Transport Network Evolution

The Shift from SONET/SDH to OTN

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Introduction

The dominant protocol in the transport network over much of the past two decades has been SONET/SDH. Recently, however, OTN has taken hold as the protocol of choice for transport networks of today. All major service providers are committed to deployment of OTN as their central transport technology and the telecom equipment manufacturers have clearly responded with a shift away from development of transport systems based on SONET/SDH in favor of newer systems based on OTN.

This paper contrasts these two transport protocols to provide some perspective on how and why OTN has supplanted SONET/SDH as the transport protocol of choice.

Rationale for OTN

Transport protocols have evolved over a very long time and each generation has inherited many attributes and behaviors from its predecessors. This is very apparent when comparing SONET/SDH and OTN.

SONET/SDH was originally designed to efficiently multiplex the most prevalent telecommunications signals in the late 1980s which were DS1, DS3, and E1. This was accomplished by defining transport containers of 1.5 Mb/s 2 Mb/s, and 50 Mb/s that were multiplexed into aggregate signals ranging from 155 Mb/s to 10 Gb/s. This fine granularity was well suited toward the typical client bandwidths of that time, but prevented SONET/SDH from scaling to efficiently carry larger payloads (e.g. 10 Gb/s).

Initially, SONET/SDH network elements were connected directly by fibre optic cables and served as the photonic and physical layers of the OSI stack (layers 0 and 1). Beginning in the 1990s, the introduction of DWDM technology to address the need for increased bandwidth over a single fiber led to deployment of WDM networks serving as an underlying transport network to the existing SONET/SDH network infrastructure. This resulted in service providers needing to deploy, provision and maintain two separate transport layer networks.

One very attractive attribute of DWDM networks is that they transport client data very transparently. While SONET/SDH technology transparently transports PDH signals, it requires adaptation or partial termination for data signals and for multiplexing of lower rate SONET/SDH signals. This causes issues when transporting one service provider's SONET/SDH signals through another service provider's network because network management functions contained in transport overhead channels are unable to transparently traverse another service provider's network.

The definition of OTN came at a time when all of these issues were well understood in the deployed SONET/SDH networks. OTN was therefore expressly defined to focus on transport of larger bandwidth signals, encompass both DWDM and existing TDM transport network layers and to provide transparent transport of client signals across an OTN network.

Comparison with SONET/SDH

It is no surprise that OTN has many similarities to SONET/SDH as many of these functions were taken from previous technologies when SONET/SDH was defined. The similarities include:

- Framing and scrambling
- Layers (path, line, section)
- BIP-8 error monitoring
- Forward and Backward error and alarm indications
- communication channels
- APS protection signaling
- Byte multiplexing

However, despite all the obvious similarity, there are some significant differences between SONET/SDH and OTN that results from some lessons learned in the many years of deployment and operation of SONET/SDH equipment.

Layers (Section, Line, Path)

SONET/SDH is defined to have three layers (line, section and path) whereas OTN includes only section and path. The SONET line layer (or Multiplex Section in SDH) was introduced to facilitate fault isolation and protection. The Tandem Connection Maintenance (TCM) functionality in OTN provides more flexible network fault monitoring and protection and makes the line layer unnecessary.

Frame Structure

The numbers of rows and columns which make up a SONET/SDH frame are different than in OTN but this is of little significance. The primary difference in frame structure is that OTN containers are defined to have a fixed number of bytes and a varying frame duration whereas in SONET/SDH there is a fixed frame period and the number of bytes in the frame varies according to the rate of the signal. For example, OTU1, OTU2, and OTU3 all have 16320 bytes (4080 columns x 4 rows) and frame periods of 48.971, 12.191, and 3.035 µs respectively. Conversely, OC-3, OC-12, and OC-48 have 3x810, 12x810, and 48x810 bytes respectively and a fixed period of 125µs.

Signal Bit Rates

All SONET/SDH signal rates are even multiples of the base rate of 51.84 Mb/s as higher rate signals are composed of an even multiple of the 9x90 byte STS-1 structure. Because OTN frames of dissimilar rates all have the same number of bytes one might expect that the resulting frame rates are even multiples of one another. This is not the case. Each successively higher OTN rate is based on fully encapsulating the lower level frame and adding OTUk overhead (including FEC). This has implications for clocks/timing in that, unlike SONET/SDH, higher rate OTN signals are not an integer multiple of the lower rate signals.

