Transport Network Evolution: from TDM to Packet

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Abstract: Transport networks and technologies are undergoing transformation. The genesis of that transformation is packet switching embedded on transport equipment together with DWDM, OTN, and SONET/PDH switching. This paper summarizes the drivers and involved technologies.

OCIS codes: (060.4259) Networks, packet-switched; (060.4253) Networks, circuit-switches

1. Introduction

Traditional transport networks have been synonymous with Time-Division-Multiplexing (TDM) switching. TDM switching is based on the allocation, reservation and switching of time slots per connection (circuit) along a connection path. TDM-circuit rates and signals are defined and fixed by standard bodies (e.g., DS1, DS3, OCn, VCAT of STS-1s, ODUk, ODUflex, etc.). A TDM connection carries a SONET/PDH/ODU client signal, a fiber channel, or packets (e.g., Ethernet frames). Each of these clients may in turn be carrying similar traffic types transparently to the transport network. From transport viewpoint, there is one service (TDM). There is no differentiation among the carried traffic except for the adaptation needed at the transport edge, e.g., Ethernet transport over SONET using GFP-F or GFP-T encapsulation. More specifically, there is no differentiation among different packets on the same connection. A connection bandwidth is reserved all the time irrespective of the client and the client activity, and cannot be shared with other connections. A physical port/TDM channel cannot be shared across connections either. Traditional transport networks perform one-to-one mapping between a client physical port/ TDM channel and a transport circuit.

Packet transport is the enablement of transport networks to switch packet connections rather than TDM connections at the client ports and across the transport network. Packet switching operates at packet level and identifies connections based on information in the packet header. In addition, the packet header can carry information about the service the packet needs (Class of Service (CoS)), allowing packets to be treated differently on the same connection. The formats of Connection and CoS identifiers depend on the packet technology used. Packet switching brings four distinct dimensions to transport when compared to TDM: (1) connection bandwidth flexibility, (2) statistical multiplexing, (3) ability to provide differentiated services for packets carried over the same connection and across connections, and (4) sharing of a physical client packet port (e.g., Ethernet) among multiple connections.

This paper first reviews the drivers for packet transport. It then describes an evolved packet optical transport network view. Last, it presents an overview of technologies used for packet transport.

2. Transport Evolution to Packet – The Drivers

During the last decade, there has been a tremendous shift in the nature of traffic carried in carrier and enterprise networks, stemming from Internet growth, and the movement of video and voice from TDM to packet over the Internet Protocol (IP). While Ethernet has been very popular in Local Area Network (LAN) environments, providing multi-point and broadcast services for over two decades, the last decade has seen the movement of Ethernet technology to the Wide Area Networks (WANs), incrementally replacing legacy SONET and PDH. In particular, Ethernet (from 10Mbps to 10Gbps and now going to 40Gbps and 100Gbps) became popular for access links, incrementally replacing private TDM leased lines, as evidenced by the recent wireless backhaul shift to Ethernet accompanied by 4G wireless shift to all-IP. Ethernet Virtual Connections (EVCs) over the same physical Ethernet port define the end-to-end connections. Ethernet also gained popularity for interconnecting carrier routers and switches, replacing traditional Packet over SONET (POS) interfaces. This move to Ethernet was heavily driven by three factors (1) lower cost per Mbps, (2) flexibility in connection rates, and (3) support for high-speed links.

The shift in traffic from TDM to packet did not motivate changes in transport until recently as the packet traffic volume became substantial. Packet network elements distinct from transport network elements were always needed to perform packet switching and take advantage of statistical multiplexing gains, while transport networks did not. Those packet switches were always physically connected to transport equipment to provide for wide area transport. Packet transport evolution brings packet switching and packet statistical multiplexing to traditionally TDM/optical transport networks, in many instances eliminating the need for externally connected switches to perform this function. The net gain is reduction in Capex and Opex by reducing the number of nodes and physical ports, and saving bandwidth in the transport network.

