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DATA SWITCHING FUTURE

OTN USED AS A COMPLEMENT TO MPLS/ETHERNET TO ENHANCE DELIVERY IN NEXT GENERATION NETWORKS

The OTN hierarchy is a key part of the deployment of next generation networks in which multiple services are delivered via IP. For greatest efficiency in terms of power consumption and low latency, packet networks should use this hierarchy alongside MPLS/Ethernet, in conjunction with WDM, to interconnect major network nodes.

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OTN – THE NEXT TRANSPORT TECHNOLOGY

The growth of network traffic has caused operators to seek new technical solutions to the ever-present challenge of containing costs, while providing enough capacity. Pressure for high quality of service (QoS) and rising bandwidth for services, such as video and mobile broadband, means that simply adding more "best effort" IP packet capacity is not enough. A layered approach is needed to enhance each area of network performance. The surge of packet traffic and changes in service mix [1] have triggered gradual changes in how each layer is implemented, and in the balance of investment between layers.

In the transport layer, there is particular pressure to reduce costs and increase capacity and flexibility for both packet and circuit traffic. One solution now being adopted is the optical transport network (OTN), defined by the International Telecommunication Union – Telecommunication Standardization Sector (ITU-T). OTN defines network architecture requirements, interfaces and a hierarchy of bit rates. Together, these form a key part of the transformation that is being provided by next generation networks (NGN). NGNs converge a range of services onto a shared network, itself based on a mixture of technologies, in contrast to the formerly frequent and more costly arrangement of a separate network, "silo" or "stovepipe" per service.

Transport is about planning for medium- to long-term network capacity. Despite this, a transport network can be provisioned in minutes or can switch paths in less than a tenth of a second to overcome network faults. A transport network includes a hierarchical architecture, plus network management and resilience. It covers a wide range of technologies, including wavelength division multiplexing (WDM), synchronous digital hierarchy (SDH), synchronous optical networks (SONET), switches for Ethernet/Multiprotocol Label Switching (MPLS), and microwave radio links.

Now added to the list is the OTN, a transport technology based on electrical processing. It takes over where SDH/SONET runs out of capacity, is much simpler than packet processing, and complements the optical processing done in WDM systems. The value of using OTN with WDM is that OTN provides a low-cost method for improving the packing of each wavelength, plus enough visibility of the traffic content to allow more effective monitoring than WDM. A further benefit is that the electronics in an OTN switch can provide wavelength conversion. This overcomes the problem of an arriving wavelength finding its ongoing path already occupied or "blocked" by another signal at the same wavelength. Such blocking can be an issue in complex WDM networks.

SOLVING TODAY'S NETWORK TRAFFIC PROBLEMS

Faced with predictions of enormous traffic growth, the ITU-T created the G.709 recommendation [2] [3] for an OTN in 2003 to solve a number of problems that were predicted to emerge in optical networks. Typically, it can take five to six years for the significant deployment of major ITU-T recommendations (for example SDH/SONET) to take place. The telecoms bubble and industry downturn, however, caused further delays in the OTN case. Today, the traffic levels have resulted in many network operators requesting OTN-based products, and device technology has advanced to make it easier to deliver these products.

Operators are turning to OTN to address the following issues:

- The growth of optical WDM systems requires high utilization of each wavelength. The capability of WDM systems is growing in terms of higher bit rates carried per wavelength. However, these rates of 10Gbps and upwards cannot be effectively supported by the widely deployed SDH/SONET structures because they were optimized for lower speeds. Therefore, a new form of switching and multiplexing is needed to supplement SDH/SONET, and it must carry a wide range of payloads in order to match the needs of the NGN
- Processing complexity for the highest capacity switch nodes in core networks must be reduced to minimize cost and power consumption. This means any new form of switching and multiplexing must be simpler than SDH/SONET and packet systems
- Optical interfaces have gained vendor overheads for error correction and system management, making inter-vendor signal transfers difficult. A standard interface similar in principle to SONET's "mid-span meet" is needed
- The main target payloads of Ethernet and SDH/SONET have inadequate facilities to monitor errors at high data rates. Better error check codes are needed
- Carriers want to transport a whole Ethernet or SDH/SONET signal and add nested overheads for each operator's management tasks. This is to support "carriers' carrier" operation across multiple operator networks for wholesale/bulk traffic. A new overhead structure is needed.

