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Global Networks: A KDD-SCS / Lucent Technologies Collaboration



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Traditional global networks have used SDH rings to provide TDM connectivity between shore stations with back-haul facilities to nearby major cities. In recent years, this architecture has been stressed due to increased bandwidth requirements, need for packet-switched data connectivity, and seamless city-to-city connections. A new view of global networks is emerging, consisting of a λ-centric mesh network that integrates both submarine and terrestrial networks. This paper summarizes trends and discusses enabling technologies, and is a collaboration aimed towards embodying these trends in evolving global networks.

This paper addresses:

- Traditional global (submarine plus terrestrial) network architecture and the issues associated with these networks
- Evolutionary λ-based networks and how they address these issues
- Deployment of λ-based networks with the intelligent optical cross-connect, featuring LambdaRouter as a key enabling technology
- Innovative services made possible by the new global network architecture
- Description of the Global λ-Networking Test Bed (a joint effort between KDD-SCS and Lucent Technologies to demonstrate the new global architecture)
- An end-to-end global network that embodies the unique capabilities of the KDD-SCS/Lucent Technologies collaboration

Traditional Global Networks: Issues and Trends

In the traditional global network, traffic is aggregated at a city POP (Point of Presence), delivered over SONET/SDH rings to a landing station, where it is further aggregated on to sea-going rings for transport to another landing station (see Figure 1). At the receiving landing station the reciprocal process occurs: the traffic is disaggregated and sent on to the city POP, as depicted in Figure 1.

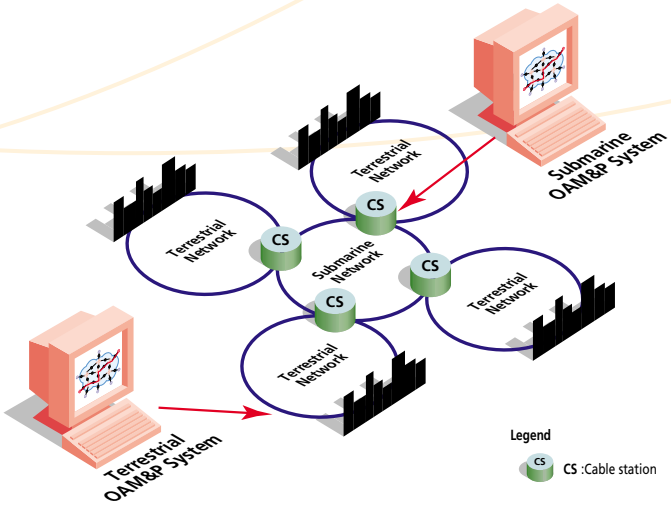

Figure 1. Traditional Global Network

While the land-sea partitioning with its segregated OAM&P (Operations, Administration, Maintenance and Provisioning) domains has served us well for the past few decades, it has become clear that the needs of the industry are changing.

Following are key issues and evolutionary trends that will be discussed:

- City-to-city connectivity: integrated OAM&P
- Bandwidth explosion
- Data dominance
- Network topology considerations

City-to-city Connectivity: Integrated OAM&P

The industry has recognized that its OAM&P needs are best served by city-to-city connectivity. As shown in Figure 2, the global network extends from POP to POP, with a single OAM&P environment, and the distinction between submarine and terrestrial networks is blurred or eliminated.

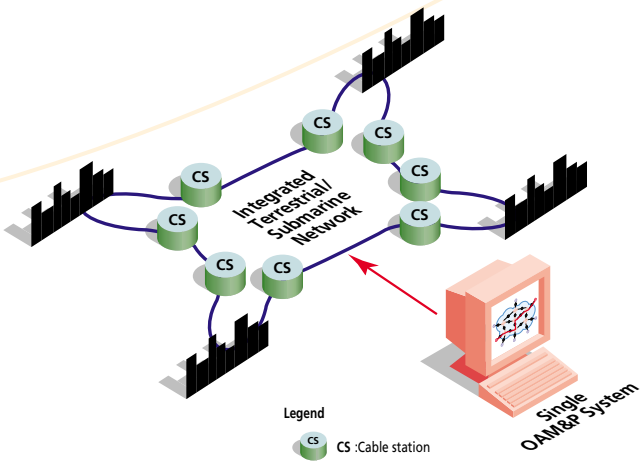

Figure 2. City-to-City Connectivity

In general, the segmented environment of Figure 1 requires multiple OAM&P systems. As a result, the network management systems become unwieldy, with a duplication of functionality between the segments. By contrast, in the monolithic OAM&P environment (Figure 2), greater automation and economies of scale should inevitably result.

