OPTICAL NETWORKS

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About the Tutorial

Optical networks are telecommunications network of high capacity. They are based on optical technologies and components, and are used to route, groom, and restore wavelength levels and wavelength-based services.

This tutorial is divided into distinct chapters, which explains the structural features of optical fibers and their connections in networks. The nature of optical networks along with the recent developments in the Optical and Networking systems using optical sources and devices is also dealt with.

Audience

This tutorial is designed for learners who have interest in learning the networking concepts using optical sources. It will be useful for those having some idea regarding networking and optical sources.

Prerequisites

Readers will benefit from this tutorial if they are aware of basic networking concepts. A fair idea on digital networking and digital communication systems will be a plus.

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1. Optical Networks – Introduction

The current thinking about IP over WDM by outlining a path to optical data networking, that includes multiple data networking protocol coupled with a protocol-neutral optical networking infrastructure is challenged. This tutorial discusses the diversity of data networking protocols and network architectures for optical data networking.

The bandwidth explosion ushered in by the popularity of the Internet has led to a paradigm shift in the telecommunication industry from voice-optimized circuit-switched services to data-optimized packet-switched services. The notation of supporting "data directly over optics" has been fueled by the promise that elimination of unnecessary network layers will lead to a vast reduction in the cost and complexity of the network.

In this view of reduced or collapsed network layers, existing TDM systems such as Synchronous Digital Hierarchy (SDH) plays a diminishing role, and optical transport networking emerges as the underlying transport infrastructure for the resultant "network of networks".

Optical Internet

Optical internet working, for example, as defined by the Optical Interworking Forum (OIF), is a data-optimized network infrastructure in which switches and routers have integrated optical interfaces and are directly connected by fiber or optical network elements, such as Dense Wavelength-Division Multiplexers (DWDMs).

At present, however, the notion of IP directly over WDM is little more than cleverly disguised marketing. Almost invariably, IP over WDM is IP packets mapped into SDH, coupled with SDH based point-to-point DWDM systems. SDH standalone elements, often referred to as Time-Division Multiplexer (TDMs), are not required, but SDH remains an integral element of the data networking equipment interface.

Ever-increasing reliance on the presence of SDH in DWDM systems limits technological innovation. For example, it may inhibit packet over fiber applications such as Asynchronous Transfer Mode (ATM), Gigabit Ethernet (GbE) and 10 GbE over DWDM. Nor does it bring us any closer to realizing the ultimate vision of optical transport networking.

As compared to the present view of IP over WDM, there is a more balanced view of data/transport network evolution. This balanced view is based on two fundamental principles:

- Every data network is unique, in a marketplace governed by differentiation.
- The Optical Transport Network (OTN), as the underlying infrastructure "network of networks" should be capable of transporting a wide variety of client signals, independent of their format.

Together, these fundamental principles form the basis for the notion of optical data networking.

2. Optical Networks – Convergence Networks

Today's TDM-based transport networks have been designed to provide an assured level of performance and reliability for the predominant voice and based-line services. Proven technologies, such as SDH, have been widely deployed, providing high-capacity transport, scalable to gigabit per second rates, for voice and leased-line applications. SDH self-healing rings enable service-level recovery within tens of milliseconds following network failures. All of these features are supported by well-established global standards enabling a high degree of multivendor interoperability.

Today's Network

In contrast to today's TDM-based transport networks (and, to some extent, with ATM networks), "best-effort" IP networks generally lack the means to guarantee high reliability and predictable performance. The best-effort service provided by most legacy IP networks, with unpredictable delay, jitter, and packet loss, is the price paid to achieve maximum link utilization through statistical multiplexing. Link utilization (e.g. the number of users per unit of bandwidth) has been an important figure of merit for data networks, since the links are usually carried on leased circuits through the TDM transport network.

Given the inherently bursty nature of data traffic, the fixed-bandwidth pipes of TDM transport may not be an ideally efficient solution. However, this inefficiency has traditionally been considered of less importance than the network reliability and congestion isolation features of a TDM-based transport network provider.

