

Network Planning, Operation, and Maintenance Practices for Undersea Communication Systems

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Undersea cable systems are becoming more complex as they evolve from isolated systems to global networks. This evolution has created new challenges for network planners, cable installers, and those responsible for cable maintenance. This paper describes the philosophies and ensuing strategies for these activities. Specifically, the AT&T-Submarine Systems, Inc. (AT&T-SSI) maintenance, repair, management, planning, operation, and administration of cable systems are discussed.

Introduction

This paper reviews current system-maintenance strategies and network-planning activities required to support undersea cable systems.

The AT&T Submarine Systems, Inc. (AT&T-SSI) maintenance strategy for these systems is to:

- Install highly reliable, easily maintainable equipment;
- Provide the capability for rapid service restoration following an outage; and
- Use network-management systems to support the operation, monitoring, and administration of both wet and dry plant equipment.

As discussed in the *Design Requirements for the Current Generation of Undersea Cable Systems* paper, customer expectations of transmission performance, vis-à-vis traffic interruption, continue to increase.¹ The combination of both very high traffic volume and potentially long repair time necessitates innovative approaches to maintenance-architecture and repair strategy. Historically, AT&T has had dual roles in the maintenance of these systems, as both a provider and user. As a provider, SSI designs and engineers the systems with sufficient robustness and redundancy for a planned 25-year life. In addition, AT&T is often designated as the maintenance authority, performing routine maintenance and monitoring by using the inherent features and functionality of the systems.

As undersea product offerings have migrated from coaxial analog and regenerative technologies, customer expectations and requirements have also evolved, with respect to the operations and support systems used for administration and monitoring.

The following activities support these systems' network-planning functions:

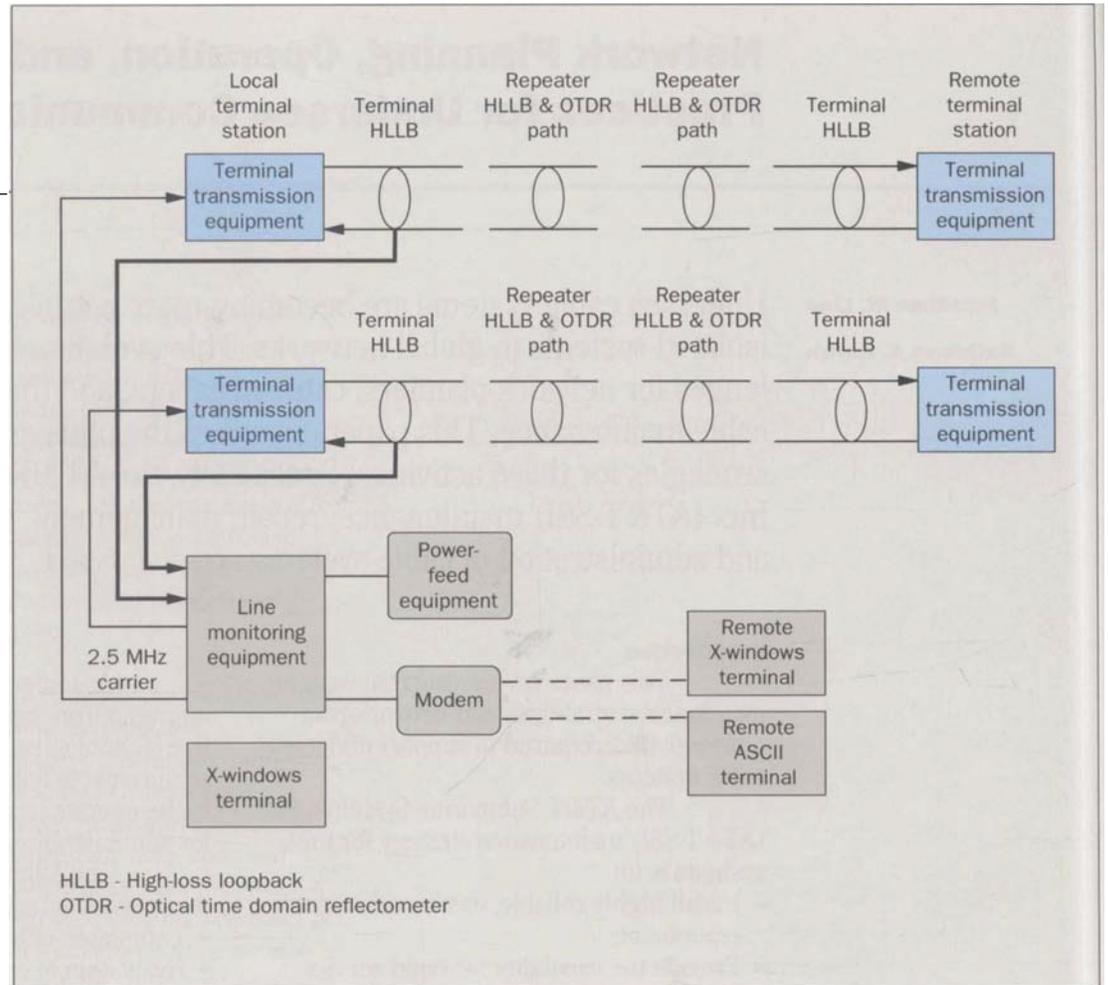
- Estimation of traffic demands;
- Evaluation of cable routes and landing points; and
- Development of capacity allocation and loading strategies.