THE ROLE OF OTH

An initial step in the creation of OTN was a "digital wrapper" for interfaces that would solve a subset of the problems. This wrapper is sometimes used alone. The ITU-T then added more features, notably a new multiplexing hierarchy of gigabits-per-second data rates, known as the Optical Transport Hierarchy (OTH). Although the OTH is a subset of the OTN, the terms OTN and OTH are often wrongly confused as equivalents. Just like SDH/SONET, the OTH is based on time division multiplexing (TDM) frames rather than packets to keep costs down and meet several performance goals:

- Deterministic performance – zero interaction is required between different service streams, in order to guarantee service level agreements (SLAs)
- Transparency for all service types, both legacy and future – TDM has a good track record of providing transparent characteristics
- Low latency (delay) through cascaded networks – tandem connection through multiple operators' packet networks adds too much delay for business services
- Low power consumption in switching centers of very high capacity – multi-terabit switch node capacity is required: a demand that keeps rising
- Error correction for extended spans – forward error correction (FEC) overcomes background errors and effectively boosts optical performance to allow extended distances. The OTN supports the more powerful, enhanced FEC (EFEC).

In addition, in order to retain high path availability and to minimize the need for staff retraining, processes for operations, administration and management (OAM) are like those of SDH/SONET. Again, based on lessons from SDH/SONET, synchronization has simple operation with low operational expenditure (opex).

HANDLING THE BOOM IN TRAFFIC GROWTH

OTN provides an extra set of transport-related features that reduce costs for the management of bulk traffic, compared to packet-based products. OTN is generally combined with one or more other technologies in a single transport platform, typically within a subrack. For example, it can be combined in various ways with WDM, SDH/SONET and MPLS/Ethernet. These fit in the conventional layered view of telecom networks, shown in Figure 1 – a view loosely based on the open systems interconnection (OSI) model of data networks.

Organizing a telecoms network into layers makes it easier to maintain, grow and replace portions in line with changing demands. Each layer is designed to carry traffic transparently from the layers above, and therefore can be changed with minimal impact on the other layers. Regular capacity increases in each layer are needed to keep up with the rapid growth of packet-based services. The upper layers, 4-7, analyze packet contents for network and service policies; layer 3 routes packets; layer 2 switches and aggregates them; and layer 1 carries them on copper, radio and fiber. Each network layer can contain several different technology layers. Convention dictates that the term transport primarily includes layer 1, but as packet traffic grows the term has been extended to include layers 2 and 3.

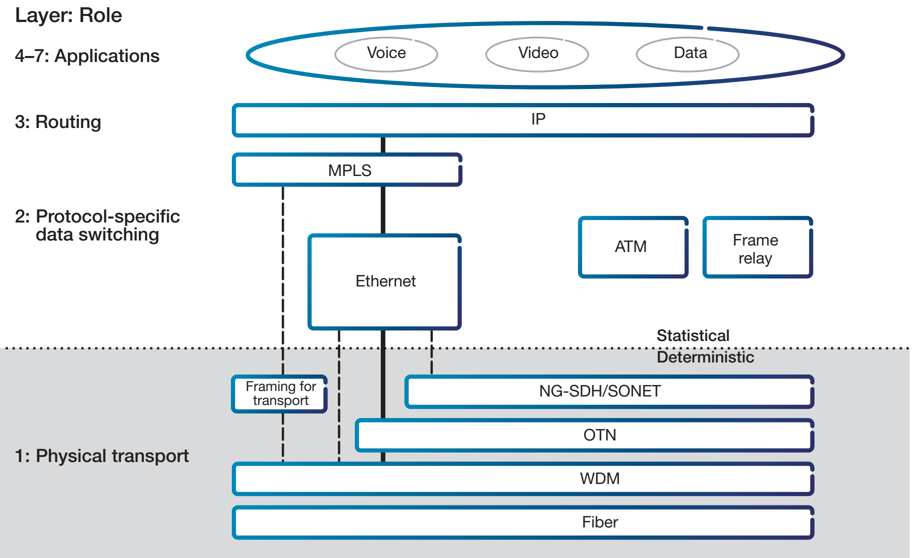

Figure 1: Examples of inter-layer connections today. The solid line from IP to OTN represents a long-term trend

ANSWER FOR COST, CAPACITY AND COMPLEXITY

Protocols for the signal structure on a physical interface define the type of information to be carried. OTN interfaces to G.709 can be used alone, as they are on many packet-based products, notably routers and Ethernet switches. They provide the following:

- Monitoring of errors and other performance aspects
- FEC or EFEC to improve optical budgets by 6-8dB; the latter gives a range extension of up to 40km of fiber
- Communication channels for management, such as for alarms and for monitoring the quality of each stage of a tandem connection through multiple networks
- Control of spare channels for protection (dedicated backup) and restoration (shared backup).