The surging demand for high bandwidth and differentiated data services is now challenging this dual architecture model of TDM-based transport and best effort packet networks. It is not cost-effective to extend the usefulness of best-effort networking by over provisioning network bandwidth and keeping the network lightly loaded.

Furthermore, this approach cannot always be achieved or guaranteed due to spotty demand growth, and is a particular issue for the network access domain, which is most sensitive to the economic constraints of underutilized facilities. As a result, in general, data service providers today do not have the network infrastructure support to provide customer-specific differentiated service guarantees and corresponding service-level agreements.

Next Generation Network

Next generation network architectures for cost-effective, reliable, and scalable evolution will employ both transport networking and enhanced service layers, working together in a complementary and interoperable fashion. These next-generation networks will dramatically increase, and maximally share, backbone network infrastructure capacity, and provide sophisticated service differentiation for emerging data applications.

Transport networking enables the service layers to operate more effectively, freeing them from constraints of physical topology to focus on the sufficiently large challenge of meeting service requirements. Hence, complementing the many service-layer enhancements, optical transport networking will provide a unified, optimized layer of high-capacity, high reliability bandwidth management, and create so-called optical data networking solutions for higher capacity data services with guaranteed quality.

Optical Transport Networking: A Practical View

Visions of optical networking have captured the imagination of researchers and network planners alike, since the rapid and successful commercialization of WDM. In the original vision of optical transport networking, a flexible, scalable, and robust transport network emerges, catering to an expanding variety of client signals with equally varied service requirements (flexibility, scalability, and survivability coupled with bit rate and protocol independence).

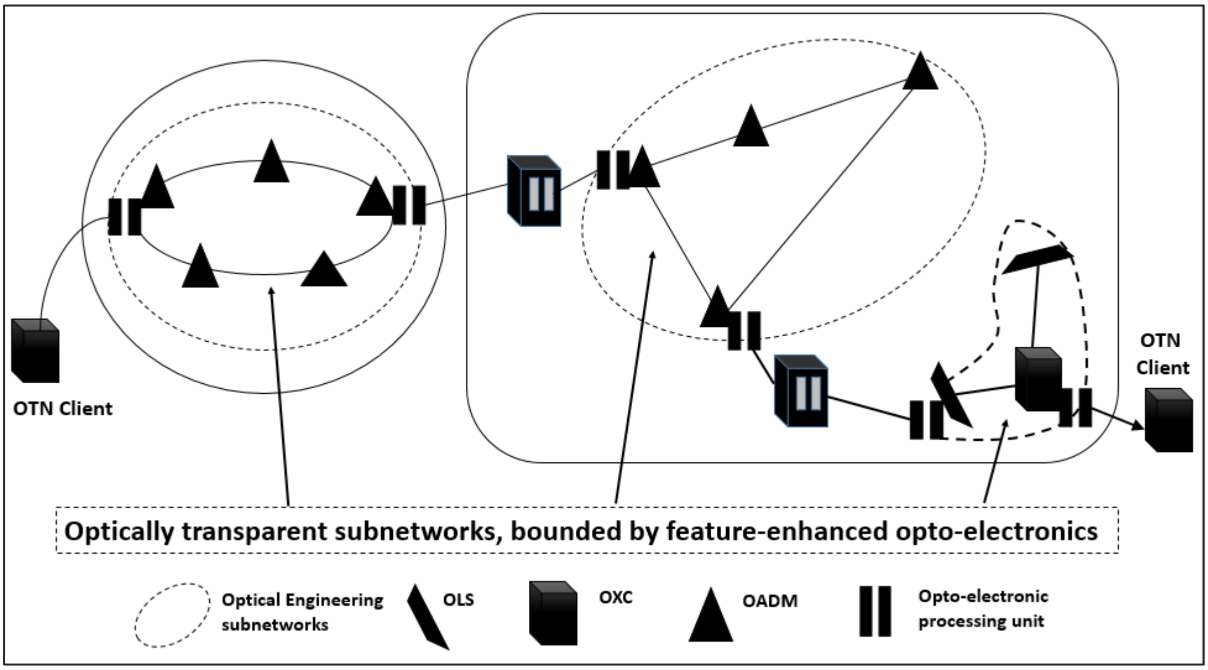
The promise of a transport infrastructure capable of meeting the burgeoning bandwidth demands well into this new century, wherein wavelengths replace timeslots as the medium for providing reliable transfer of high-bandwidth services across the network, is indeed tantalizing. But what is optical networking? The answer varies widely, and in fact has evolved over recent years. Early attempts at optical networking focused on optical transparency and the design of optically transparent networks on a global scale.