Bit Error Detection

BIP-8 monitoring of SONET/SDH is largely carried over to OTN, but because of the differences in frame structure (fixed number of bytes vs. fixed period) OTN does not suffer from the effect of a single BIP-8 count covering a progressively larger number of bytes for bigger path signals (e.g. STS-12c, STS-48c, etc.).

Transparency

One of the key properties of the DWDM networks is that they are capable of transporting client protocols in a very transparent manner, including OTN client signals. This means that it is possible to multiplex OTN signals into higher rate signals without sacrificing transparency for data, overhead and timing. SONET/SDH transports PDH signals transparently, but cannot transport other SONET/SDH signals without terminating timing and certain overhead.

Multi-Operator Networks (TCM)

One of the management shortcomings of SONET/SDH was that it did not have good data integrity and fault isolation methods for multi-operator environments. Monitoring of SONET/SDH signals is tied directly to the path, line, and section layers. The path monitoring is end-to-end, the section monitoring is between each pair of regenerators and the line is between ADM nodes. It is cumbersome for each operator to monitor services between the network elements, especially if the ADM nodes span more than one operator's network. TCM decouples the monitoring from the path and section layers and allows defining of multiple (up to six) arbitrary

pairs of connection monitoring end points so that an operator is provided with a single set of alarms and bit-error counts associated with any portion of their network. Tandem connection was eventually introduced into SDH, but was never very heavily deployed.
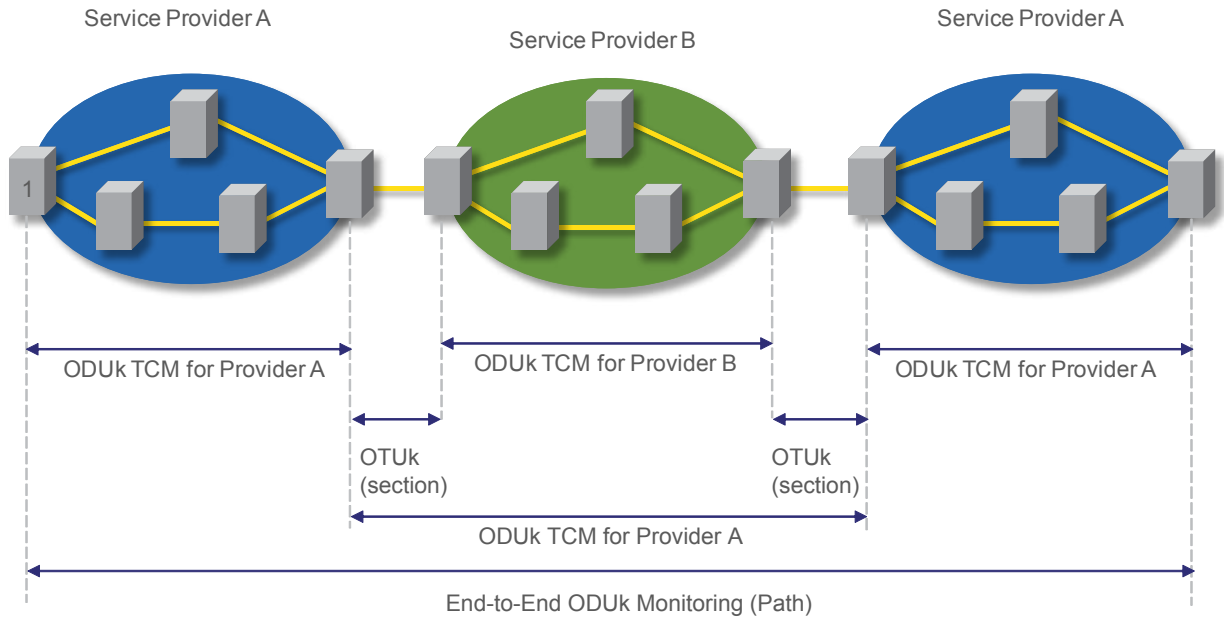

Figure 1 – TCM for Multi-Operator Networks

Figure one depicts how a single layer of TCM can be used by multiple service providers to individually monitor their portion of the network. OTN supports six individual TCM instances which can be nested or overlapped to accommodate more complete network monitoring scenarios.

