Technologies and Practical Aspects of Next Generation Optical Networking

Milorad Cvijetic
NEC Corporation of America, Herndon, VA, USA
e-mail: milorad.cvijetic@necam.com

ABSTRACT
We have been witnessing a rapid transition to unified packet-based core/edge network architecture by major telecom carriers all around the globe. Core network architecture becomes a two-layer structure based on data packet transport over DWDM (Dense Wavelength Division Multiplex) bandwidth pipes, which is the most effective way of providing sharing network capacities, enabling efficient protection schemes, and delivering guaranteed end-to-end performance. At the same time, there is a need for the next generation optical access network that will deliver packetized bandwidth to both residential and business end users. In this paper we will review the technologies and practical aspects related to the next generation optical networking.
Keywords: Optical networks, 100 Gb Ethernet transport, Wide Area Networks (WAN), Access networks.

1. INTRODUCTION

There is a growing need for a packetized bandwidth driven by demand from both residential and business users [1]. The information that has been exchanged in telecom networks today come mostly as an IP carried traffic originating mainly from data, or video sources. The growth in data services for both business and individual users is both substantial and steady. The general networking architecture of most major carriers can be represented by three concentric circles, as shown in Figure 1.

The central part of this structure is a long-haul core network interconnecting big cities, or major communication hubs. This is a two-layer network structure based on data packet transport over DWDM bandwidth pipes. The information data packages, once aggregated at edge, will travel any distance by core network before they arrive to de-aggregation edge node. In today's converged network environment, a rapid transition to unified packet based core network architecture is occurring. The second part of the network from Figure 1 is the edge network, which is deployed within a smaller geographical area, such as a metro area, or a certain geographic region. The edge network is often recognized as an important segment for intense manipulation of signals and services, through local signal grooming, exchange, and service convergence. Finally, the access network is a peripheral part of the network dealing with the last-mile access, which relates to the distribution of services to individual end-users, such as corporate business units, government departments, medical facilities, entertainment organizations, scientific institutions, or private residential users. The physical network topology that best supports traffic demand is generally different for different parts of the networking structure presented in Figure 1. It could vary from mesh (deployed in the core and edge networks), to ring (deployed in all portions of a network), or to star topology (deployed mostly in an access network).

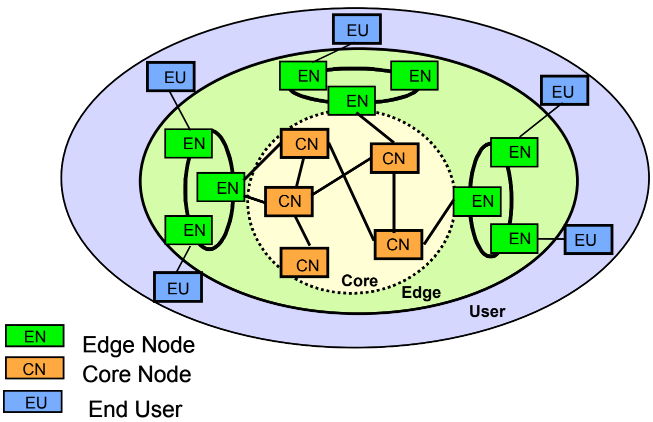

Figure 1. Generalized networking architecture.

This paper presents an overview of major topics related to introduction of future packet transport network infrastructure [1-3]. We will pay a special attention to advanced technologies for next generation access networks, packet transport in metro and core networks, and for long haul transmission of 100 Gb/s signals that are envisioned to be building blocks of future DWDM systems.

2. ACCESS NETWORKS

In access networks, there is a strong trend of introducing optical fibers all the way to the end users. Passive optical networks (PON) have been proven as an economical approach to deliver broadband services to individual and corporate users. The PON solutions come in different flavors such as Ethernet based PON (EPON), or PON based on framing of voice, data, and video into ITU standard specified frame (GPON). As the PON technologies are becoming more IP centric, there is an expectation that next generation PON solutions will be based on unified standard jointly worked between IEEE and ITU. In terms of capacity, PON architectures today can provide a guaranteed bandwidth of up to 1 Gb/s per user .

Deeper penetration of fibers, as illustrated in Fig. 2, identified by fiber to the home (FTTH), or fiber to the desk (FTTD) applications, is now limited to a specific geographical areas such as Asia, where fiber plant is more advanced, while deployment of the FTTH systems is more cost effective and affordable from the end-user perspective. Fiber to the home is now Ethernet based solution capable of delivering Fast Ethernet (FE) or Gigabit Ethernet (GE) bandwidth directly to the customer.