Bandwidth Explosion

The demand for higher bit-rates in transoceanic applications is fueled in part by the popularity of the Internet, and in part by business needs to exchange data across distant locations. It has driven the development of new technology to dramatically increase submarine transmission capacity. Research and commercial capacity increase over the past decade is reflected in Figure 3.

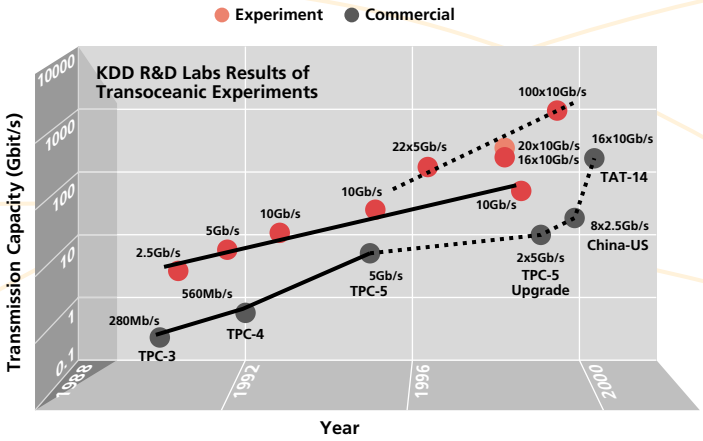

Figure 3. Progress of Transoceanic Long-Haul

Transmission using DWDM Technology

The capability of transoceanic Terabit transmission was reported for the first time at ECOC'99 (European Conference On Optical Communication) in Nice.[1] The next generation of submarine cable systems for transmitting Terabit capacities over trans-oceanic distances is under intensive development by KDD-SCS.

In the expected Terabit submarine cable systems, hundreds of wavelengths will be transmitted over a single fiber at rates of 10Gb/s. At the same time, to increase the cable capacity, a new type of submarine optical cable capable of accommodating eight fiber pairs has been developed. Consequently, thousands of wavelengths will be de-multiplexed and terminated at land-

[1] T.Tiritani et al., "1Tbit/s (100x10.7Gbit/s) Transoceanic Transmission using 30nm-Wide Broadband Optical Repeaters with Aeff-Enlarged positive Dispersion Fibre and Slope-Compensating DCF", Nice, France, post-deadline paper, PD2-8.

ing stations by Submarine Line Terminal Equipment (SLTE), in contrast to the current generation of submarine WDM systems providing 4 fiber pairs, each supporting 16 λs at 10Gb/s per λ (see Figure 4).