Practical Solution

In the absence of viable "all-optical" solutions more practical solutions for optical networking accommodate the need for opto-electronics to support optical signal regeneration, and optical signal performance monitoring. In what is termed all-optical networking, signals traverse the network entirely in the optical domain, with no form of opto-electronic processing. This implies that the all signal processing including - signal regeneration, routing, and wavelength interchange - takes place entirely in the optical domain.

Due to limitations of analog engineering (e.g. limiting factor in a properly designed digital system is an accuracy of the conversion of the original analog message waveform into digital form) and considering the current state-of-the-art in all-optical processing technology, the notion of global or even national all optical networks is not practically attainable.

In particular, opto-electronic conversion may be required in opto network elements to prevent the accumulation of transmission impairments - impairments that result from such factors are fiber chromatic dispersion and nonlinearities, cascading of non-ideal flat-gain amplifiers, optical signal crosstalk, and transmission spectrum narrowing from cascaded non-flat filters. Opto-electronic conversion can also support wavelength interchange, which is currently a challenging feature to realize in the all optical domain.



In short, in the absence of commercially available devices that perform signal regeneration to mitigate impairment accumulation and support wavelength conversion in the all-optical domain, some measure of opto-electronic conversion should be expected in near-term practical optical networking architectures. The resulting optical network architectures can be characterized by optically transparent (or all-optical) subnetworks, bounded by feature-enhanced opto-electronics, as shown in the above figure.

Client Signal Transparency

Beyond analog network engineering, practical considerations will continue to govern the ultimate realization of the OTN. Paramount among these considerations is the network operator's desire for a high degree of client signal transparency within the future transport infrastructure.

What is meant by "Client signal transparency"? Specifically, for the desired set of client signals targeted for transport on the OTN, individual mappings are defined for carrying these signals as payloads of optical channel (OCh) server signals. Signals expected in the OTN include legacy SDH and PDH signals, and packet-based traffic such as Internet Protocol (IP), ATM, GbE and Simple Data Lnk (SDL). Once a client signal has been mapped into its OCh server signal at the ingress of the OTN, an operator deploying such a network need not have detailed knowledge of (or access to) the client signal, until it is demapped at the network egress.

The optical network ingress and egress points should delimit the domain of OTN client signal transparency. Hence, the most important factor in realizing client signal transparency is to eliminate all client-specific equipment and processing between OTN ingress and egress points. Fortunately, it is easier to accept client-dependent equipment at the ingress/egress, since it is generally dedicated on a per-service basis.

