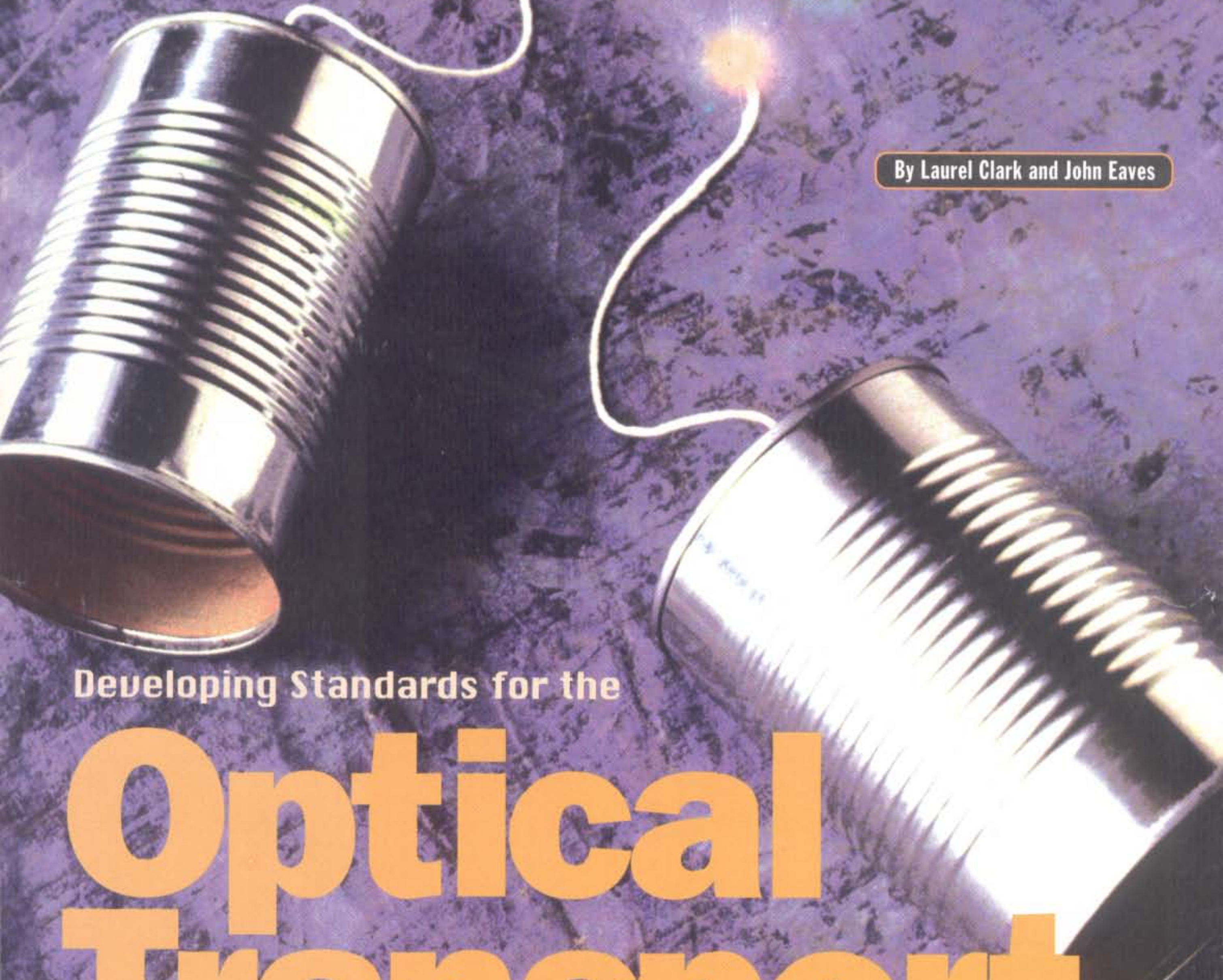
Developing Standards for the

Optical Transport Network

By Laurel Clark and John Eaves

With the rapid expansion of fiber optic telecommunications, the need for prospective standardization is critical. The authors provide a current picture of where the international standardization effort stands and the challenges confronting those both defining and working within them.