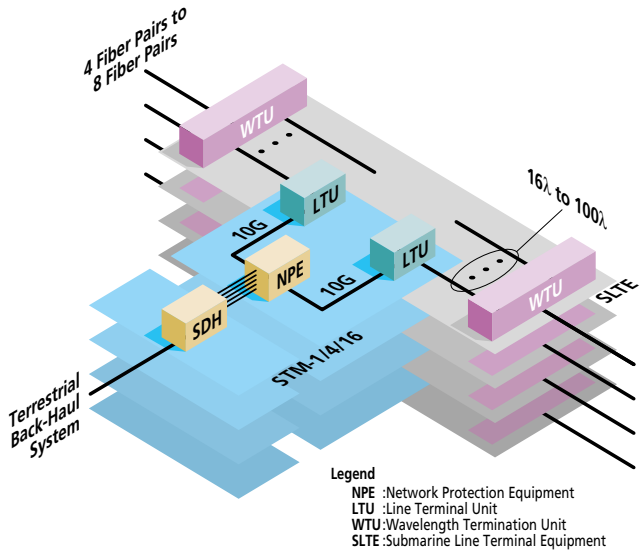

Figure 4. Terminal Equipment Configuration at Landing Station

Footprint, Power, and Cost

When STM-64 lines are de-multiplexed to tributaries, the footprint of the terminal equipment is expected to increase by an order of magnitude. When Terabit submarine cable systems are deployed (assuming the equipment is co-located), the amount of space required for SONET/SDH equipment to transfer the capacity to the terrestrial back-haul system at the shore-end cable station will be also increase similarly. A like argument applies to the power used by the terminal equipment.

For WDM submarine systems, the terminal cost becomes dominant in the total system cost. The unit price of wet plant may increase somewhat, but it is not a strong function of the capacity of the system. The terminal equipment costs will increase in proportion to the number of wavelengths of the system. For example, in a 160Gb/s transoceanic submarine cable system, more than 50% of the system cost is in the terminal equipment, i.e. SONET/SDH equipment. For a Terabit system, if the same network architecture continues to be used, the terminal equipment cost, and therefore, the total system cost will significantly increase.

The Data Revolution

The industry shift from voice-optimized, circuit-switched services to data-optimized, packet-switched services is by now well under way. As a consequence, the value of SONET/SDH as an intermediate multiplexing layer is diminishing.

Many vendors are developing solutions designed to carry IP traffic directly over DWDM, and various standardization bodies are addressing the same problems. The industry trend is to bypass the need for SONET/SDH based networks and to develop technologies capable of supporting optical networks capable of carrying any optical signal regardless of the signal format.

The notion of supporting “data directly over optics” has been fueled by the need to eliminate unnecessary network layers. This will lead to a vast reduction of equipment in the network and therefore the cost, footprint and complexity of the network are expected to drop substantially.

Survivability and Topology

Survivability is an essential ingredient in telecommunications networks. The network topology leads to different restoration schemes. The two major network topologies are ring and mesh (see Figure 5).

Ring Networks

In current submarine networks, the ring network architecture is widely used for network protection. A SONET/SDH ring network protection uses the APS protocol that has been standardized by ITU-T and is well established. For undersea applications the Network Protection Equipment (NPE) supporting 4-fiber rings is required to comply with the transoceanic protocol.[2]

In optical networks, by embedding a SONET/SDH signal within an FEC envelope as per ITU-T G.975, ring network protection can be implemented. KDD-SCS offers such optical NPEs whose first model has been proven in the field.

[2] Described in ITU-T G.841, Annex A. (Types and Characteristics of SDH Network Protection Architectures)

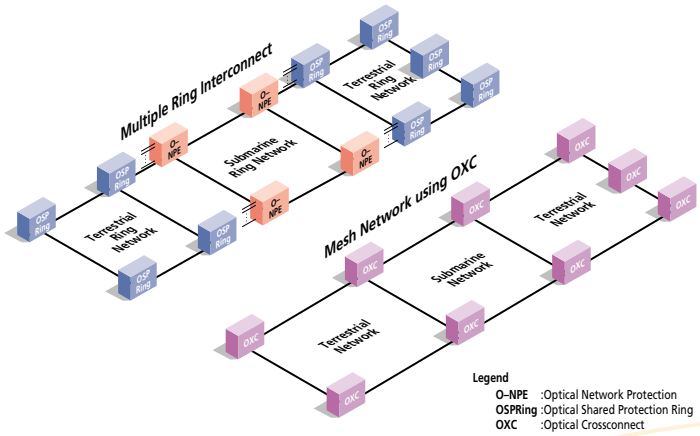

Figure 5. Comparison of Ring and Mesh Networks

Mesh Networks

Ring-based protection tends to be faster than mesh restoration because it is a simpler, more constrained approach. However, as mesh methods close the performance gap, mesh networks are expected to gain acceptance in optical layer networking for several reasons:

- Mesh networks offer a more flexible topology than rings, and can adapt to changing traffic patterns more efficiently than ring networks.
- Mesh networks uses network protection and restoration capacity more efficiently than ring networks. This is because in the former there are generally multiple choices for the restoration path, whereas in the latter there is only one. Because of this reason, mesh networks are more forgiving under multiple failure scenarios, and offer higher availability.
- Extra capacity is required for ring networks over that for their mesh counterparts on the ring boundary segments, as shown in Figure 5.