Optical Transport Networking via Digital Wrappers

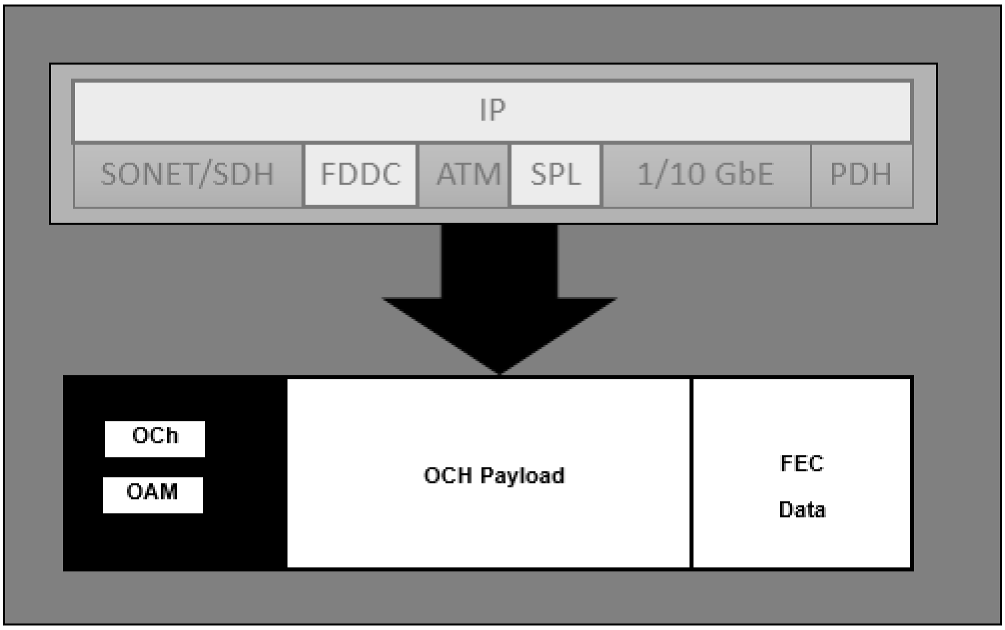
The widespread use of DWDM technology has presented service providers with a new challenge: how to cost-effectively manage the increasing number of wavelengths to provide fast, reliable services to their end customers. To effectively manage wavelength or OChs, requires that optical networks support per wavelength or OCh-level operations, administration and maintenance (OAM) functions.

ITU(T) Rec. G872 defines some functionality for OCh-level OAM implemented in the form of overheads without specifying how this overhead is to be carried. Until now, the only feasible way to support signal regeneration and to monitor, analyze, and manage OChs (wavelengths) was to rely on SDH signals and equipment throughout the network. This requires that the signals on each of the wavelengths in the WDM system be SDH formatted.

An Optical Channel (Wavelength)

Taking advantage of the existing opto-electronic regeneration points in DWDM systems, the notion of using digital wrapper technology will provide functionality and reliability similar to SDH, but for any client signal, bringing us one step closer to realizing the original vision of optical transport networking.

Digital wrapper technology provides the network management functions outlined in ITU(T) Rec. G.872 to enable OTNs. These include optical-layer performance monitoring, Forward Error Correction (FEC), and ring protection and network restoration on a per-wavelength basis, all independent of the input signal format as shown in the following figure.



The notion of using a digital (or TDM) wrapper "around" the OCh client to support channel-associated OCh overhead has recently been proposed, and has in fact, been adopted as the basis for definition of the OCh. This scheme will take advantage of the need for OCh regeneration to add additional capacity to the OCh client. Of course, once we have a means of adding overhead to the OCh client signal digitally, it makes sense to use this to support all of the OCh-level OAM requirements.

In particular, digitally added overhead makes it almost trivial to solve the major performance monitoring problem of the OTN, namely providing access to Bit Error Rate (BER) in a client-independent manner. By optionally using FEC, the digital wrapper method can significantly enhance the BER performance of the client signal, further minimizing the requirement for opto-electronic conversion.