Undersea-System Maintenance

Depending on specific customer requirements, current undersea cable systems have fault-localization features and built-in redundancy, which provide robustness and a rapid restoration capability. The system-maintenance strategies and solutions discussed in this paper are applicable, in varying degrees, to either repeated² or non-repeated³ systems. The strategies and solutions enable AT&T-SSI to meet specific customer needs that arise in point-to-point, branched, ring-networked, and festoon applications, as discussed in *The Application of Undersea Cable Systems in Global Networking* paper.⁴ They also enable the provisioning of turn-key solutions for end-customers.

Routine operation and maintenance procedures can vary, depending on the cable system and customer requirements.

Figure 1. Transmission difficulties can be predicted well in advance of an actual system failure. In optical-amplifier systems, line-monitoring equipment (LME) in the terminal, in conjunction with high-loss loop-back (HLLB) paths in the repeaters, perform in-service, per-line performance monitoring. In addition, the LME and HLLB also perform out-of-service fault location. This drawing illustrates the relationship of the LME, line-monitoring system (LMS), terminal transmission equipment, and undersea plant in a repeatered system.



Practices can be as simple as periodic visual checks of terminal-station equipment and sections of the cable, or as complex as extensive and elaborate maintenance routines. These procedures can include proactive use of the reporting and measurement capabilities of various subsystems, such as undersea supervisory apparatus, terminals, multiplexers, and power-feed equipment (PFE).

SSI has incorporated specific product features to meet customer expectations, whereby transmission difficulties can be predicted well in advance of an actual system failure. In optical-amplifier systems, line-monitoring equipment (LME) in the terminal, in conjunction with high-loss loop-back (HLLB) paths in the repeaters, perform in-service, per-line performance monitoring. The LME and HLLB paths also perform out-of-service fault location, as discussed in the *Undersea Optically Amplified Repeatered Technology, Products, and Challenges* paper.² Figure 1 shows the relationship of the LME, line-monitoring system (LMS), terminal transmission equipment, and undersea plant in a repeatered system.

Operations performed by the LME are designed to report on the undersea plant's "health" from either

Panel 1. Abbreviations, Acronyms, and Terms

- CIT—craft-interface terminal
- COTDR—coherent optical time-domain reflectometer
- HLLB—high-loss loop-back
- LME—line-monitoring equipment
- LMS—line-monitoring system
- NMS—network-management system
- NE—network element
- OSS—operations support system
- OTDR—optical time-domain reflectometry, or optical time-domain reflectometer
- PFE—power-feed equipment
- PM—performance management
- SDH—synchronous digital hierarchy
- SL—submarine lightwave
- SME—SL mediation equipment
- SSI—the Submarine Systems, Inc. business unit of AT&T
- TMN—telecommunications management network
- URM—Universal Restoration Manual