New World View: Lambda-Based Networks

A new network model is emerging to address the evolutionary needs of the global network.

Through the use of intelligent OXC Systems in conjunction with DWDM technology, an intelligent optical transport layer is defined that allows the fiber infrastructure to be shared dynamically. This is accomplished through the flexible end-to-end provisioning of wavelength (λ) channels.

The concept of λ-based *networks* is born: groups of interconnected λ channels form a network, each such network disjoint from the other while riding the common underlying fiber infrastructure. In a λ-based network, OXCs provide the ability manipulate optical channels.

As shown in Figure 6, with the intelligent optical transport layer, the new network model consists of three layers:

- *The service layer*, which provides end-to-end services, without regard to the underlying network topology.
- *The λ layer*, which provides wavelength and network topology management.
- *The fiber layer*, which constitutes the transport infrastructure for the multitudinous wavelengths in the λ layer.

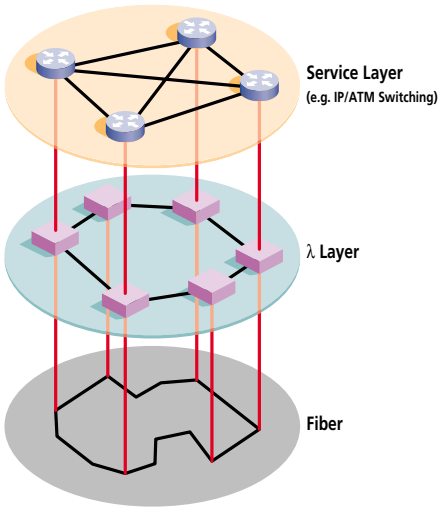

Figure 6. New Network Model

Benefits of the Optical Transport Layer in Global Lambda-Based Networks

The deployment of global λ-based networks will be useful in removing multiple transport and OAM&P infrastructures, since λ-based networks can accommodate different signal formats in a common network platform. It is expected that the signal format conversion and tributary aggregation, together with OAM&P relating to tributaries, get pushed out to the network edges.

Global networks will operate in the λ layer where the equipment involved consists mainly of Optical Cross-Connect systems (OXCs) and back-haul transport equipment. SONET/SDH add-drop multiplexers and routers are network elements supporting the service layer. As a result, the core transport network architecture is simplified and minimized.

At the landing station, the aggregation of traffic to λs removes the large number of tributary interfaces and SONET/SDH interconnection equipment associated with terrestrial back-haul networks when the tributary interfaces are pushed to network edges. The role of SONET/SDH network equipment will be taken over by the optical layer network equipment, with a dramatic footprint reduction, due to the λ granularity.

The minimization of network equipment, together with the removal of SONET/SDH equipment interconnecting to terrestrial networks, will contribute to a large scale reduction in equipment cost.

Enabling Global λ-based Networks with LambdaRouter

LambdaRouter Optical Cross-Connect

Lucent Technologies WaveStar™ LambdaRouter, along with its associated software, provides optical cross-connect functions with a single-stage free space optical interconnection for NxN wavelengths. The optical switch of LambdaRouter is based on the MEMS (Micro-Electro Mechanical System) technology. A 256x256 optical cross-connect fabric was first demonstrated at Telecom '99 in Geneva. LambdaRouter has a scalable optical fabric; one that can be scaled up by a factor of 4 in the current release. Compared to electronic fabrics, the MEMS-based optical fabric provides a reduction in power consumption. In addition, the optical ports have been tested to support wavelengths carrying up to 40 gigabits per second.

