OTN and NG-OTN: Overview

This document presents an overview of Optical Transport Network (OTN) and Next-Generation Optical Transport Network (NG-OTN), which are seen as a future dominant technology in the digital and analogue backbone transmission evolution for both the commercial and NREN community, providing support for a wide range of Time-Division Multiplexing (TDM), packet and IP narrowband and broadband services.

Optical Transport Network

The OTN architecture concept was developed by the ITU-T initially a decade ago, to build upon the Synchronous Digital Hierarchy (SDH) and Dense Wavelength-Division Multiplexing (DWDM) experience and provide bit rate efficiency, resiliency and management at high capacity. OTN therefore looks a lot like Synchronous Optical Networking (SONET) / SDH in structure, with less overhead and more management features.

It is a common misconception that OTN is just SDH with a few insignificant changes. Although the multiplexing structure and terminology look the same, the changes in OTN have a great impact on its use in, for example, a multi-vendor, multi-domain environment. OTN was created to be a carrier technology, which is why emphasis was put on enhancing transparency, reach, scalability and monitoring of signals carried over large distances and through several administrative and vendor domains. All these are issues that the NREN community is currently struggling to solve.

The advantages of OTN compared to SDH are mainly related to the introduction of the following changes:

- Transparent Client Signals:

  In OTN the Optical Channel Payload Unit-k (OPUk) container is defined to include the entire SONET/SDH and Ethernet signal, including associated overhead bytes, which is why no modification of the overhead is required when transporting through OTN. This allows the end user to view exactly what was transmitted at the far end and decreases the complexity of troubleshooting as transport and client protocols aren’t the same technology. OTN uses asynchronous mapping and demapping of client signals, which is another reason why OTN is timing transparent.

- Better Forward Error Correction:

  OTN has increased the number of bytes reserved for Forward Error Correction (FEC), allowing a theoretical improvement of the Signal-to-Noise Ratio (SNR) by 6.2 dB. This improvement can be used to enhance the optical systems in the following areas:

  - Increase the reach of optical systems by increasing span length or increasing the number of spans.

  - Increase the number of channels in the optical systems, as the required power theoretical has been lowered 6.2 dB, thus also reducing the non-linear effects, which are dependent on the total power in the system.
  - The increased power budget can ease the introduction of transparent optical network elements, which can't be introduced without a penalty. These elements include Optical Add-Drop Multiplexers (OADMs), Photonic Cross Connects (PXCs), splitters, etc., which are fundamental for the evolution from point-to-point optical networks to meshed ones.
  - The FEC part of OTN has been utilised on the line side of DWDM transponders for at least the last 5 years, allowing a significant increase in reach/capacity.

- Better scalability:

  The old transport technologies like SONET/SDH were created to carry voice circuits, which is why the granularity was very dense – down to 1.5 Mb/s. OTN is designed to carry a payload of greater bulk, which is why the granularity is coarser and the multiplexing structure less complicated.

- Tandem Connection Monitoring:

  The introduction of additional Tandem Connection Monitoring (TCM) combined with the decoupling of transport and payload protocols allow a significant improvement in monitoring signals that are transported through several administrative domains, e.g. a meshed NREN topology where the signals are transported through several other NRENs before reaching the end users.

  In a multi-domain scenario – "a classic carrier's carrier scenario", where the originating domain can't ensure performance or even monitor the signal when it passes to another domain – TCM introduces a performance monitoring layer between line and path monitoring allowing each involved network to be monitored, thus reducing the complexity of troubleshooting as performance data is accessible for each individual part of the route.

Finally, a major drawback with regards to SDH is that a lot of capacity during packet transport is wasted in overhead and stuffing, which can also create delays in the transmission, leading to problems for the end application, especially if it is designed for asynchronous, bursty communications behavior. This over-complexity is probably one of the reasons why the evolution of SDH has stopped at STM 256 (40 Gbps).