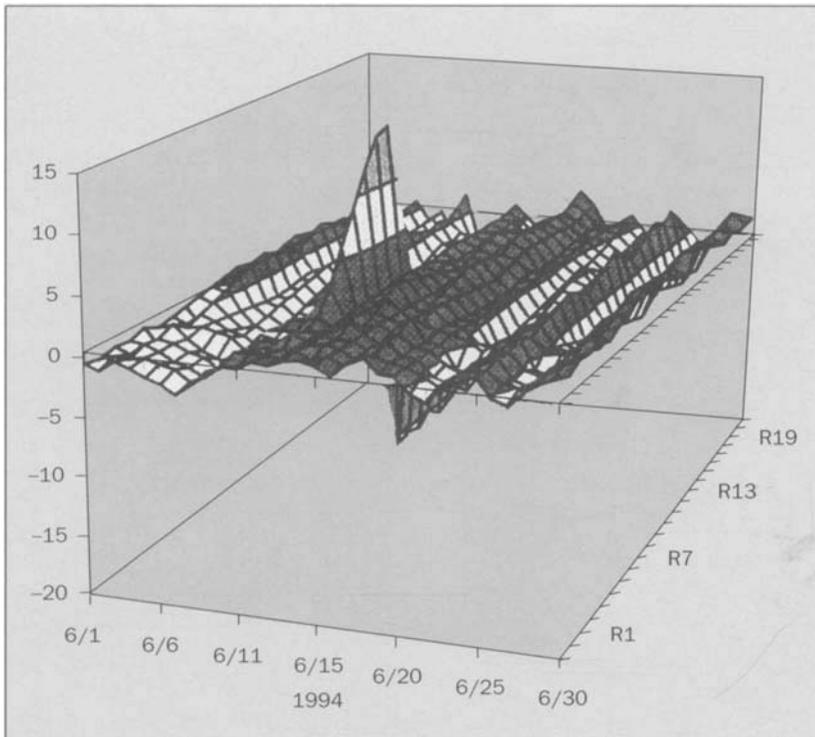


Figure 2. This three-dimensional historical report illustrates loop gains, over time, for a fiber pair. Loop-gain measurements indicate the performance of repeater spans. The peak shows loop-gain measurements on a fiber pair when there is a break in the fiber, in the receive direction, between repeaters R12 and R13. This report typifies a fiber pair that experienced a break and that was subsequently repaired. Variations in the surface, other than the fault peak, are representative of normal performance deviations.

cable termination point. The LME can also locate any degradation—to within one repeater span-pair—that can result in an impending fault. The LME's data facilitate routine analysis to detect changes in system performance over time. For instance, any emerging trends are observed to determine either if they are seasonal or related to some failure mechanism. In particular, it is recommended that an in-service, once-a-week check be made for any changes in transmission characteristics. Further, in less than one day, in-service monitoring can distinguish between local and distributed degradations under conditions of reduced end-to-end margin.

To assist in this analysis, tabular and graphical computer reports can be generated for recent measurements, as well as for historical data over user-specified time periods. In addition, reports are generated automatically when changes in measurements exceed a specific threshold.

Figure 2 is an example of a historical report. This three-dimensional illustration presents loop gains, over time, for a fiber pair. Individual span performance can be derived from consecutive repeater loop-gain measurements. The peak shows loop-gain measurements on a fiber pair when there is a break in the fiber, in the receive direction, between repeaters R12 and R13. This report typifies a fiber pair that experienced a break and that was subsequently repaired. Variations in the surface, other than the fault peak, are representative of normal variations in the performance of the undersea fiber spans.

