and restoration. In these instances, undersea terminals can be managed from a central or remote location. Nevertheless, the domestic undersea network supports the most sophisticated services and applications, as well as providing considerable capacity for growth.

Regional Networks

Undersea technologies are uniquely suited to the provision of regional networks linking several countries. In most areas of the world, the preponderance of outbound telephone traffic from countries in a region is directed toward other countries in the same region. Nevertheless, most countries want to maintain sovereignty over their own traffic and do not want their neighbors to have access to it.

A properly designed undersea network, using the latest technology, resolves this sovereignty issue by placing the majority of the network on the sea bottom. Each country obtains independent access to the network by means of undersea branching technology. Such networks are very cost effective, because many countries can be linked by a single cable. Outbound traffic from the region is aggregated at the point(s) of connection to the inter-regional tier. A proposed system that will encircle Africa, known as Africa ONE, and the Pan-American Network, which traverses the west coasts of North America, Central America, and South America, illustrate the application of new technology to this crucial link in the global network chain. Figure 3 illustrates the Africa

ONE network configuration.

Regional networks must be versatile to accommodate both the inevitable differences in growth rates and the changing alignments within a region over the networks' life. As long-term investments, networks must also have adequate capacity for exponential growth over at least two decades. These requirements dictate the use of fiber optics in a managed network environment, and undersea fiber-optic technology is generally the most economical and politic solution. (Inland countries lacking coastal access can have all but the final segment of a fiber-optic system carried on the undersea network, and their traffic can be merged with the network through the inter-regional gateway of their choice.)

Due to the extraordinary capacity offered by fiber-optic cables, it is also possible to merge the domestic and regional tiers within the same cable. This is achieved by providing the regional network with additional landing points within a country and by keeping domestic traffic separate from regional traffic by means of routing over separate fibers. This is an extremely cost-effective solution to meeting the need for high-quality connectivity among coastal centers.

Inter-Regional Networks

Inter-regional tiers are most often associated with undersea systems. It was in major transoceanic links that the technology was first introduced, and it is there that the undersea approach remains predominant and largely unchallenged. Thus, the twofold technological thrust for the inter-regional networks is to:

- Stay ahead of the exponentially-increasing demand for transmission capacity, wrought by the continual expansion of the global marketplace and the rapid evolution of broadband services; and
- Offer architectures that provide for literally uninterrupted service, that is, no "dropped" calls.

Multigigabit-per-second transmission rates of third-generation (SL2000) systems, combined with the latest self-healing (no dropped calls) networks, provide a level of capacity, quality, reliability, and per-circuit cost that cannot be matched by any other technology. Intercontinental connections, which today are being installed as complete, self-healing ring networks, tie the world's regional networks together, creating a global network-of-networks capable of managing traffic streams worldwide.

Special-Application Networks

The newest of the four architectures is special-application networks.[3] The emergence of this type of system was induced by the increasing desire of customers for broadband and high-capacity networks to serve their own corporate or internal communications needs, coupled with the availability of economical customer-premises equipment, high-speed digital terminal equipment, and high-capacity undersea transmission systems. An example of this type of architecture is a network serving a consortium of petroleum companies having offshore oil platforms. These platforms must have communication, monitoring, and control capabilities among themselves, as well as with the mainland.

Network Configuration Options

The architectures linking all parts of the global community, which were described earlier, are now realizable. This is because of the ability to combine technological capabilities based on optical-amplifier transmission-system platforms, network-protection equipment (NPE), which is capable of reconfiguring network-transmission plans without dropping calls, and add/drop multiplexers (ADMs). These capabilities make it possible to design network configurations for specific systems. They allow meeting the particular needs of capacity, reliability, fault tolerance, restoration, upgradability, and national sovereignty. A description of standard network configurations used for undersea communication follows. As noted, these configurations can be either adapted individually or combined to meet specific customer needs.[8]

Some examples of available network configurations are the:

- Star. This configuration consists of a terrestrial hub station, with separate cables branching from the hub to the various, required landing points. In the basic star configuration, a nation's traffic is not required to pass through another nation on its way from the hub. In other words, this configuration optimally meets the requirement of preserving national sovereignty. It requires only one cable landing-point terminal, which represents an economic savings. However, the star also requires a separate cable for each nation. It is a relatively costly configuration, therefore, when nations are geographically distant.
- Branched Star. This configuration provides the same

capability as the basic star, except that the splitting of traffic is done underwater, minimizing the cost of separate cables between remotely located landing points. Splitting of traffic is accomplished with a branching unit that interconnects the fibers of a single trunk cable with separate fibers inside two branches. In the future, branching units having a wavelength-splitting capability will be provided to allow wavelength-division multiplexing (WDM) channels to be separated, between various routes of a branched system, from a single trunk fiber.