OTN's G.709 interface to the photonic layer is becoming more important as high bit rate creates more concerns over optical impairments and their effect on signal integrity and spectral efficiency in Long Haul system design. OTN has the ability to transport, monitor and provision TDM, packet and IP traffic directly onto DWDM wavelengths at ultra-high capacity.

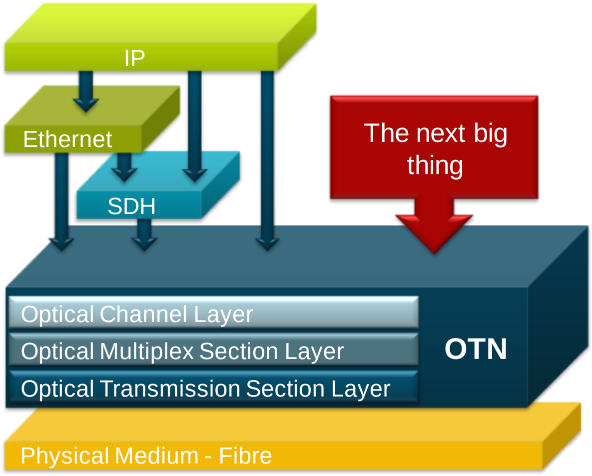

Figure 1: OTN – the next big thing

The requirements for optical transmission monitoring at high capacity are far more stringent, because the small pulse widths and higher light intensity required for high-capacity transmission cause exponential increases in optical effects and signal sensitivity to noise, problems to which OTN offers solutions in the form of ever more enhanced error correction and signal processing capability.

OTN has all the capabilities required to monitor, manage, and control each client signal transported on a particular wavelength in the network. In this way, OTN adds operations, administration and maintenance (OAM), and provisioning and troubleshooting functionality to optical carriers.

OTN provides the network management functionality of SDH and SONET, but on a per-wavelength basis. A digital wrapper, which is flexible in terms of frame size and allows multiple existing frames of data to be wrapped together into a single entity, enables more efficient management through a lesser amount of overhead in a multi-wavelength system. The OTN specification includes framing conventions, non-intrusive performance monitoring, error control, rate adaption, multiplexing mechanisms, ring protection, and network restoration mechanisms operating on a per-wavelength basis.

The OTN technology architecture is being further defined as capacity increases, as service focus becomes more data-centric, and as multi-domain monitoring and provisioning become more important. This development is known as Next-Generation OTN, and its definition is currently being led by Study Group 15 in the ITU-T.

Next-Generation Optical Transport Network

Next-Generation OTN is a development of the OTN standard described above, maintaining the SDH-like OAM functionalities, with added development that enables more efficient mapping of and support for data signals such as Ethernet and IP. This transformation has been called the Packet Optical Evolution or the Packet Optical Transport Service (P-OTS), with OTN as the carrier for packet services such as Multi-Protocol Label Switching – Transport Profile (MPLS-TP), Provider Backbone Bridge Traffic Engineering (PBB-TE), Synchronous and Connection-Oriented Ethernet, or IP/MPLS.

The transmission of IP and Carrier-Grade Ethernet over WDM networking architecture means that networking, end-to-end circuit monitoring, management and protection functions that were previously provided by the SDH network are now being implemented on the WDM layer network. This removes a layer from the transport infrastructure and achieves better bit-transfer efficiency.

On the optical layer, development of functions such as wavelength configuration, automatic power balancing and optical-layer performance monitoring can help to reduce operational expenditures in a time of decreased technology-enabling finance. On the digital layer, technological and architectural convergence is a major factor in transport networking: metro networks merge more and more with long-haul optical transmission networks, again with reduced cost as a key motivation.

Therefore, in the absence of SDH at the high end of backbone capacity, with the merger of Access and Core Transport planning, and given the advent of all-optical and multi-domain networking, a new transport technology is required.

Next-Generation OTN proffers a solution to the converged transparent transport of TDM, packet and IP-based services and goes beyond point-to-point wavelength services by implementing a more flexible architecture based on Optical Channel Data Units (ODU), including ODU-k, ODU-0 and sub-0, ODU-ne and ODU-flex.