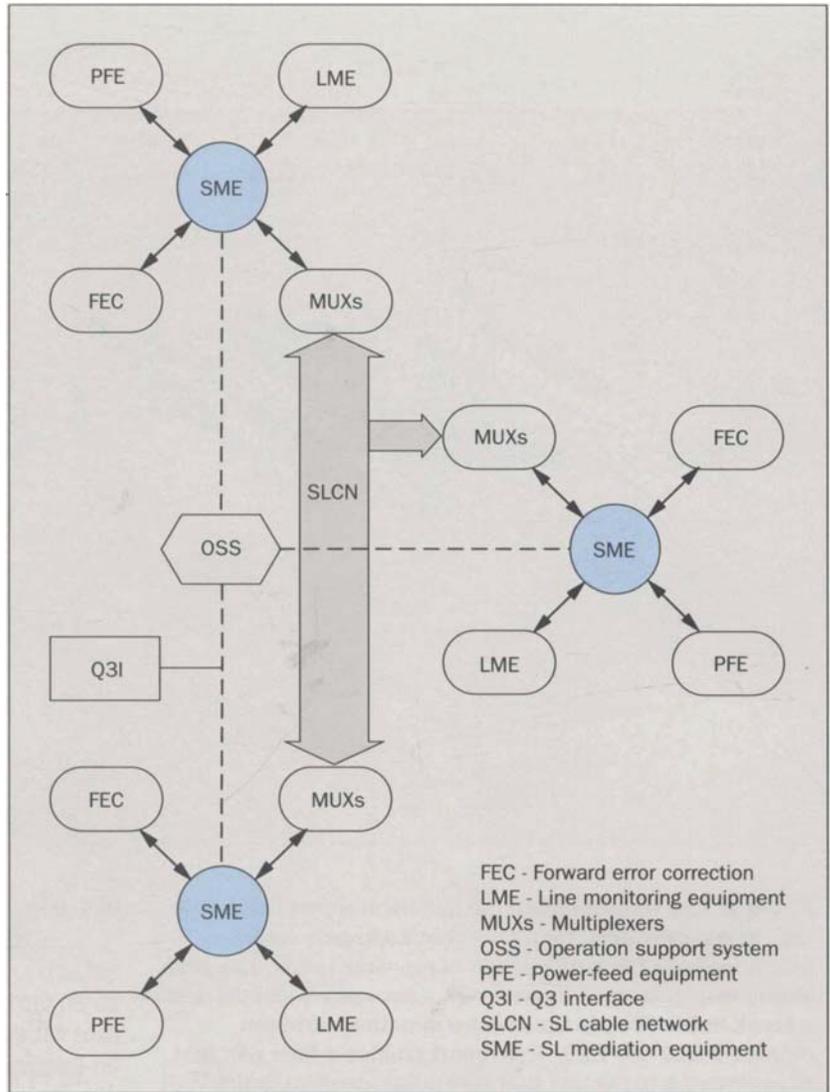
Fault Location, Restoration, and Repair

Two techniques are commonly used to detect and repair faults in undersea cable systems: *terminal* and *wet-system* methods. A discussion of each follows.

Terminal Fault Location and Repair. Undersea terminal apparatus detects and reports equipment failures by audio-visual indications. Optionally, it can also communicate with other maintenance systems (see the subsection on Integrated Network-Management Solutions and the discussion of SME). In addition, the equipment may provide automatic and manual switching for protected subsystems. Far-end alarms and performance parameters are transmitted to local terminal equipment, which then can discern whether a fault is incoming or outgoing. Terminal equipment is designed with redundant key subsystems. The terminals have been configured so that maintenance personnel can easily replace faulty circuit packs with locally stocked spare equipment.

Wet-System Fault Location and Repair. Each SSI undersea cable system has the inherent capability to locate such faults as cable shunts, fiber breaks, and repeater failures. Different fault-localization techniques, however, are available. For repeatered systems, they include use of the undersea supervisory system, low-frequency electroding, dc resistance, PFE voltage/current measurements, and optical time-domain reflectometry (OTDR) testing. Non-repeatered systems use the same techniques, except for the undersea supervisory system and PFE voltage/current measurement processes. When available, the easiest and most expeditious method is the

Figure 3. SL mediation equipment (SME) is logically associated with undersea cable terminations, and can be interconnected by means of cable or alternate communication facilities. This illustration shows an undersea network-management system (NMS) supporting a higher-level operations support system (OSS). The NMS is a three-terminal, branched, undersea cable network having a centralized telecommunications-management-network (TMN) architecture. SME is linked to an external OSS for consolidated network management.



undersea supervisory system.

When used in conjunction with sophisticated, real-time digital signal processing performed by the LME, the passive, undersea supervisory system can isolate to one section a fault in optical-amplifier equipment. The paper on *Undersea Optically Amplified Repeatered Technology, Products, and Challenges* provides additional details about LME.² Once a fault in a particular section is isolated, back-scatter testing pinpoints it using either an optical time-domain reflectometer (OTDR) or, optionally, a coherent OTDR (COTDR). The COTDR is an out-of-service capability that facilitates obtaining an OTDR plot for each fiber span in a system.