The unprecedented growth of the telecommunications services market is fueling the rapid expansion of new and existing high capacity transport systems for interoffice and long distance networks. Technologies like optical amplifiers and wavelength selective optical components have enabled the widespread deployment of very high capacity wavelength division multiplexed (WDM) optical transmission systems into these network segments. Although initially conceived and deployed to satisfy capacity demands for point-to-point applications, multiple wavelength optical systems also make possible the consideration of optical signal routing within an underlying optical layer of the transport network. With the introduction of optical multiplexing and signal routing capabilities, we see the beginnings of an evolution toward an optical transport network that promises simplified operations, reduced equipment cost through the elimination of high-speed electronic equipment, and the ability to carry a variety of optical signals with different bit rates and formats.

Even as the technical capabilities of the optical layer expand, service demands will continue to push ever higher the needed capabilities of these networks, including the requirement to interconnect them at carrier and customer boundaries. To help manage the introduction of the necessary technologies for this increasingly complicated network, network operators look to telecommunications equipment, services, and performance standards. Utilization of standards-compliant services and equipment allows users to benefit from increased competition through economies of scale, enables interconnectivity between networks, and increases confidence that performance quality can be maintained across network boundaries.

This article provides an overview of some current and emerging international standards for the physical layer of point-to-point optical transmission systems and the future optical network. Although most optical networking standards are in their infancy, significant decisions are now being made regarding the fundamental characteristics and capabilities of optical networks. A phased approach has been proposed for the development of this family of optical networking recommendations, starting with point-to-point systems and growing to include multiplexing and cross-connect systems. This article briefly addresses sub-system, component, and fiber standards, identifying those aspects particularly relevant to the system and network perspective. Management and service quality standards are equally vital to successful network operation, but are not discussed here because significant work in these areas for the optical network has not yet begun.

Background

The current focus of work toward developing specifications for the optical transport network is the International Telecommunications Union (ITU). To put the work of the ITU in perspective, it is useful to review the history and charter of the organization.

The Telecommunications Age began in 1844 with the first public telegraph transmission. Telegraphy networks grew rapidly through the nineteenth century, but due to an absence of standards and uniform operating procedures among carriers, messages generally had to be transcribed and retransmitted between carrier boundaries. To avoid a multiplicity of bilateral agreements among the network operators, 20 European nations decided to establish a framework agreement on common rules to standardize equipment for generalized interconnection, adopted uniform operations procedures, and established common international tariff and accounting rules.

The ITU (then the International Telegraphy Union) was created in 1865 by these participating nations to work out subsequent amendments to this initial agreement. In 1934, the International Telecommunication Union was created to oversee the standardization of all forms of communication among countries, and in 1947 it was agreed that the ITU would be a specialized agency of the United Nations. The role of the ITU has evolved over the last 133 years to cover standards for a wide range of telecommunications networks and services, including international standards for fax, ISDN, JPEG and MPEG algorithms, ATM (asynchronous transfer mode), and the Synchronous Digital Hierarchy (SDH). The ITU is currently leading efforts to establish appropriate standards for the optical transport network.

The ITU is organized into three main sectors

- ITU-R: responsible for managing efficient use of the radio-frequency spectrum and satellite orbits;