Optical Cross-Connect (OXC) Systems will provide the capability to steer optical channels, which is the key to efficient utilization of a mesh network. OXCs are expected to follow label switching protocols (or MPLS-like protocols) to provide the routing functionality and the restoration in mesh networks.[3]

The ability to support λ-based networks is the key to keeping pace with unpredictable traffic demands and multiple protocols. The LambdaRouter technology supports the ability to create λ-global based networks which, unlike traditional SONET/SDH networks, provides bandwidth scalability and networking flexibility for today's networking environment.

Wavelength Path Provisioning and Dynamic Routing

A software platform known as SoftWave™ has been also developed by Lucent Technologies to manage wavelength paths in a network of LambdaRouters. This software platform can provide fast "point-and-click" provisioning of light-paths between given end-points in an optical network, which is key for on-demand bandwidth allocation (Figure 7). It also provides network restoration capabilities by performing dynamic routing by computing the optimal path between any given points in the network based on the state of the network and the link information between LambdaRouters.

[3] D.Awduche, Y.Rekhter, J. Drake, R. Colton, "Multiple-Protocol Lambda Switching: Combining MPLS Traffic Engineering Control with Optical Cross-Connects", IETF Internet Draft.

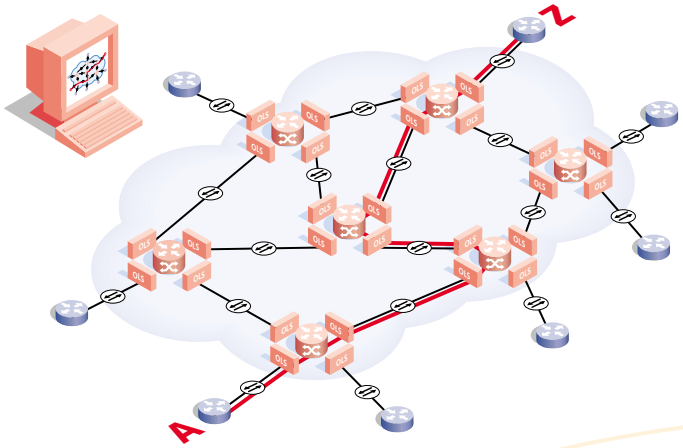

Figure 7. "Point and Click" Provisioning via SoftWave

Lambda-Based MPLS

For management of large-scale OXC-based mesh networks, the capability to perform node and link auto-discovery is essential to facilitate the autonomous switching and routing functions. To enable such functions, MPLS-based traffic engineering tools will be developed, consisting of an implementation of λ-based MPLS protocol together with the distributed database systems containing LambdaRouter network link and node states.

In the advanced phase, an optical network will have the capability to reconfigure itself in real time based on service levels set by the end customer. It is a network which can auto-discover new routes when new nodes are added. This will enable Optical Virtual Private Line (O-VPN) services together with Flat Rate or Usage Based billing Options. These functions will create a new paradigm of an intelligent optical network.

Future Network Services

Global optical networks will support new telecommunication services aimed at meeting the carriers' needs.

Major global carriers provide city-to-city connectivity in their global data networks. In order to differentiate from other service providers in both metropolitan and global networks they need to be able to provision broadband capacity in granularity increments of at least STM-16 in a fast and economical way. The central objective of the transparent λ connection is to enable this kind of service, using optical layer technology throughout the entire network of integrated submarine and terrestrial systems.

The deployment of data networks to connect data centers across global networks is an important telecommunication service. λ connectivity can simplify the network architecture. The data center is usually located in a metropolitan area and can be connected to other data centers though a direct λ connection as shown in Figure 8.

This is a major simplification in comparison to the present mode of operation, where data traffic is transported with many "hops" through multiple IP routers and multiple facilities. Hence the direct optical end-to-end connection enables "One Hop" routing and improves the performance of the packet transport as well as the system economy. The advantage of the optical layer networking will be enhanced as the service capacity increases.