Inclusion of FEC

Forward Error Correction (FEC) is used in transport networks to correct transmission errors that are typically a result of excessive dispersion due to long fiber routes. Although there are some proprietary implementations of SONET/SDH with forward error correction capabilities (typically for STM-64/OC-192), it is not part of the standard and deployment is very limited. By contrast, FEC is part of the OTN standard. In addition to this there are several proprietary FEC schemes for OTN which have better performance than the Reed-Solomon FEC specified in the OTN standard.

VCAT vs. ODUflex

Virtual concatenation (VCAT) was introduced to SONET/SDH to enable 'right-sized' containers for mapping a variety of client signals including Gigabit Ethernet, FibreChannel, and Video. VCAT is also defined for OTN, but field deployment of this feature is non-existent. Instead, ODUflex has been subsequently defined as a simpler and preferred mechanism to build an OTN container of the appropriate size for a wide range of clients. The key difference between VCAT of OPUs and an ODUflex are that ODUflex is a single container of variable size rather than a set of containers grouped together. Therefore the ODUflex is more easily managed (one payload, one container, one set of overhead) and does not require a mechanism for resolving differential delay. Of course, being a single container it cannot support the multi-path routing and protection that VCAT offers.

Mapping Justification

SONET/SDH used pointers in fixed overhead positions in the frame to locate the beginning of an SPE (synchronous payload envelope) which is able to float within the fixed structure of the STS frame. OTN returned to the positive/negative stuff mechanism similar to that used in PDH multiplexing. Both of these mechanisms are designed to tolerate small clock differences between the client signal and the server layer signal by providing periodic opportunities to fit an additional byte into the SONET/SDH/PDH frame or to mark a payload byte as 'unused'. This Asynchronous Mapping Procedure (AMP) approach requires that the payload bandwidth of the server signal is well matched to the client signal being mapped. A newer Generic Mapping Procedure (GMP) has recently been defined in OTN as another mapping/justification method which allows for mapping client signals of any smaller bandwidth into a given server layer payload by enabling an unlimited number of "stuff bytes" to be inserted into any frame.

Hierarchical Multiplexing

Multiplexing of PDH signals followed a hierarchical structure where DS0s were multiplexed into DS1, DS1s into a DS2, and DS2s into a DS3. SONET/SDH avoided this hierarchical multiplexing to prevent network elements from having to undo multiple levels of multiplexing before switching or re-grooming lower bandwidth signals. Originally OTN followed this same philosophy by recommending only single stage multiplexing (e.g. ODU1 multiplexed directly into ODU3 rather than first being multiplexed into ODU2). However, more recently the OTN standard has defined multi-stage multiplexing for all OTN container sizes. Therefore OTN now supports both multi-stage multiplexing similar to PDH and direct multiplexing similar to SONET/SDH.
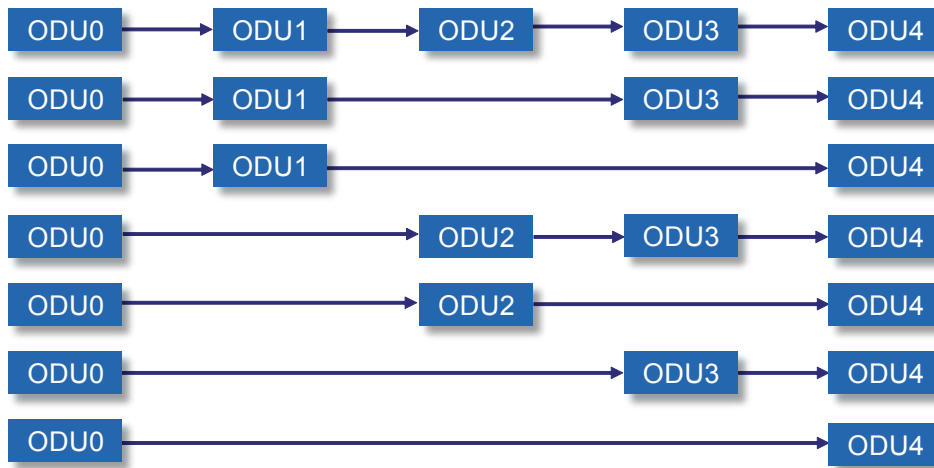

Figure 2 – Hierarchical Multiplexing

The result is a large number of possible multiplexing combinations. Figure 2 shows the seven ways in which an ODU0 may be multiplexed into an ODU4.