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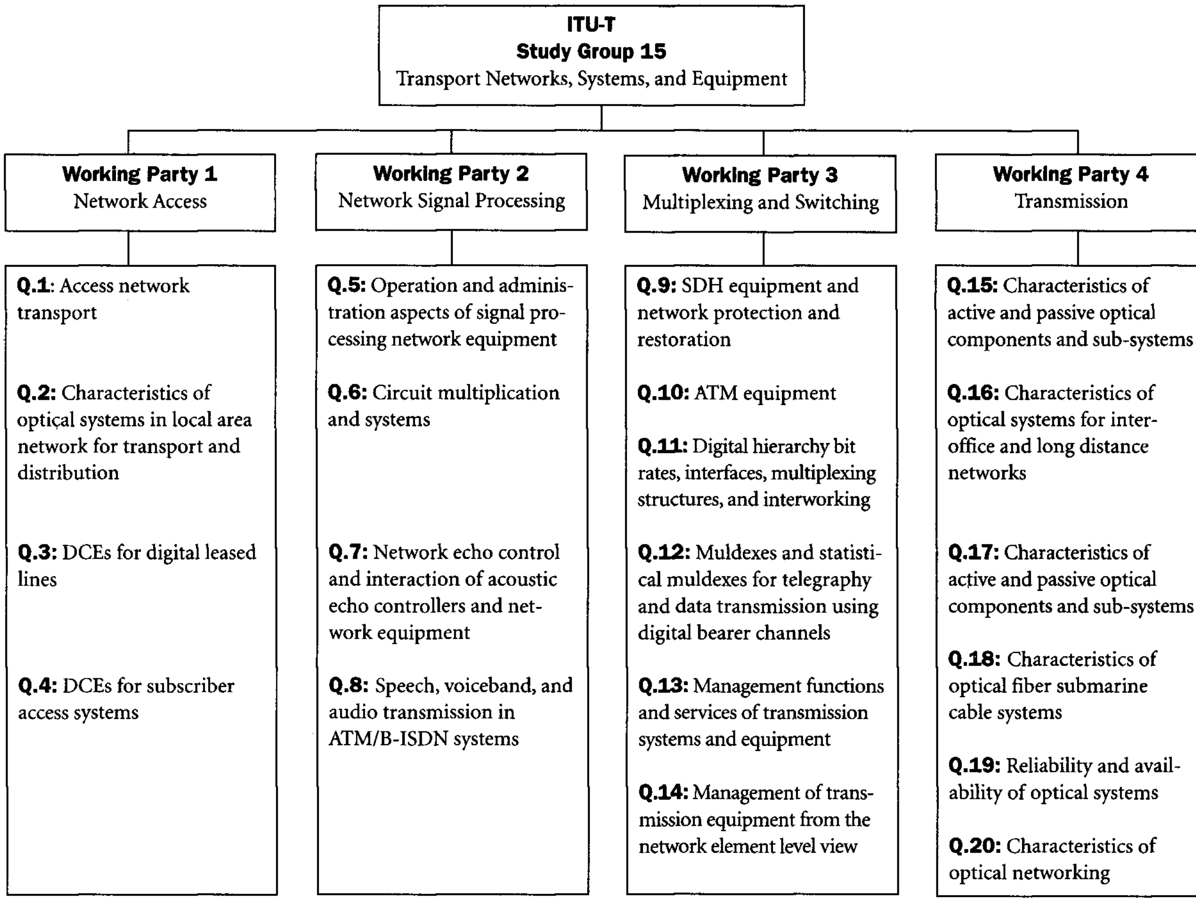

Figure 1. Organization of ITU-T Study Group 15.

- ITU-D: supporting the needs of developing countries in expanding their national telecommunications networks; and
- ITU-T: responsible for telecommunications standards development.

The scope of standards necessary for modern telecommunications networks and services is enormous and so the ITU-T work is organized into 14 Study Groups (SGs), which have expertise in specific technology or service areas. In turn, each SG is organized into various Study Questions under which the individual ITU-T Recommendations are developed. The constituent Study Questions for SG15 are shown in Figure 1. The technical input to the Study Questions comes from ITU member organizations, which currently include 187 member countries and 400 private sector organizations.

Recommendation Name	Responsible ITU Organization
G.655—Characteristics of a non-zero dispersion single-mode optical fiber cable (1996)	ITU SG15 WP4 Q.15
G.661—Definition and test methods for the relevant generic parameters of optical fiber amplifiers (1996)	ITU SG15 WP4 Q.17
G.662—Generic characteristics of optical fiber amplifier devices and sub-systems (1995)	ITU-SG15 WP4 Q.17
G.663—Application related aspects of optical fiber amplifier devices and sub-systems (1996)	ITU SG15 WP4 Q.17
G.671—Transmission characteristics of passive optical components	ITU SG15 WP4 Q.17
Draft G.691—Optical interfaces for single-channel SDH systems with optical amplifiers, and STM-64 systems	ITU SG15 WP4 Q.16
G.692—Optical interfaces for multi-channel systems with optical amplifiers	ITU SG15 WP4 Q.16

Figure 2. List of physical layer Recommendations for optical amplified systems, sub-systems, and components.

Of course, the development of international standards must recognize the unique needs of various nations and the work of national and regional standards organizations. In the U.S., work related to optical networking is currently being done in Subcommittee T1X1.5 of Committee T1 and in TIA Subworking Group FO2.1.1, primarily as a vehicle for developing consensus within the U.S. for input to the ITU. T1X1.5 deals mainly with network architectures and functions while FO2.2.1 deals with physical layer aspects. In Europe, the European Telecommunication Standards Institute (ETSI) develops telecom-

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munications standards for the members of the European Union (EU) countries. Within ETSI, the current focus of work for the optical network is in Technical Committee TM (Transmission and Multiplexing).