This promises improvements to service-layer networking efficiency, protection and restoration functions, scalability and flexibility.

This next generation of optical networking will develop the transmission layer from a static networking medium to become an intelligent dynamic transport network infrastructure supporting high-capacity multiplexed applications over multi-domains, which in fact is the “Next Big Thing” for networking.

Figure 2 below summarises the principles of this architecture, which is composed of a base layer of analogue and digital OTN transport and switching, and on top of that a centralised IP network. (The example shows an NREN network connected to a converged DWDM and OTN-based transport NREN SP network. This is described in more detail in Converged DWDM and OTN-Based Transport below.)

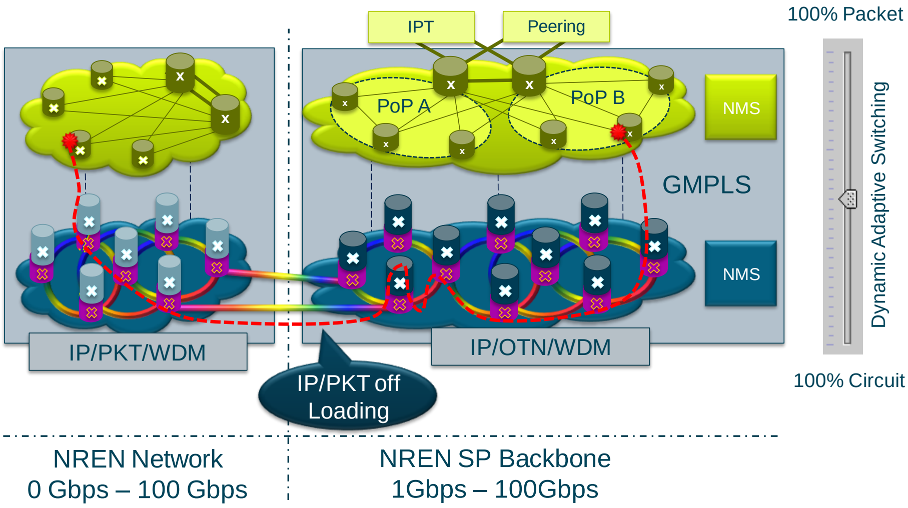

Figure 2: Principles of NG-OTN architecture

An NREN Service Provider (SP) network like this would support current and future NREN services, including multi-domain services, and would optimise the operation and maintenance of NREN networks.

The current interconnection points between two or more NRENs could be kept as they are, using a traditional handover on SDH or Ethernet, which means that there would be no new requirements for NREN networks interconnecting to an NREN SP network that is based on OTN. However, to realise the full potential of OTN technology, the handover should be OTN-based.

Converged DWDM and OTN-Based Transport

Each Point of Presence (PoP) in an OTN-based NREN network would encompass colourless and directionless DWDM equipment combined with digital OTN switching or grooming functionality, which could be decoupled in locations where there is no need for digital OTN switching. In addition, each PoP would support client traffic transparency for seamless uptake of packet, TDM and IP traffic, as shown in Figure 3 below.

Major OTN switches should be deployed in strategic locations, in close proximity to colourless and directionless DWDM equipment, for more advanced handling of packet, TDM and IP traffic flows.

In order to achieve fibre optic resiliency, and to support the overall restoration topology, the backbone would be based on a combined mesh-and-ring-structure, supporting, as a minimum, 2 branches per PoP into the network. The overall network would require strategically placed Reamplifying, Reshaping, Retiming (3R) generation in order to cope with resiliency and restoration.