Typical Equipment Platforms

Equipment for the SONET/SDH network evolved over many years. It began primarily with simple terminal multiplexers, which mapped and multiplexed many DS1/E1 and DS3 signals into OC-3/STM-1, OC-12/STM-4 and OC-48/STM-16 transport signals. The next evolution was the Add/Drop Multiplexer (ADM) which enabled ring topologies and linear add/drop chains. The Multi-service Provisioning Platform (MSPP) added capability for a larger variety of client signals such as Ethernet and ATM. Lastly these MSPPs evolved into Multi-service Transport Platforms (MSTP) which typically included DWDM and/or OTN capabilities.

OTN capable equipment evolved from both the MSPPs of the SONET/SDH network as well as the Optical Add/Drop Multiplexers (OADM) in the DWDM network. The earliest implementations of OTN in the network were as a digital wrapper function. This involved taking non-OTN signals (e.g. SONET/SDH) and simply mapping them into OTN prior to transmission without performing any multiplexing or switching. The primary benefit of this was the forward error correction (FEC) of the OTN protocol which enabled better performance, especially over long distances. This digital wrapper functionality was introduced into both MSTPs and OADMs. More recently the OADM has evolved into a software reconfigurable version known as the Reconfigurable Optical Add/Drop Multiplexer (ROADM) and these systems typically have both transponder cards (performing digital wrapper functionality) as well as muxponder cards which include a multiplexing stage to combine multiple lower speed signals into a single OTN signal.

The latest transport platform, known as the Packet Optical Transport System (P-OTS), combines transponder and muxponder functions present in the ROADM with OTN container (i.e. ODUj) switching. In many cases these systems are also capable of packet switching for services such as Ethernet or MPLS to enable a more flexible transport platform designed to natively handle both circuit and packet switching functions.

Challenges of OTN

The evolution from SONET/SDH to OTN has created a transport layer protocol that takes many of the best aspects of SONET/SDH (and previous generation protocols) and adapts them to current network demands (multi-carrier networks, larger bandwidths, integration of DWDM technology). However, OTN is not without its own challenges which will likely affect the smooth deployment of OTN equipment.

Standardization of FEC

Forward error correction is specified by the OTN standards, but typically vendors (both silicon and equipment vendors) have developed proprietary FEC schemes in order to provide better performance. This creates some complications in the deployment of equipment from an interoperability perspective, but this is mitigated quite well by the fact that the standard FEC definition does exist and can be used on links which interconnect equipment from different vendors. However, from a commercial silicon perspective it means that the silicon being developed to be widely deployed must support multiple FEC schemes thereby adding to the cost and time of development.

Supporting several mapping methods and many multiplexing possibilities inevitably complicates the provisioning, monitoring, and debugging of large transport networks. It also adds considerable complexity to the design and testing of OTN equipment which increases cost and delays availability of solutions.

Deployment of OTN

To date the deployment of OTN has primarily been for the transport of SONET/SDH and 10GE signals. Many recent changes to the OTN standards have broadened functionality to support 40 Gb/s and 100 Gb/s operation and added better capability for Gigabit Ethernet and other protocols such as FibreChannel and Video. While there is certainly a market for multiplexing and transporting many low rate signals (<10 Gb/s), the majority of OTN deployment will be in the core of the transport network and continue to focus on large bandwidth pipes.

The introduction of OTN switching through development of P-OTS equipment delivers the true networking aspect of OTN and enables a wider set of deployment scenarios and protection options in the network. Although in SONET/SDH networks, much of the recent equipment was capable of SONET/SDH switching, the majority of the deployed network elements were primarily performing multiplexing and protection switching with only a few large core nodes really focused on switching. Also, there was a large focus on ring topologies for SONET/SDH systems but it is likely that deployment of OTN equipment will be more focused around a meshed network approach. The planned integration of packet switching capability with OTN switching in

P-OTS equipment may also have a significant effect on how OTN equipment is deployed.

Conclusion

While OTN has clearly taken many elements from previous network technology such as PDH and SONET/SDH, it is certainly a significant evolutionary step in transport technology. Service providers around the world have committed to OTN as their transport technology of choice and there is much time and energy being spent on developing new equipment to enable a greatly expanded rollout of OTN into the Service Provider networks. While it is difficult to say that an old technology is dead when it continues to ship in very significant volume (as even T1/E1 does today), there has clearly been a shift away from SONET/SDH to OTN for the transport network of the future.

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