3. Evolution to the Next Generation Packet Optical Transport

Modern transport equipment has evolved to combine SONET ADMs and DWDM/ROADM in the same optical node in what is known as ADM on the blade. Lately, further evolution added SONET switching fabric to the optical node allowing for SONET switching across ADM cards in the same chassis to provide for better connection grooming, while satisfying SONET performance requirements.

SONET fabric and SONET switching, being TDM in nature, still lacked the advantage of packet multiplexing. Packet multiplexing need was realized early on and was attempted on transport equipment via Ethernet Resilient Packet Ring (RPR) technology. However, RPR did not find tremendous success due to cost and ring-topology rigidity. This stemmed the evolution, or revolution, of Packet-Optical Transport Platforms (P-OTPs).

P-OTPs aim at integrating packet switching, SONET switching, OTN switching and DWDM/ROADM in the same transport node. Technologies that enable such integration already exist today and will continue to evolve with the advent of OTN. The main difference among existing implementations is the switching fabric design. Some keep the SONET switching logic and circuitry separate from that of ODU and packet, while others use service-agnostic fabric. In either case, each service domain requirements and characteristics are preserved. Service modules (packet, SONET and OTN) provide the tributary and switching services, performing the appropriate processing on SONET frames, packets, and ODUs, as well as their interworking. The benefits of P-OTPs are:

1. Integration of switching services (packet, SONET and ODU) with DWDM/ROADM on the same platform, eliminating external physical ports that would be otherwise needed to interconnect such services, minimizing the total number of physical platforms, and realizing Capex and Opex savings.
2. Flexibility in personalizing a P-OTP for full SONET, ODU or packet services including any mix. This provides services continuity, eliminates the need for deploying single-service platforms, and caters for shifts in services, while providing protection in investment against such shifts.
3. Interworking between packet, SONET and ODU services, providing flexibility in transport optimization. It should be noted that when SONET and packet services are peer layers, ODUks become the means for multiplexing these services on the same wavelength. That is, OTN is the convergence layer.
4. Transport of packet using GFP over OTN, eliminating SONET framing overhead. A wavelength or ODUk is dropped at the packet switching points for packet switching as needed.

4. Packet Transport Technologies

The evolution focus in packet transport is on enabling connection-oriented services, including point-to-point (p-to-p) and point-to-multipoint (p-to-mpt). Ethernet (e.g., IEEE 802.1ad [1]) and Multi-protocol Label Switching (MPLS) [2] have been adopted for providing these packet services. Enabling Ethernet switching or MPLS switching in the transport is an equipment vendor choice and a network operator choice albeit there are key technological and operational differences. It should be noted that in all cases, client Ethernet ports are expected to be dominant. The same may apply for line-side ports. Ethernet and MPLS technologies have been widely used in packet networks for a number of years. They are still evolving with additional capabilities and enhancements, specifically catering to transport requirements. Packet transport technologies strive to: (1) provide transport for multiple client technologies although Ethernet is expected to be exceedingly dominant, (2) support large number of connections (3) support high degree of resiliency and fast recovery from failures, and (4) support data plane OAM for diagnostics and failure notification. This section provides an overview of Ethernet and MPLS technologies as they apply to transport networks.

4.1 MPLS and MPLS-TP:

MPLS has been widely used in carrier transport networks to transport IP packets, and Layer2 (e.g., ATM, Ethernet, Frame Relay (FR), PPP) and Layer1 (e.g., DS1, DS3) connections over an MPLS Packet Switched Network (PSN). Layer2 and Layer1 MPLS transport uses the MPLS Pseudowire Emulation (PWE3) architecture [3]. A 20-bit label in the 32-bit MPLS header identifies a connection. The packet MPLS header also contains a 3-bit traffic class identifier to enable differentiated scheduling and queuing services for MPLS packets on the same connection and across connections at switching nodes. Existing MPLS technology, including GMPLS and PWE3, already caters for a large set of packet transport requirements. There are other services enabled by MPLS, such as Layer2 and Layer3 Virtual Private Networks (VPNs), that are not relevant for packet transport as scoped in this paper.