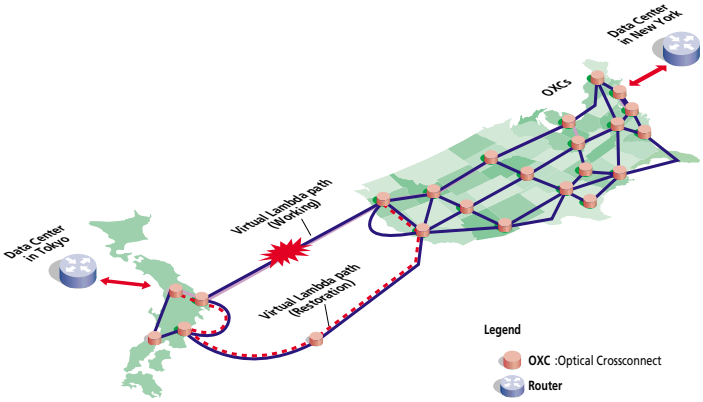

Figure 8. λ-based Connection between Data Centers located in Metropolitan Area

Lambda Services

With optical layer networks, new business models can be envisioned. The proposed system supports the implementation of the services needed for these new businesses. For example:

- New Leased Line Services
- On-Demand λ Provisioning Services
- Optical Virtual Private Network Services
- Capacity Wholesale Business

New Leased Line Services

Network transparency and fast Point-and-Click provisioning will enhance the availability of leased line services. In the optical layer networks, the multiple levels of network restoration and protection can be embedded on a per λ path basis. This functionality is desirable to deliver services complying with diverse client requirements.

On-Demand Lambda Provisioning

On-demand λ services based on real-time establishment of λ connections enables the creation of various new business opportunities. For this reason, on-demand λ services will be for a much sought-after capability in future networks. For instance, on-demand λ provisioning capability enables bandwidth trading, where the λ's will be traded as a commodity. Instead of the current IRU-based bandwidth, this feature reduces investment risks and the overhead costs, especially for ISPs. This feature also enables capacity portability that facilitates the bandwidth trading market.

Optical Virtual Private Networks

For enterprise customers, λ-based private global networks can be constructed leasing λ resources in the optical layer network infrastructure. In other words, λ-based global intranet services can be deployed. The signaling coordination between the data networking equipment and optical layer networks will be the key technology to implement O-VPN.

Capacity Wholesale Business

The carrier's carrier business in the global network is expected to be another important future telecommunication service. It is desirable for the major global service providers to have end-to-end capacity assured by SLA, since it is less costly to obtain capacity from one provider rather than from multiple retail sellers.

Just as the dark fiber business has proven valuable to new service providers, λ-based services will be valuable to those providers who lack sufficient telecommunications infrastructure. The sales of λ capacity holds the promise of large revenue to carriers having global networks operating in the optical layer.

Global λ-Networking Test Bed

To validate the concepts discussed above, KDD-SCS and Lucent Technologies have jointly established a Global λ-Networking Test Bed (Figure 9), which will provide a setting to demonstrate concept evolution and application of the next generation of intelligent submarine and terrestrial integrated optical networks.

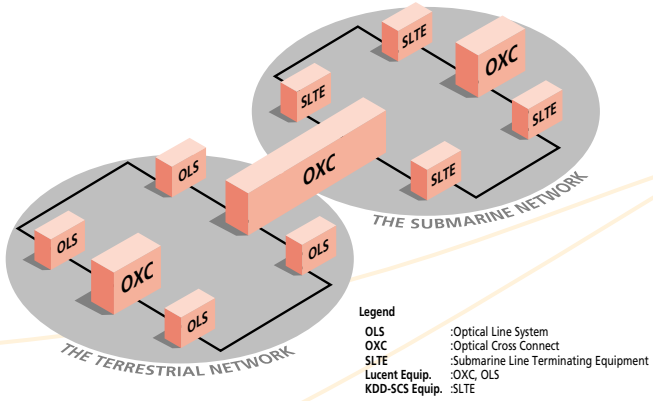

Figure 9. KDD-SCS/Lucent Technologies Global λ-Networking Test Bed

The Test Bed combines the value of KDD-SCS's submarine technology and Lucent Technologies' terrestrial transport equipment.