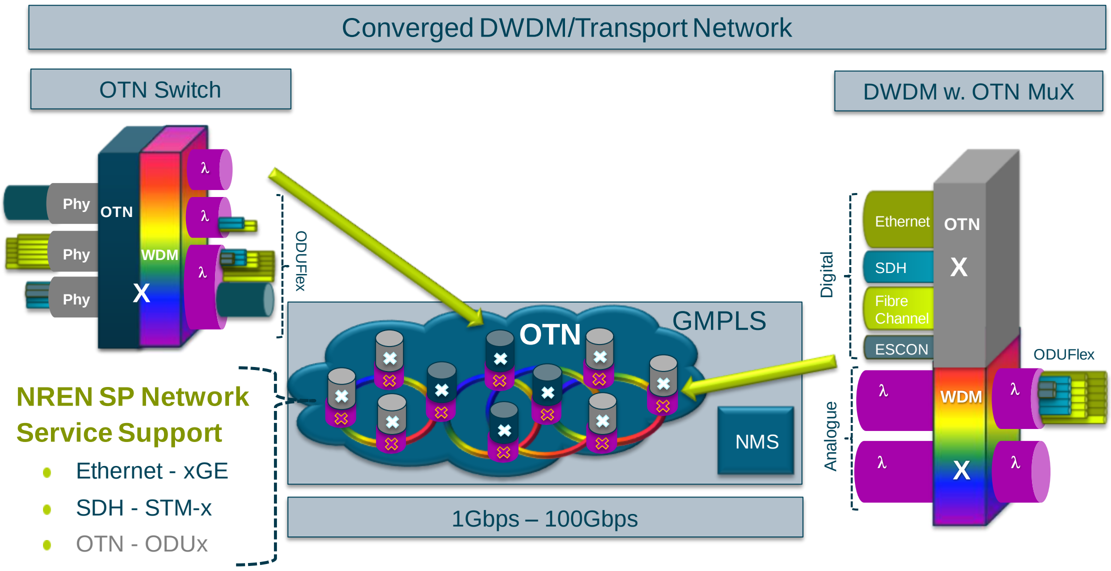

Figure 3: Structure of the converged DWDM and OTN-based transport

The OTN switching capacity would be built hierarchically, with the highest capacity near the main traffic junctions, and reducing in capacity towards the edges. The main traffic junctions would be handled by the OTN switches; the dges would be handled by colourless and directionless DWDM equipment, combined/integrated with digital OTN switching or grooming equipment located at each NREN, providing full support for the OTN-based NREN network services seen from the client side.

A transport architecture like this would turn the OTN-based NREN SP network into a carrier's carrier network. NREN traffic would then be wrapped into OTN and backhauled via wavelength pipes originating from the NREN locations and terminating in strategically located digital OTN switches – the red links in Figure 4 below.

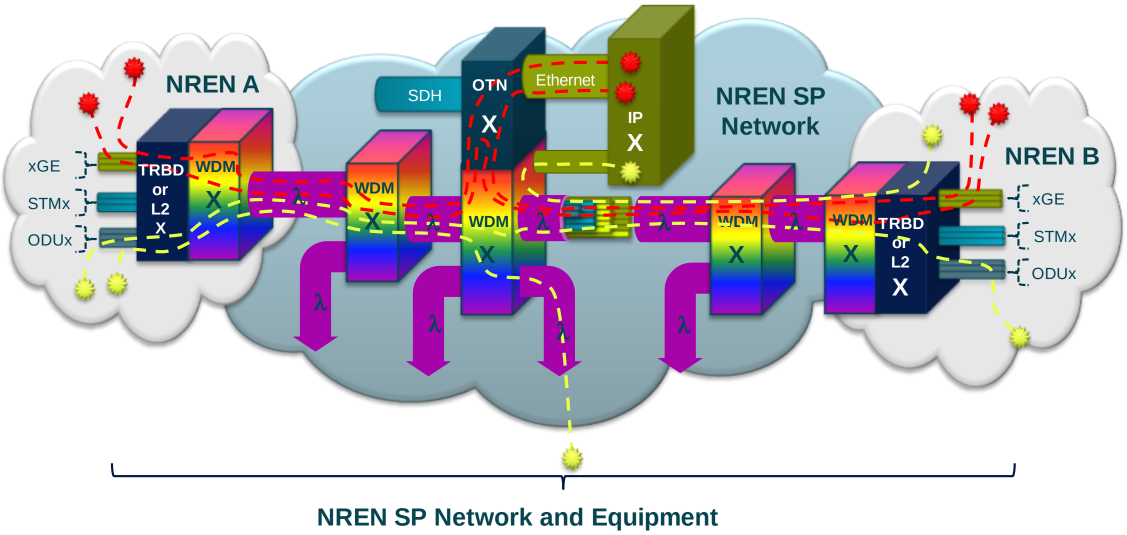

Figure 4: Options for handling NREN traffic in a converged DWDM and OTN-based transport