Laying the foundation for optical networking standards: Point-to-point optical systems standards development

Physical layer standards

The development of international standards intended to enable the mixing of different suppliers' equipment within a single optical line system began in 1989, in the ITU SG15 Working Party 4, with work partitioned into optical component, fiber, sub-systems, and systems aspects. A number of recommendations (Rec.) were developed that sought to describe the basic physical properties of optical transmission systems, primarily to support interconnection of SDH signals within and between network operator domains. In the case of the system recommendations, work focused on defining the parameters and parameter values that describe the optical interfaces. For the subsystem, component, and fiber recommendations, work focused on those parameters that describe transmission performance. As a result, this collection of standards is often characterized as describing the 'physical layer'. A list of these recommendations is shown in Figure 2.

Optical interface standards for multiple (and single) channel systems in long-haul point-to-point applications

The first two recommendations covering optical interfaces for optically amplified single- and multi-channel SDH systems focused on point-to-point long-haul applications, Draft Rec. G.691 and G.692 respectively. The purpose of these recommendations is to specify the optical interfaces so that transverse compatibility (also known as mid-span meet) can be achieved at elementary cable sections, thereby enabling the possibility of mixing different manufacturers equipment within a single optical section. The concept of mid-span meet applied to systems both with and without in-line optical amplifiers, as shown in Figure 3 where MPI-S and MPI-R designated the 'main path interfaces' to the embedded fiber plant. In the case of a multiple channel system, the fiber at the main path interfaces carries more than one optical channel multiplexed onto a single fiber using unique optical carrier frequencies.

Full characterization of these interfaces requires specifying optical signal parameters including optical power level, spectral characteristics, and wavelength; optical path parameters including attenuation, chromatic, and polarization mode dispersion and reflectance; and receiver characteristics including sensitivity, overload, and path penalty tolerance.

In the 1993–1996 ITU Study Period, progress to standardize the optical interfaces for multi-channel as well as STM-64 (10 Gb/s) single-channel systems was slow. This was due, in part, to different interests among the participating network operators and the emergence of pre-standard commercial products from a number of suppliers. Coupled with the inherent complexity of amplified optical transmission systems, these differences have made agreement on optical interface parameters for mid-span meet difficult to achieve.

Nevertheless, some significant agreements regarding the definition of "application codes" for both single- and multi-channel systems were reached by the end of the ITU study period in 1996. Applications codes define the basic characteristics of each type of transmission system to be standardized and are intended to represent a sufficiently large set of network applications. Application codes enable operators to procure equipment from different vendors targeted for the same general application. These characteristics include

- Fiber type [dispersion-shifted (3), dispersion-unshifted (2), and non-zero dispersion shifted fiber (5)]

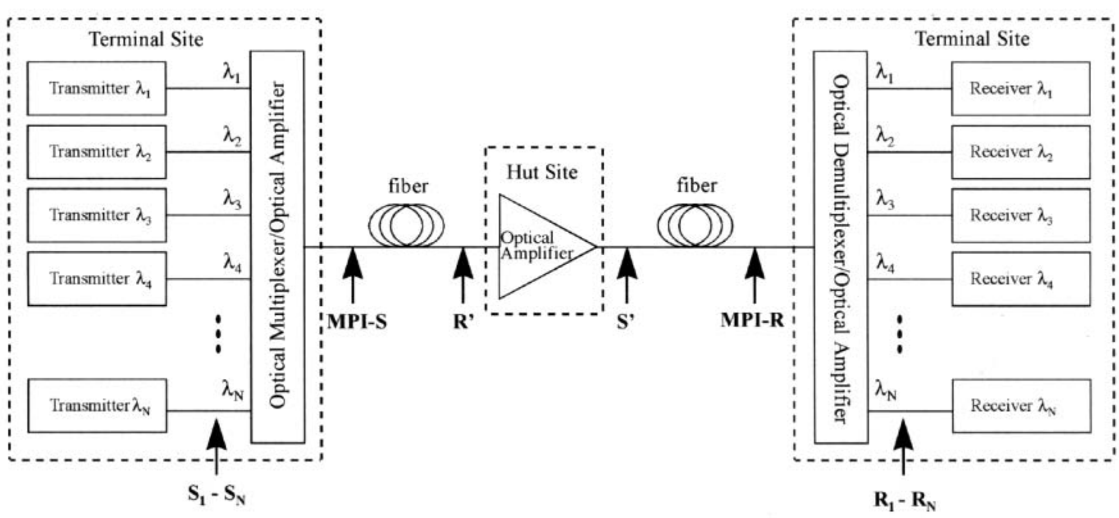

Figure 3. Multiple channel optical system with possible optical interfaces for mid-span meet (single direction shown).