Alternatively, OTN interfaces can be combined with the OTH, described below, in order to add TDM-based traffic management in the form of switching and multiplexing.

BUILDING THE OTH

The purpose of a hierarchy of data rates, such as defined by OTH, is to allow efficient multiplexing and switching (sometimes known as grooming) of different services. Multiplexing of different rates allows multiple traffic streams to be combined for efficient loading of transport pipes, and also to be switched together for resilience against network faults. These are essential requirements of any transport technology. The OTH uses TDM technology but carries both packet and non-packet payloads. (Multiplexing is a term used mainly for TDM and WDM. In packet processing, multiplexing is known as aggregation.)

On top of each signal to be multiplexed or switched, the OTH adds successive overheads, as shown in Figure 2, to build optical payload units (OPUs), then optical data units (ODUs) and finally optical transport units (OTUs). The letter k indicates the line rate: 1 = 2.6Gbps, 2 = 10.7Gbps, 3 = 43Gbps and so on. The letter n indicates the number of wavelengths supported. OTM0 represents an optional OTM with reduced functionality. At the OTU level, the EFEC is added before the signal becomes defined as an optical channel (OCh). Each overhead provides some of the features defined in the OTN recommendation.

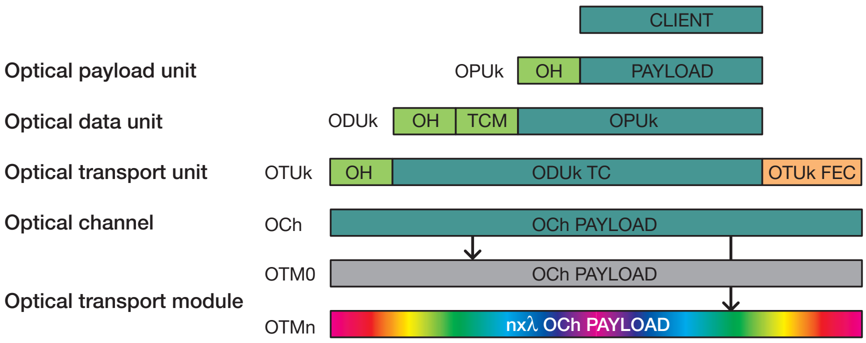

Figure 2: Stages in the OTH assembly process for a payload

After this process, the signal is ready to be put onto a wavelength, designated by the Greek letter lambda λ). At that level, a further and complementary stage of multiplexing and switching can take place, but this time in optical format for the highest bandwidth and degree of transparency to payload format (see “An advanced switching option” below). Figure 3 shows the overall process of merging MPLS label switched paths (LSPs) with other traffic into WDM.

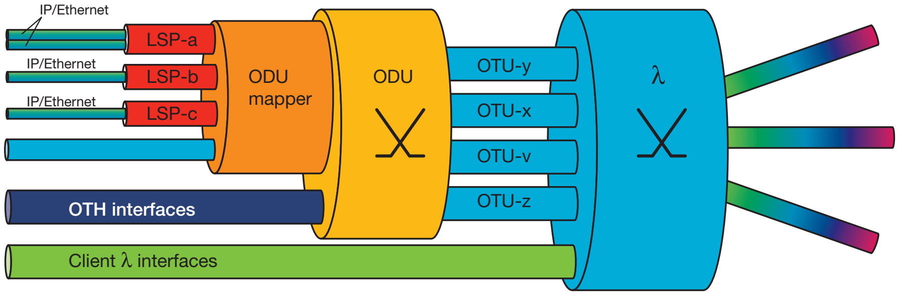

Figure 3: Multiplexing process from IP/Ethernet through MPLS and ODUs to λ

The OTH was originally intended for core networks, so its rates matched the accepted transport rates of 2.5, 10, 40 and recently 100Gbps. Each one has specific overheads, so for example, the nominal 100Gbps becomes 112Gbps as an OTU-4 in the OTH. As traffic grew, it became clear that the OTH could have value in metro areas [4], for mobile backhaul [5] and even in access networks. As a result, new rates were added for 1Gbps Ethernet, known as ODU-0, and also arbitrary multiples of 1.25Gbps, known as ODUflex. These provide flexibility for services that have not yet been defined: for example, possible future storage area networks. The creation of multiple ODUflex rates parallels the virtual concatenation (VCAT) option in SDH/SONET. In the future, when 100Gbps is not enough, higher rates such as 400Gbps or 1Tbps (1000Gbps) can be added.