Alternatively, traffic could be piped directly from NREN A to NREN B or, in this example, from NREN B to the centralised IP core, in dedicated point-to-point wavelength pipes – the yellow links in Figure 4 above.

It is important to emphasise that the NREN SP's colourless and directionless combined/integrated DWDM equipment should be hosted or located in close proximity to the NREN A or B PoP. However, the NREN interface will be Ethernet, SDH/SONET or OTN and, on the line side, ODUx and ODUFlex carried by wavelengths, as shown in Figure 5 below.

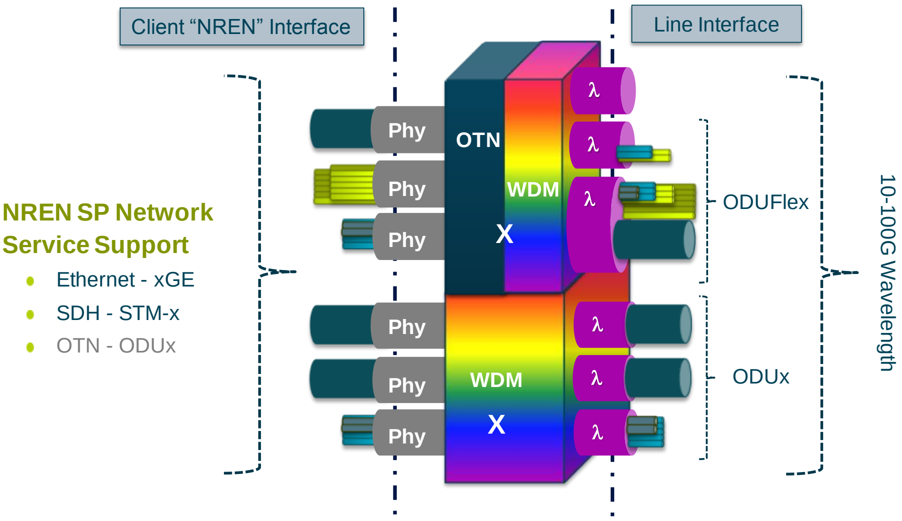

Figure 5: NREN and line interfaces in a converged DWDM and OTN-based transport

Glossary

3R	Reamplifying, Reshaping, Retiming
DWDM	Dense Wavelength Division Multiplexing
FEC	Forward Error Correction
IP	Internet Protocol
ITU-T	International Telecommunication Union – Telecommunication Standardisation Sector
IXP	Internet Exchange Point
MPLS	Multi-Protocol Label Switching
MPLS-TP	Transport Profile
NG-OTN	Next-Generation Optical Transport Networking
NREN	National Research and Education Network
OADM	Optical Add/Drop Multiplexer
OAM	Operations, Administration and Management
ODU	Optical Channel Data Units
ODU-k	Optical Channel Data Unit-k
OEO	Optical-to-Electrical-to-Optical
OPUk	Optical Channel Payload Unit-k
OTN	Optical Transport Networking
PBB-TE	Provider Backbone Bridge Traffic Engineering
P-OTS	Packet Optical Transport Service
PoP	Point of Presence
PXC	Photonic Cross Connect
SDH	Synchronous Digital Hierarchy
SG15	ITU-T Study Group 15
SNR	Signal-to-Noise Ratio
SONET	Synchronous Optical Networking
SP	Service Provider
TCM	Tandem Connection Monitoring
TDM	Time-Division Multiplexing