The main hardware components are:

- KDD-SCS OS-W SLTE system which provides submarine 10Gb/s networking together with new enhanced FEC functionality
- Lucent Technologies WaveStar LambdaRouter, which provides OXC capabilities
- Lucent Technologies WaveStar OLS-400G Optical Line System which provides terrestrial 10Gb/s transport

The network software components are:

- Lucent Technologies SoftWave that will be used to manage the O-VPNs and provide point-and-click λ provisioning. SoftWave will provide automated mesh restoration.
- KDD-SCS MC which will provide network element level management for the submarine network
- Lucent Technologies SNMS which will provide element-level management for the terrestrial network.

The Global λ-Networking Test Bed can be configured in various forms, such as a dual-ring or mesh networks, to meet the expected customers' requirements.

Key to enabling the seamless networking between submarine and terrestrial systems is the implementation of proper translation between the proprietary network signaling systems together with the reconciliation of the equipment interface specifications. The interworking between SLTEs and LambdaRouters is one of the major efforts to provide new lambda services. At the same time, this seamless network connectivity between KDD-SCS's and Lucent Technologies' equipment can reflect on the creation of the unified global network management systems.

The Global λ-Networking Test Bed is expected to demonstrate and prove the following concepts:

- Signal format independence of the O-VPNs
- Automatic network reconfiguration in response to failure or overload conditions
- Automatic adjustment when service level parameters are modified by the end user
- Unified network management throughout the entire system

The joint KDD-SCS and Lucent Technologies Global λ-Networking Test Bed is under development and is scheduled to be constructed by 2nd Quarter, 2001. The proposed network functionalities will be tested throughout 2001. The test results will be reflected in the new concepts for global networks beyond 2001, which seamlessly integrate submarine and terrestrial networks based on the optical routing technologies.

KDD-SCS/Lucent Technologies End-to-End Implementation Concept

Given the several initiatives taking place today for the expansion of the submarine transmission capacity, as well as the ones planned to happen in the near future, global carriers are expected to face dramatic and increasing competitive pressures.

In spite of this fact, it is well recognized by the industry that the bandwidth supply derived from these projects will drive an extraordinary ability to cost effectively develop and use new applications and these new applications will require more and more bandwidth. This is becoming the nature of the supply-demand cycle that global carriers will face in the bandwidth business.

In order to overcome these variations in the demand and supply profiles, it is imperative that global carriers can successfully:

- Develop bandwidth-intensive services to support the new applications customers will use (demand creation initiative);
- Pursue time-to-market leadership and to establish the desired market share position and customer satisfaction (effective supply initiative).

The end-to-end implementation KDD-SCS and Lucent Technologies are developing as a result of the experiments in the Test Bed will address the items mentioned above, by providing global carriers the integration of the following set of capabilities:

- The system design, project management and submarine equipment capabilities from KDD-SCS;
- All-optical network capabilities from Lucent Technologies.

The end-to-end joint implementation from KDD-SCS and Lucent Technologies will also create value to customers by streamlining the coordination process in the deployment of both submarine and terrestrial networks.

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Glossary

APS	Automatic Protection Switching
ATM	Asynchronous Transfer Mode
DWDM	Dense Wave Division Multiplexing
FEC	Forward Error Correction
IP	Internet Protocol
IRU	Indefeasible Right of Use
ISP	Internet Service Provider
KDD-SCS	Kokusai Denshin Denwa-Submarine Cable Systems
MC	Maintenance Controller
MEMS	Micro-Electro Mechanical System
MPLS	Multi-Protocol Label Switching
NE	Network Element
NPE	Network Protection Equipment
OAM&P	Operations Administration Maintenance and Provisioning
OLS	Optical Line System
OTU	Optical Translator Unit
O-VPN	Optical Virtual Private Network
OXC	Optical Cross-Connect
POP	Point of Presence
SDH	Synchronous Digital Hierarchy
SLTE	Submarine Line Terminating Equipment
SNMS	Sub Network Management System
SONET	Synchronous Optical NETwork
STM	Synchronous Transport Module
TDM	Time Division Multiplexing
WDM	Wavelength Division Multiplexing

Notes

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