In-service fault location, however, is still the preferred method. Even so, some out-of-service procedures can locate faults not detectable by in-service methods. In less than one hour, out-of-service routines can localize a fault to a single amplifier section. Certain wet-system degradations, such as a failed pump laser, do not require repair due to the self-regulating action of a series of erbium-doped fiber amplifiers operating under compression, as discussed in the *Undersea Optically Amplified Repeatered Technology, Products, and Challenges* paper.²

More extensive faults or degradations sometimes necessitate wet-system repairs. These repairs can require sophisticated equipment, specialty ships, and submersible equipment. Also, depending on the topology, they can introduce significant lengths of additional cable.⁵ A customer receives wet-system repair procedures as part of a comprehensive documentation package.

Traffic Restoration Vis-à-Vis Network Capabilities.

Special protection systems in transmission-network ring configurations automatically restore traffic carried over fiber-optic cable that has failed completely. These systems are designed to restore service without "dropping" calls. Then, after service restoration, the maintenance systems discussed earlier are used to isolate the fault, facilitating planning of the repair.

Integrated Network-Management Solutions

As undersea telecommunication networks become more sophisticated and complex, the need for networked maintenance-and-reporting support systems becomes crucial. This is especially true of synchronous digital hierarchy (SDH) undersea cable systems using optical-amplifier technology.

Customers now require undersea cable-system operators to plan, provision, install, maintain, operate, and administer networks with increased reliance on net-

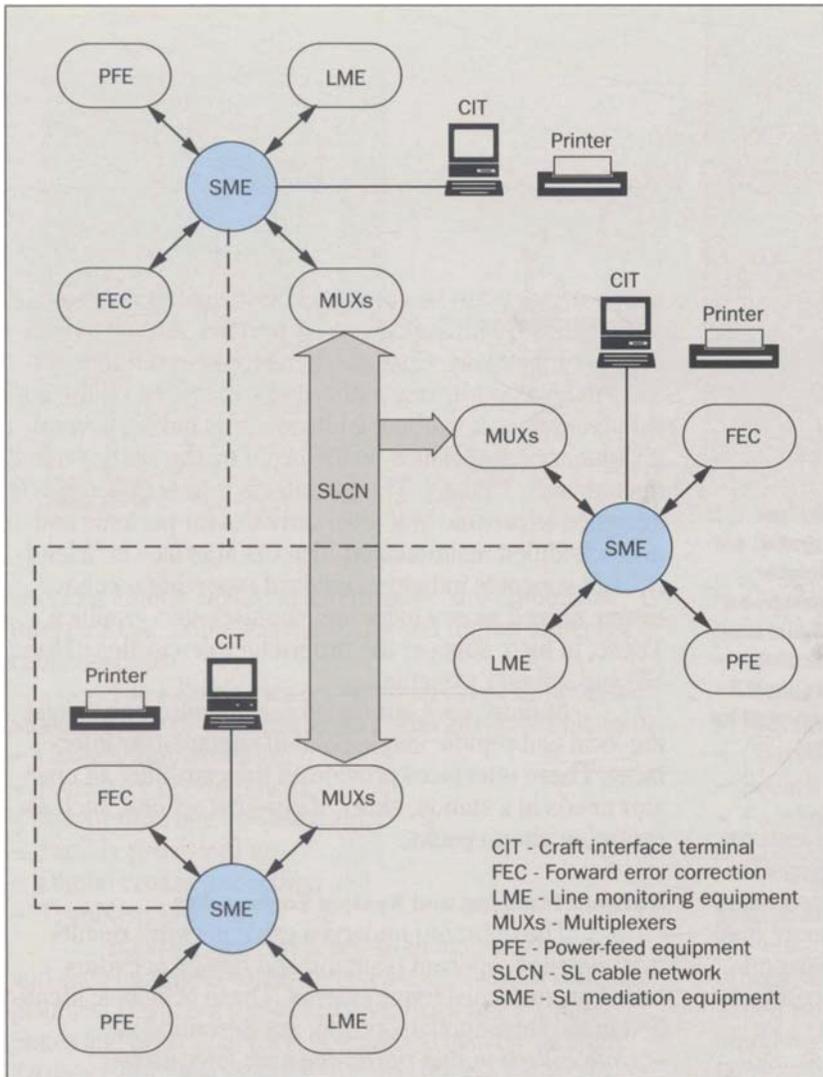


Figure 4. This illustration shows a stand-alone undersea network-management system (NMS). As in Figure 3, SL mediation equipment (SME) is logically associated with cable terminations. SMEs can be interconnected by means of undersea cable or alternate communication facilities. In this case, a three-terminal, branched, undersea cable network having a *de-centralized* telecommunications-management-network (TMN) architecture is shown. SME is networked to provide distributed access to individual network elements.

provide monitoring and control points, are considered NEs. Hierarchically, each of these elements is connected to the SME.