— *Trunk and Branch.* This configuration connects several countries to a single trunk cable by means of branching units. Trunk technology is based on optical amplifiers and the hub/node equipment on SDH products to allow maximum flexibility in growth and reconfiguration. Branches may be relatively short and non-repeatered for interconnection simplicity.

— *Festoon.* This configuration is an increasingly popular alternative to a land-based system, especially when the continental terrain provides difficult installation and maintenance challenges. The festoon is basically a series of loops between major coastal cities, and it is often deployed—though not always—as repeaterless systems. In anticipation of future increased capacity requirements, these repeaterless applications are typically engineered with higher-fiber-count cables than those required for initial service. Thus, the installation and expense of a new, supplemental, undersea system having higher capacity is eliminated. Additional terminal equipment is the only future requirement. The architecture of a festoon frequently mirrors that of a typical, land-based installation. Such an architecture may often be used as a supplemental, diverse route to an existing land-based system.

— *Ring.* This configuration is predominately designed to address the issue of automatic restoration without dropping calls, even with a cable failure. The ring configuration is essentially a set of connected, point-to-point cables having twice the requisite transmission capacity. In case any single failure occurs within the ring, such as a cable cut, traffic is routed around the ring on the spare cable —away from the inoperable segment—and on to its original destination. Shore-based SDH transmission equipment (NPE) provides automatic failure detection and switch-over control for the entire ring without dropping a call. During periods when the whole system is operat-

ing, the reserve capacity can be put into service on a preemptory basis. It is important to reiterate that, given the reliability of undersea cables, the probability of interruption of even this part-time traffic is extremely low. Ring systems are being deployed across the Atlantic and Pacific oceans during the 1994 to 1996 time frame. Standards governing the transmission equipment, such as ADMs and NPE, are now being studied for undersea applications by the International Telegraph and Telephone Consultative Committee - International Telecommunications Union. Thus, ring networks provide the restoration capabilities required of the regional-system customers discussed earlier.

— *Branched Ring.* This configuration extends the basic capability of the ring with the addition of a branching unit. The branched-ring structure retains the self-healing nature of the ring, but provides independent connections to the hub, requiring only a single landing point per terminal. The branched ring, then, can be thought of as a merger between the branched star and the ring, retaining most of the benefits of each. In fact, the primary difference between a branched star and branched ring is the single connection that closes the ring. Such a connection can be made in a number of ways, including hook-up through other networks. With proper planning, a network can be installed as a branched star configuration or trunk-and-branch arrangement and upgraded later to a branched ring, as other networks or point-to-point systems are built.

Selection of the optimum configuration for a specific application is not based only on present traffic needs and initial landing points, but also on anticipated needs. The flexibility of the system technologies offers the opportunity, by means of upgrades, to modify the original network configuration during the system's life, prolonging its usefulness.

The Future of the Global Network

The challenge for the future is to rationalize the fast-growing global network. Fourth-generation technology will bring per-fiber capacity of tens of gigabits per second and ever-more-flexible networking options. The ongoing merger of information technologies will continue to bring demands for ever-more-sophisticated services. We can expect to see many more applications of undersea fiber technology in domestic networks, as all the coastal

countries of the world are connected through regional networks, and all regional hubs are joined in a vast inter-regional network that extends across all the world's oceans and seas in both hemispheres.[9]

In so doing, we will continue to draw on the strengths that have kept AT&T technology in the forefront of global telecommunications: evolution based on extensive experience; breakthroughs founded on broad-based fundamental research; and, continuing dedication to quality and reliability that places customers' needs first.

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