Study Issue (Responsible Study Question)	Example Issues to be Considered
Components and Sub-systems (Q.17/15)	• Wavelength-tunable devices • Wavelength/frequency transponders or convertors, • Optical circulators, optical modulators, and optical cross-connect components • Components and subsystems for add/drop multiplexers
Functional Characteristics (Q.9/15)	• Transmission defects and consequent actions • Optical protection switching and optical path protection • Implementation issues for optical cross-connects and add/drop multiplexers
Physical Layer Aspects (Q.16/15)	• Physical interfaces • Wavelength/frequency hierarchies • Power level management • System aspects of optical nonlinearities • Impact of network topology on physical layer
Network Architectural Aspects (Q.19/13)	• Network layer structure and functions • Network transparency • Network capacity and scalability • Optical ring topologies and interconnections • Apportionment of performance parameters
Structures and Mappings (Q.11/15)	• Overhead functions and definitions • Network node interface
Network Management Aspects (Q.13/15 and Q.14/15)	• User interfaces • Optical path/channel management • Add/drop multiplexing • Wavelength administration Operations, Administration, and Maintenance aspects of optical transport systems

Figure 4. ITU-T Assignment of Work Issues for the Optical Network.

Topic	Related Existing Recommendations	New Draft Recommendations Under Development
Framework Recommendation for Optical Networking (Q.20/15)	———	G.onf
Optical Components and Sub-systems(Q.17/15)	G.661, G.662, G.663, G.671	G.onc
Functional Characteristics (Q.9/15)	G.681	G.oeg (types and general characteristics of optical network elements) G.oef (functional characteristics of optical network elements)
Physical Layer Aspects (Q.16/15)	G.955, G.957, Draft G.691, G.692	G.onp
Architectural Aspects (Q.19/13)	G.803, G.805	G.otn
Optical Overhead Definitions, Structures, and Mappings (Q.11/15)	G.707, G.832	G.ons
Management Aspetts (Q.13/15 and Q.14/15)	G.774-x, G.784, G.831	G.onm (general management aspects of optical network elements) G.oni (management information models of optical network elements)

Figure 5. Topics and Existing and Proposed ITU-T Recommendations for Optical Transport Networking.

- Number of optical channels (1, 4, 8, 16, 32)
- Channel data rate (using the SDH notation STM-4, STM-16, and STM-64)
- Target amplifier span length /span loss [80 km/22 dB (L), 120 km/33 dB(V), 160 km/44 dB (U)]
- Number of amplifier spans for each code (unrepeatered, 3, 5, 8)

The following notation is used to describe any one application code: (number of channels - used only for multiple channel systems)(target distance)(number of amplifier spans) - (STM rate).(fiber type suffix). For example, an optical transmission system that supports eight OC-48/STM-16 channels for nominally 400 km with target amplifier spacings of 80 km on dispersion unshifted fiber would be represented as 8L5-16.2.

In addition to the application codes, a grid of optical frequencies spaced 100 GHz (~0.8 nm) apart and referenced to 193.1 THz (1552.52 nm) was established for multiple channel systems, wherein individual channels are assigned to specific grid frequencies. While industry seems to have embraced the ITU frequency grid, the grid by itself does little to ensure compatibility between systems from different vendors. Not only does the number of grid wavelengths greatly exceed that used by today's commercial systems, but as noted previously, agreements on most other necessary interface parameters are currently absent from Rec. G.692.

This work will continue and expand through the current study period (1997–2000), with the development of a new recommendation on physical layer interface parameter specifications for the optical network, including specifications for transversely compatible metropolitan networks. These activities are described in greater detail in the section below, "Development of optical networking standards in the current ITU-T Study Period."

Optical amplifier sub-systems and optical components

While work on the systems standards progressed, parallel activities to define optical amplifier and optical component transmission parameters were underway. One of these, Rec. G.663, addressed application-related aspects of optical fiber amplifiers (OFA) and provided an overview of how they are envisioned to be used in transmission systems. Rec. G.663 also includes a description of the factors influencing OFA transmission applications, including optical nonlinear effects, polarization and dispersion properties, optical surge generation, self-filtering effects, and noise accumulation.