SME is a minicomputer-based system that supports graphical craft-interface terminals (CITs). These local and remote windows-based CITs are icon driven and feature point-and-click item selection. SME also supports relational data-base functions and upward communication capabilities. It does this through Q3 interfaces using the International Organization for

Standardization stack that transports *common management-information service element* managed objects to a higher-level OSS. SME supports three levels of users, and access is controlled through logins and passwords. The highest-level user has access to all CIT functions, including the authorization of additional users. Midlevel users have access to all readable CIT data and can also configure equipment, such as multiplexers. The lowest-level user can access only readable information, and cannot configure the multiplexer.

SME is logically associated with undersea cable terminations. It can be interconnected by means of undersea cable or alternate communication facilities. Figure 3 illustrates a three-terminal, branched, undersea cable network having a centralized TMN architecture. SME is linked to an external OSS for consolidated network management.

Figure 4 illustrates a three-terminal, branched, undersea cable network with a decentralized architecture. SME is networked to provide distributed access to the individual NEs.

worked, computer-aided maintenance tools that meet international standards. Currently, SSI meets all known customer requirements for network-management-system (NMS) support by configuring standard offerings as described in this paper.

The NMS function of an undersea cable system can be part of a larger telecommunications management network (TMN). The TMN includes operations support systems (OSSs) and their connections to submarine lightwave (SL) mediation equipment (SME). Alternatively, the NMS function can operate in a centralized or decentralized arrangement for stand-alone applications. Both configurations support integrated, surveillance-and-control activities during system installation, normal operation, maintenance, fault location, and repair activities. With respect to network management, an undersea cable system can include one or more network elements (NEs)—depending on customer needs—as shown in Figures 3 and 4. Such key components as LME, multiplexers, and PFE, which

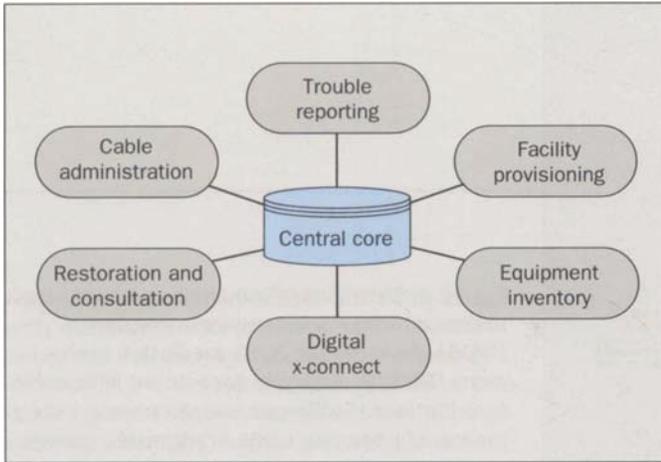


Figure 5. AT&T Submarine Systems, Inc. (AT&T-SSI) has developed a value-added portfolio of vertically integrated services that enables customers to manage and administer both international, domestic networks and digital undersea cable systems. Each service is realized as an individual module, and is supported on a UNIX/ORACLE data-base platform. The platform can accept future enhancements, and it can grow as customer needs grow. Each module can also be customized to meet specific customer requirements.

Functionally, SME provides the following features:

- *Performance management (PM) information presentation*, which provides operators with the data necessary to perform preventive maintenance and to ensure quality. The monitoring of PM data can detect end-to-end transmission-system degradation before service-affecting error thresholds are reached. PM parameters for G.821 are *errored seconds*, *severely errored seconds*, and *outage*. In addition, alert thresholds may be provisioned.
- *Fault-management capabilities*, including alarm reporting at the CIT, notification of key circuit-pack trouble reports, and logging-in the data base of alarms generated by digital line errors, PFE, and terminals (multiplexers). Alarms are filtered through a reduction process designed to display only the root cause of multiple alarm signals. This automated function effectively prevents information overload whenever many related faults are indicated simultaneously.
- *NE monitoring of key subsystems*, such as multiplexer data collected per G.821 or G.826 parameter sets, PFE status conditions, forward-error-correction performance (if so equipped), and the LMS system.
- *Historical logging*, including the collection, time stamping, long-term storage, and reporting of transmission-equipment performance data, alarms, acknowledgments, and significant operator and system activities.