Switch fabrics for OTN are mostly based on TDM, but packet-based fabrics exist. The Optical Internetworking Forum (OIF) is harmonizing future aspects with the promise of combining multi-protocol and multi-layer (layers 1 and 2) switching in one fabric. Irrespective of internal technology, OTN switches are being offered in a range of sizes to meet different operator needs, from multi-terabit platforms to support server farms, to smaller switches for managing metro and mobile backhaul networks. The smaller switches, being closer to users, are more likely to use ODUflex options.

AN ADVANCED SWITCHING OPTION

OTN is becoming the mechanism of choice for electronic switching for telecoms applications, where the requirement is to be largely transparent to the protocol carried. It replaces electronic cross-point switching, which does not provide multiplexing or content monitoring, and is based on analog crosspoints. For these crosspoints, switch capacity is described in the form of 256x256 ports, for example. While crosspoint switching is possible over a range of data rates, it can be limited to a single rate in cases where multi-stage switching is used, in turn requiring pulse regeneration for the highest data rate.

Crosspoint switching is also available in true optical form. In its ability to handle a wider range of data rates it is much more flexible than the electronic form, but still lacks multiplexing and content monitoring. Performance is optimized for the wavelength of each light beam to be within the usual transport wavelength windows of 1300nm or 1500nm. Both electronic and optical forms are widely used in localized content applications such as broadcast studios and video processing.

If we compare the terminology for the two forms, electronic and optical, we find that where interfaces are optical but switching is electronic (as in OTN), the architecture is designated as optical-electronic-optical (OEO). Where everything including the switching is optical, the designation is optical-optical-optical (OOO) or "photonic." The term "optical switching" is used correctly to describe this OOO form, but often used incorrectly to describe OTN. The incorrect use arises from the high level of payload transparency provided by OTN, which can seem to approach that of true optical switching.

WDM switching, a further form of optical switching, is being widely used in telecoms networks in preference to optical crosspoint switching. Operators introducing OTN are typically doing so alongside WDM switching as a way of gaining the extra benefits of monitoring and more flexible multiplexing. WDM switching is based on reconfigurable optical add-drop multiplexers (ROADMs). A ROADM is typically based on wavelength selective switches (WSSs), and offers switching of individual wavelengths between multiple WDM ports in a network mesh or star arrangement. A ROADM is typically much more compact and reliable than an optical crosspoint switch, as it is highly integrated and allows for internal redundancy.

As mentioned above, operators increasingly seek OTN switching to complement their optical switching. The majority of their traffic, however, is expected to remain optically switched, due to the specific advantages of both crosspoint and WDM switching. These advantages include:

- Enormous payload (in other words, modulation) bandwidth can be carried on each switched light beam – up to 100Gbps proven on current designs, such as by Ericsson in line with OIF definitions
- There is almost total freedom of modulation format, allowing for future innovation
- Power consumption for each bit switched is the lowest of any technology. Optical switching avoids the problems of heat removal that can trouble other high-capacity switching platforms
- Both switching time and capital expenditure (capex) per bit switched are also the lowest of any technology, so optical switching is ideal for network resilience to overcome cable breaks.

As mentioned above, OTN can be combined on shared platforms in various arrangements, not only with WDM but also with SDH/SONET and MPLS/Ethernet. OTN, including OTH, was first offered in platforms combined with SDH, as Europe expressed the initial interest. The recent trend has been to offer combinations alternatively with WDM switching and with Ethernet/MPLS, and in addition with SONET now that interest is growing in North America. There is a trend towards the packet-optical transport platform (P-OTP), also known as the packet-optical transport system (P-OTS). This allows for the modular fitting of switching options from Ethernet, MPLS, SDH/SONET, OTN and configurable WDM/photonics [5].

CONTROL PLANE

Key to keeping operating costs down is successful integration of OTN management and control functions with those for related technologies, SDH/SONET and WDM. The plan is to include some MPLS features in the future to simplify provisioning and restoration operations. These can be provided by network management but increasingly are done by a transport-specific automated control plane. This notional plane represents the flow mechanism for control messages, as distinct from the notional data plane which represents the flow of revenue-earning traffic.