Optical fiber standards

As result of the work on optically amplified system standards, the 1993–1996 study period also saw the introduction of a new type of optical fiber specifically intended to support transmission systems with multiple optical wavelengths on a single fiber. ITU Rec. G.655 for "non-zero dispersion-shifted single-mode fiber" was added to the G.650-G.654 family of single-mode fiber recommendations. This new fiber type differs from dispersion-shifted fiber (G.653 fiber) by the magnitude of chromatic dispersion permitted within the amplification range of erbium doped fiber amplifiers (nominally

1530–1565 nm). A non-zero value of dispersion is necessary within this range to suppress four-wave mixing (FWM) effects in multi-channel systems. However, different frequency allocations in emerging system implementations and the corresponding different optimum dispersion characteristics have made reaching consensus on specific dispersion values difficult. The current version of Rec. G.655 notes only that values in the range of 0.1 ps/nm-km to 6.0 ps/nm-km may meet the needs of a WDM system.

Development of optical networking standards in the current ITU-T Study Period

The optical transport network is generally recognized as an evolving capability for the interoffice and long-haul networks that takes advantage of WDM technologies to obtain systems for high capacity transport and signal routing in an essentially 'transparent' way. At the same time, the optical network should provide equivalent or improved performance, operations, and administrative capabilities as seen in modern transport networks such as those using SONET or SDH equipment, and should allow mixing of different vendors' equipment within a single network. The development of standards describing the characteristics of an optical network is challenging both technically and administratively. Indeed, it is still unknown to what extent these goals can be realized in practice for a large-scale optical network. Currently, there are a number of research testbeds and field trials for optical networks and the results of these may be expected to help determine fundamental aspects such as

- the degree to which transparency can be achieved within optical networks,
- the practical geographic scale and complexity of optical networks, and
- the level of multi-supplier capability that may realistically be achieved.

Although some argue it is too early for standardization of optical networking solutions, it would not be practical to wait before initiating standards work in this area. As experience with point-to-point WDM system standards has shown, it is often impossible to achieve a meaningful level of standards enabling interoperability between supplier products when the standardization effort starts after products are commercially available or even internally committed. For optical networking, we are in a dynamic environment where the development of standards must recognize rapidly evolving technology and commercialization opportunities, but at the same time help focus industry directions toward the goal of achieving a common set of specifications for use by both suppliers and network operators.

Beginning in 1997, the ITU-T undertook the standardization effort for optical networks with the goal to develop an initial set of specifications by the end of the current Study Period (2000). Since so many technical aspects are involved, with the interplay of one decision affecting other areas, it was decided to create a new study question (Q.20/15, "Characteristics of Optical Networking") to coordinate the various activities within the various ITU-T Working Parties and SGs. Under Q.20/15, a number of topics and associated study questions were identified as shown in Figure 4. At its April 1997 meeting, Q.20/15 proposed the development of a set of nine new ITU-T Recommendations corresponding to these study areas. A schedule was also proposed and accepted by which the first phase of standards development would focus on point-to-point line systems to be completed in 1998, with extensions to include optical add/drop multiplexing, cross-connection systems, and optical layer survivability to be completed by 2000. These new recommendations, as originally envisaged, are shown in Figure 5. It should be expected that the scope and number of these recommendations will change as the work is carried out and many of the yet-unidentified technical issues are addressed. An example is the decision by ITU-T SG 13 at its September 1997 meeting to develop a new draft recommendation, Rec. G.onr, on reference models and network configurations for the optical network. The extent to which the ambitious goal set by the international community to have these recommendations completed by 2000 can be achieved remains to be seen.

The road ahead

Despite the high level of industry interest in the current ITU-T standardization work in optical networking, a number of significant obstacles to successful standardization remain.

The technical issues deriving from the inherently analog nature of an optical network are not yet fully identified and, indeed, the practical limits of large-scale optical networking are still being evaluated. As is the case with any rapidly developing technology area, standardization of optical networks will be challenging due to the competing expectations for providing timely solutions without discouraging technology innovations.

Here, the issue of intellectual property and patent rights also comes into play. Effective development of standards requires the willingness by parties holding relevant patents to license these in a nondiscriminatory manner. Finally, the ITU and other standardization bodies must avoid creating technology-driven specifications that fail to meet market needs for the timely availability of standards-compliant commercial products. The focus of effort must not stray from application-driven requirements. Here, of course, standards bodies face a paradox, in which operator needs are tempered by the cost/availability of the underlying technology, which in turn is driven by operator needs.

These issues and others are generally recognized and are being addressed by the ITU-T. The work within ITU-T has really just begun, but is proceeding with a high level of interest by the international community and should be expected to produce optical networking specifications that will further the development of the broadband optical network transport network as we enter the next century.

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