Customers can choose to manage their undersea networks in a distributed fashion by means of access to each physical SME. Alternatively, a single-ended maintenance

strategy can be employed by accessing only one physical SME, with logical access to other SME by means of interconnectivity. Customers have requested that systems maintained by one authority be managed by the distributed-network method, while systems having several maintenance authorities be managed by the single-ended maintenance strategy. The CIT interface to SME and NEs is designed to provide first-level activities for periodic and non-scheduled maintenance. The CIT interface is "friendly," and supports industry-standard reporting mechanisms, as well as extensive and sophisticated graphics. These, in turn, support the proprietary properties of the SSI supervisory systems.

Maintenance strategies are optimized by providing local and remote single-point-of-contact user interfaces. These interfaces provide all the capability an operator needs in a station, short of physical actions, such as replacing circuit packs.

Network Planning and System Engineering

The optimum undersea cable network results from detailed, up-front planning and design activities based on customer requirements. These activities, identified in the Introduction section, are described as:

- *Data collection and traffic-demands forecasting*. Collection of traffic data to estimate current and future loads is fundamental to successful network planning.
- *Switch planning*. This activity is necessary to optimize distribution of a cable system's traffic, prepare for switching-system expansion, minimize costs, and to provide route diversity. It also facilitates load balancing among switches.
- *Bilateral traffic engineering and switch-to-switch circuit planning*. Traffic engineering and circuit planning convert the anticipated, offered loads into switch-to-switch circuit requirements and overflow patterns.
- *Facility planning*. Once circuit requirements are known, they must be allocated to facilities in a way that minimizes costs. This allocation includes diversity for failure protection, such as choosing among alternate facilities, and the appropriate deployment of other apparatus, such as compression equipment.

Operation and Administration

As shown in Figure 5, SSI has developed a value-added portfolio of vertically integrated services. These

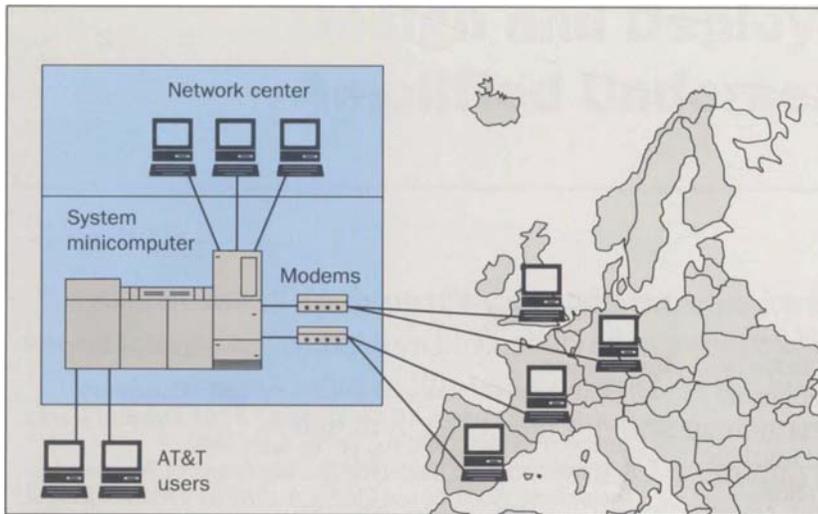


Figure 6. The value-added portfolio of vertically integrated services resides in a system's minicomputer. Customers can enable themselves to manage and administer undersea cable systems—through their network center—by accessing the minicomputer for the required software and hard-disk storage space. Customers can then access an undersea cable system, through separate modems, to verify equipment status and proper system operation.

services enable customers to manage and administer international, domestic networks and digital undersea cable systems.