Realizing the MPLS maturity and applicability for packet transport, a recent joint effort between the ITU-T and IETF has been focused on defining a transport profile for MPLS, known as MPLS-TP [4]. MPLS-TP defines the subset of MPLS features and services needed for transport, and covers gaps in OAM, routing, signaling and network management that specifically cater to MPLS-TP but generally apply to MPLS (MPLS enhancements). In MPLS-TP, Generalized MPLS (GMPLS) provides for constraint-based (e.g., bandwidth) routing, and p-to-p and p–to-mp Label-Switched Path (LSP) path computation and signaling. LSPs can also be administratively provisioned. MPLS Pseudowires (PWs) [3] are used to transport multiple layer2 and layer1 circuit technologies as discussed earlier. Per PWE3 architecture [3], PWs are tunneled over LSPs. LSPs can in turn be hierarchically nested (hierarchical GMPLS) to provide for better scale in terms of number of tunnels in the core. The combination of PWs and hierarchical GMPLS caters to overall connection scale in the MPLS-TP core. GMPLS and PW main advantages over Ethernet are (1) ability to emulate more Layer2 and Layer1 technologies, and (2) maturity of the control plane (GMPLS and PWE3) with traffic Engineering capability, although optional for MPLS-TP. There exists today MPLS OAM support for LSPs and PWs, but a number of functions are lacking. The MPLS-TP effort focuses on enriching the MPLS OAM tool-set to better address transport requirements. OAM capabilities that operate in the data plane are being added. They include the definition of monitoring points, support for Alarm Indication Signal (AIS), Remote Defect Indication (RDI), Loopback and performance measurement functions among others. In addition, a linear protection scheme and associated protocol are being defined.

4.2 Ethernet:

A p-to-p EVC can be established across the transport network to extend a p-to-p EVC between two client equipment (CE) devices, or to create a p-to-p tunnel between two transport nodes that in turn tunnels other EVCs. Using IEEE 802.1q or 802.1ad Ethernet frame format, an EVC is identified by a 12-bit VLAN ID tag in the Ethernet frame header. For p-to-p EVCs using IEEE 802.1ah frame format, an EVC can be identified by a 24-bit service identifier known as I-SID or a 12-bit VLAN ID in the 802.1ah frame header known as B-VID (B-VID identifies a tunnel EVC). VLAN-IDs can also be nested to provide for hierarchical tunneling, catering for connection scale in the transport core. On the other hand, a p-to-mpt EVC identified by a VLAN ID is a degenerate multipoint VLAN where communication among leaves and from leaves to root needs to be prohibited via configured forwarding rules. Finally, the 16-bit VLAN tag in the Ethernet frame header contains in addition to the VLAN ID, a 3-bit field used for CoS indication and often known as the p-bits or Priority Code Point (PCP), and a drop eligibility indicator (DEI) bit. PCP and DEI can help transport nodes differentiate among Ethernet frames in terms of queuing and scheduling on the same connections and across connections.

Ethernet resiliency has been traditionally provided via topology path diversity and IEEE protocols such as Multi Spanning Tree (MSTP). However, MSTP implementations have manifested slow convergence that worsens with increasing domain size. As an alternative, ITU G.8031 defines a linear protection switching scheme that provides for fast failure detection and fast recovery for p-to-p EVCs and is more suitable for Ethernet transport services. In addition, a GMPLS control plane for 802.1ah Ethernet networks is being defined at the IETF [5] to provide for constraint-based routing, connection path computation, and signaling. Finally, Ethernet OAM tools are defined in IEEE 802.1ag and ITU-T Y.1731 to provide for OAM functions such as continuity check, loopback, AIS, RDI, and performance measurements. The main disadvantage of Ethernet when compared to MPLS, is that it lacks native transport support for some technologies (e.g., Frame Relay, ATM), albeit some of these technologies are losing popularity. In addition, most Ethernet transport networks rely on either a Network Management System (NMS) or manual operations to perform connection path selection and configuration in the absence of a control plane that caters for traffic engineering requirements. NMS or administrative path selection and placement provide a predictable connection path that satisfies a connection bandwidth requirement in addition to other attributes.

5. References

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