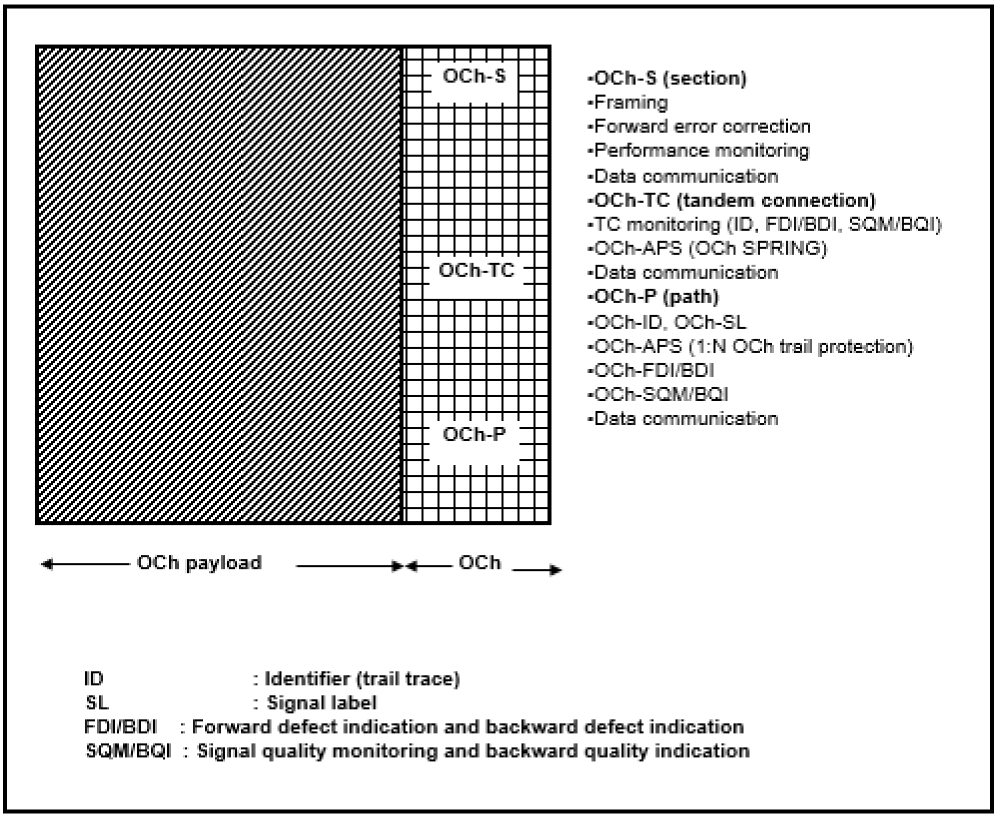
One method of enhancing the performance of the transport network is through the use of FEC, which is currently provided in some equipment. Hence, an added benefit of the digital wrapper technique is the ability to optionally support FEC for system margin enhancement.

OCh Frame Structure

In functional terms, the OCh payload and OAM should be separable from the FEC mechanism. This allows for carrying the payload and OAM end to end across the network, while using different FEC schemes on different links. An obvious example of where this might occur is between submarine and terrestrial links. In the former, new FEC codes are under investigation for the next generation of systems.

Following figure illustrates the proposed basic frame structure of the OCh, and the types of functions that may be carried in the OCh frame structure. While it might be argued that this proposal is inconsistent with long-term goals of the all optical networking, we should not expect the need for regeneration to disappear.

The distance between regeneration points will continue to increase; however, the need for regeneration at signal handoff points will remain. Coupled with the use of the Optical Supervisory Channel (OSC) to manage OChs within optically transparent subnetworks, digital wrappers will support end-to-end management of OChs (wavelength) across national or global OTNs.



3R-regeneration (Reshaping, Retiming, and Regeneration) is provided by means of optical-to-electrical conversion and vice versa, and the digital wrapper proposal takes advantage of this. Would the picture change should all-optical 3R-regeneration becomes available? If all-optical regeneration is capable of adding overhead, the argument is unchanged; only the regenerator implementation would change.