The following six services can either be accessed independently or obtained as part of an integrated platform:

- Cable administration;
- Inventory of equipment;
- Restoration and consultation;
- Facility provisioning;
- Digital cross-connecting; and
- Trouble reporting.

Each service is realized as an individual module, and each module is supported on a UNIX/ORACLE data-base platform. (UNIX is a registered trademark in the United States and other countries, licensed exclusively through X/OPEN Corp. ORACLE is a registered trademark of ORACLE Corp.) The platform is sufficiently flexible to accept future enhancements, and it can grow as customer needs grow. Modules can be customized to meet specific requirements, such as screen enhancements. Customers access the system through dial-up, secure modems, and they are introduced to a menu of services, as illustrated in Figures 5 and 6.

These vertically integrated customer services are available in two specific offerings:

- Customers enable themselves to manage and administer undersea cable systems by accessing a system's minicomputer for application software and disk storage space.
- Customers assign the management and administration of undersea cable systems directly to SSI, which provides both functions as a package.

Cable Administration. The Cable Administration System automatically tracks and assigns digital-cable-facility information. It can work with small or large digital undersea cable systems, and it is adaptable to plesiochronous-digital-hierarchy or SDH architectures.

The Cable Administration System provides users with the following capabilities and enhancements:

- Tracking and assigning cable-facility information;
- Multiplex reports;
- Ownership reports;
- Multi-cable queries;
- Foreign-extension-facility tracking;
- Customized reports and sorting;
- Security assurance;
- Foreign-extension outage reports; and
- Graphical user interfaces (GUIs).

Inventory of Equipment. An equipment-inventory system allows customers to manage—and alter the status of—equipment in cable stations (wet/dry plant), facility offices, and switching centers. It also provides customers with a wiring diagram (office layout) that identifies the equipment comprising a facility. This system also maintains a record of the component parts of each network element under its control. Inventory items can include equipment type, manufacturer, model number, relay rack, shelf, serial number, first cost, year installed, warranty date, last update, and status.

Restoration. A restoration system provides the following two on-line features:

- *Bulletin board.* This allows a system administrator to share information regarding the equipment's status with the system owners. Such data can include details about planned system outages, work being done on wet or dry plant, and restoration efforts.
- *Universal Restoration Manual (URM).* Entered and stored by a restoration liaison officer, access to the URM allows a restoration control officer, and the responsible organizations, to work from the same plan and to manage a repair operation effectively.

In providing these on-line features, a comprehensive evaluation of either a customer's existing or planned undersea cable network is performed. Such an evaluation provides a detailed report about potential restoration costs, outage frequency, mean-interruption duration, and types of

service faults. This evaluation is an important first step in defining either any problems that presently exist or any that can arise due to planned network changes or new-system deployment. The evaluation considers another important factor as well: the cable system's ability to meet owners expectations relative to service availability and reliability. Based on the evaluation, a cost-effective restoration process, for either existing or planned digital undersea cable systems, can be developed.

Facility Provisioning. This feature allows a customer to issue orders for digital facilities and to track progress up to the facility due date (date the facility is turned up). All facility schedules for equipment and testing are logged into the system, which then provides a real-time status report. Evaluating this report helps customers identify possible improvements in the provisioning process that are needed to meet the scheduled, ready-for-service date.

Digital Cross-Connecting. An embedded system tracks all digital cross-connect port assignments and facility designations at a cable termination point or facility office. The system provides mapping information for *in* and *out* ports, which are required to manage the entire digital-cross-connect operation.

Trouble Reporting. A trouble-reporting system allows a customer to log, track, and ascertain the status of specific faults. These faults can include nonworking plug-in circuit packs, broken connectors, and software defects.

Conclusion

AT&T network-management-system (NMS) solutions effectively support the activities associated with undersea cable-system installation, routine maintenance, fault location, and automatic/manual restoration and repair. Specifically, the SL mediation-equipment (SME) architecture supports stand-alone-networked and hierarchical-networked maintenance and reporting.

Traditional undersea cable products—and the vertically integrated services of cable administration, equipment inventory, restoration, consultation, facility provisioning, digital cross-connecting, and trouble reporting—have positioned AT&T as a world-class provider of undersea cable systems. Due to the continuous evolution and ever-changing nature of the global network, however, research is continuing on the development of new products, systems,

and services that will be needed in the years ahead.

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