The core technology of the control plane is generalized MPLS (or GMPLS), developed from the MPLS control plane [6]. ITU-T G.807 and G.8080 describe the automatic switched transport network/ automatic switched optical network (ASTN/ASON) architecture. Based on these origins, the transport control plane is commonly referred to as ASON, occasionally as GMPLS or ASTN, or when applied solely to WDM, as a wavelength switched optical network (WSON). Operators and standards bodies continue to link this control plane with its origin – the control plane for MPLS – now that some aspects of MPLS are being adopted for transport applications through MPLS Transport Profile (MPLS-TP) [7]. As noted above, this arrangement can simplify operations.

TIMING IMPACT ON NETWORK DESIGN

Switching with OTN or WDM gives much lower latency than any packet-based equipment. In packet networks, latency – known as “ping time” or the round-trip time from user to user – is increased by propagation delays. Low latency is vital for many services, such as financial and storage-area networks, and to achieve high-packet throughput on the internet. With the common transmission control protocol (TCP)/IP, latency as low as 200ms can limit speed to below 3Mbps because of the buffer sizes normally used. For less demanding services, a typical allowance across an operator’s backbone network would be 50ms. At 4.9 microseconds per km, fiber delays alone in a metro network can reach 5ms, which is a typical latency limit for automated protection switching of electricity supplies.

Because switching with OTN or WDM gives both low latency and very high capacity, it is complementary to routers and is often used to bypass them, especially in the case of well-filled pipes of IP traffic. The delays of transport switching nodes acting at layer 1, OTN, WDM and also SDH/SONET, are negligible when compared with fiber delays in carrier networks. For transit traffic, the delay in each node of layer 1 is typically a few tens of microseconds, although even less than this matters in some finance transactions. The fastest routers can each have similar delays under ideal conditions, but more often in practice each one adds several milliseconds – hence the need for bypass.

In any calculation of overall latency through OTN, the use of EFEC should be allowed for as EFEC typically requires multiple passes through its coding circuit and can add several tens of microseconds each time an OTN signal is terminated. EFEC is best used on long, direct routes that avoid repeated demultiplexing, switching and remultiplexing.

A second aspect of timing is synchronization timing, needed for mobile base stations and many other network applications. Although synchronization is possible via packet streams, and is now starting to be deployed, it is still most commonly done via TDM systems, which, if available, provide the simplest method. Being based on TDM, OTN preserves the TDM tradition of simple delivery of synchronization. The very low latency of OTN is an advantage because it minimizes delay variation that could degrade synchronization performance. Also, unlike SDH/SONET but like its predecessor, the Plesiochronous Digital Hierarchy (PDH), OTN can carry arbitrary third-party synchronization, so overall it eases implementation problems for operators.

SUMMARY

The OTN was introduced because a new infrastructure for transport bit rates, beyond the capability of established network technologies, was needed to accommodate dramatic traffic growth.

Faced with the need to switch and multiplex signals of ever larger bandwidth as transparently as possible, while preserving visibility of their digital contents for monitoring, the ITU-T recommended a new format to carry packet and non-packet traffic. This was specified in order to minimize several key burdens, such as power consumption, equipment size, capex and opex, while adding features to improve network performance and management.

OTN is generally implemented on shared platforms. It is being introduced alongside WDM switching by ROADMs, and alongside MPLS/Ethernet switching, to offer a range of transport switching options to suit different applications and networks.

GLOSSARY

ASON	automatic switched optical network
ASTN	automatic switched transport network
ATM	Asynchronous Transfer Mode
capex	capital expenditure
EFEC	enhanced forward error correction
FEC	forward error correction
GMPLS	Generalized Multi-Protocol Label Switching
ITU-T	International Telecommunication Union – Telecommunication Standardization Sector
LSP	label switched path
MPLS	Multi-Protocol Label Switching
NGN	next generation network
OCh	optical channel
ODU	optical data unit
OH	overhead
OOO	optical-optical-optical
opex	operational expenditure
OPU	optical payload unit
OTH	Optical Transport Hierarchy
OTM	optical transport module
OTN	optical transport network
OTU	optical transport unit
ROADM	reconfigurable optical add-drop multiplexer
SDH	synchronous digital hierarchy
SONET	synchronous optical network
TDM	time division multiplexing
WDM	wavelength division multiplexing

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