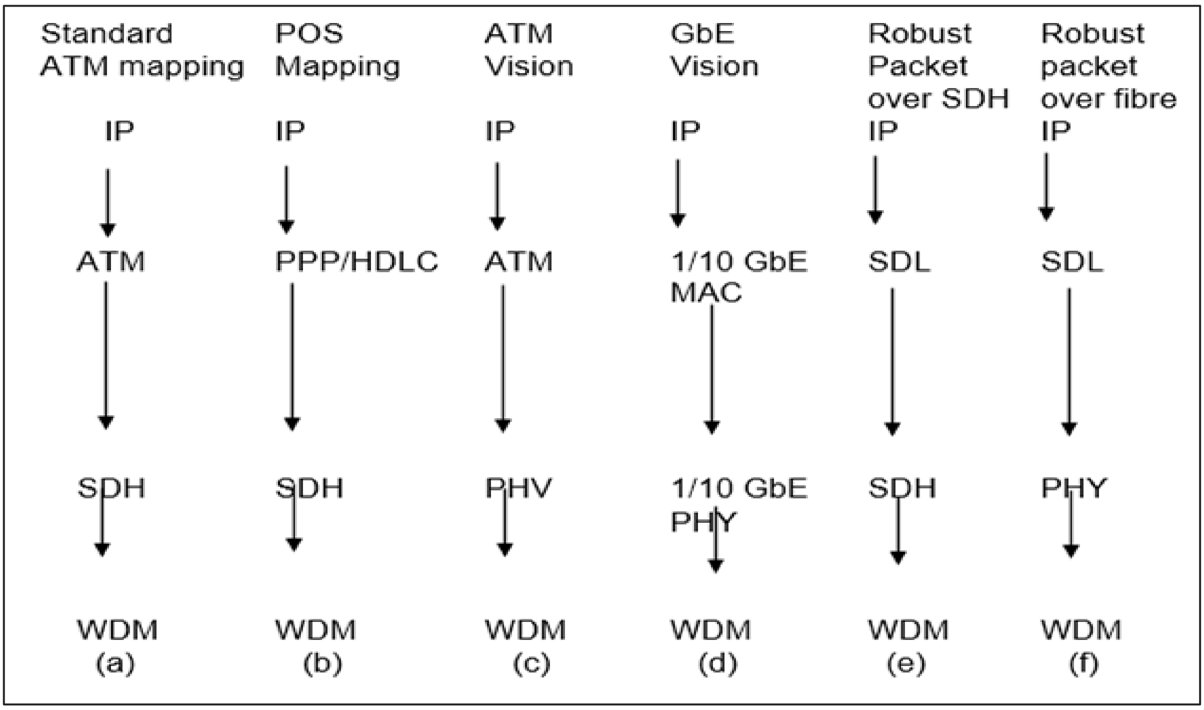
If optical regenerators are unable to add overhead, the need for OChs overhead will not disappear. Optical regenerators would then simply increase the potential distance between the opto-electronic regeneration points, and the digital wrapper would pass transparently through them. The implications of the use of digital wrappers on the evolution of optical transport networking may be profound, especially when taken in the context of data networking trends.

Protocol Stack Choices

The IP protocol is clearly the convergence layer in today's data communication networks, and it is foreseeable that it will expand this role to multi- service networks in the years to come. IP can be transported over a broad variety of data link layer protocols and underlying networking infrastructures. Following figure shows some of the possible protocol stacks or mappings of IP into a WDM network infrastructure.

What is IP over WDM?

The protocol stacks labelled a, b and d in the following figure are the most commonly deployed today. They use the classical IP over ATM over SDH mapping as shown in Fig (a); packet over SDH (POS) as shown in Fig. (b); or the classical and well-extended IP over Ethernet as shown in Fig. (d). Cases (e) and (f) use Simple Data Link (SDL), a new data link layer recently proposed as an alternative to POS. The protocol stack labeled (c) is an alternative to case (a), where the intermediate SDH layer is eliminated and a direct mapping of ATM cells into WDM is performed.



These different protocol stacks provide different functionality, in terms of bandwidth overhead, rate scalability, traffic management, and QOS. To state that any one particular mapping represents IP over WDM is extremely disingenuous.

This diversity of data link layer protocols and mappings of IP into different underlying network infrastructures is one of the major strengths of IP, and it is a characteristic that will not disappear. On the contrary, it is quite possible that new, innovative, and efficient protocol mapping will be proposed for the transport of IP packets. This is already the case for low-bandwidth and low-reliability networks, and will also be so for high-bandwidth and highly-reliable optical networks. This view also fits within the vision of "everything on IP and IP on everything".