There are several optical fiber access technologies that could be used for the next generation PON, such as 10 Gb Ethernet, dense wavelength division multiplexing (DWDM), Orthogonal Frequency Division Multiplexing Access (OFDMA), or optical code division multiplex access (O-CDMA) [2,3]. There is a request that next generation PON provides a full asynchronous transmission, more soft capacity on demand, and lower latency. It is important to mention that migrating to these new technologies raises several important challenges. For example, in order to protect legacy network investment, carriers require that next-generation services should be provided through TDM-based techniques. However, TDM-based 10G-PON networks require employment of expensive 10 Gb/s components, need complex scheduling algorithms and framing technology, and are highly sensitive to packet latency. On the other hand, WDM-PON still lacks the flexibility to dynamically allocate the bandwidth among multiple services and raises system cost due to requirements for multiple transceivers. Consequently, a cost-effective, flexible scheme that addresses these challenges is of great interest.

A novel PON architecture by using Orthogonal Frequency Division Multiple Access (OFDMA), to transparently support various applications and enable dynamic bandwidth allocation among them have been recently proposed [3]. The OFDMA-PON approach is essentially a hybrid technique, which combines OFDM and TDMA, such that the OFDM sub-carriers can be dynamically assigned to different services in different time slots. The OFDM-based PON solutions readily smoothly apply an adaptive per-subcarrier modulation and constellation expansion that may be used to cost-effectively upgrade the data rate of the existing networks from 1 Gb/s to 10^{+} Gb/s, via increased spectral efficiency.

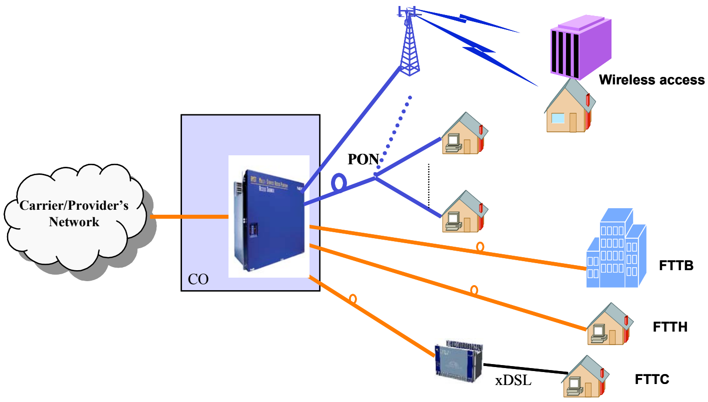

Fig 2. The main types of fiber based BB access systems.

It can also transparently support various applications and enable dynamic bandwidth allocation among them. In OFDM PON architecture, shown in Figure 3, dedicated sub-channels, which are composed of one or more OFDM sub-carriers, become a transparent pipe for delivery of arbitrary analog or digital signals for both circuit and packet switched systems. For upstream traffic, each ONU maps the data signal to the given sub-carrier(s), nulls all remaining sub-carriers, and completes the OFDM modulation to generate a complete frame [3]. For downstream traffic, the OLT reserved some sub-carriers as dedicated, transparent pipes and encapsulates packet-based data into remaining OFDM bands and time slots, according to the frequency and time domain scheduling results. The OFDM frame and other analog signals are mixed by the electrical coupler to drive the optical modulator. Each ONU selects its own data or signal from the proper sub-carrier(s), pipes and time slots. With this approach, the OFDMA-PON, which is demonstrated even for 100 Gb/s and 40 Gb/s [4] downstream bit rates, present itself as both flexible and extensible to any emerging applications in the future.

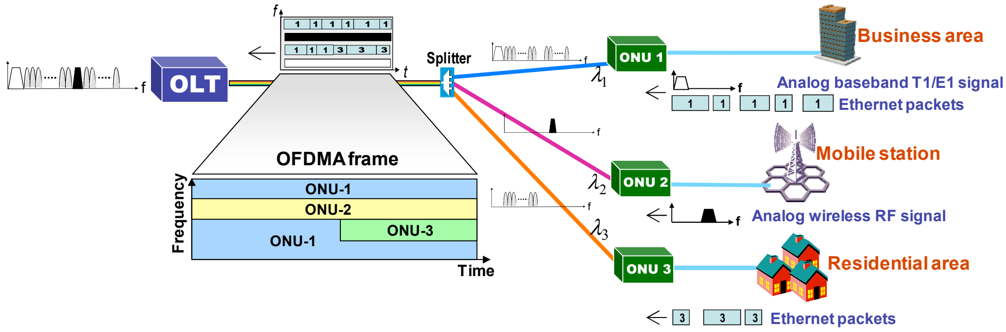

Figure 3. OFDMA-PON for concurrent delivery of multiple services.

3. PACKET TRANSPORT IN METRO AND CORE NETWORKS

As already mentioned, the carriers are increasingly facing growing demand for a packetized bandwidth from both residential and business users, as well as requests from scientific community and governments to provide infrastructure that would support large-scale data transport and processing. The bandwidth requirements are mainly driven by intense and more sophisticated IP traffic, which now includes transport of content symbolized by different IP video flavors, and advanced Web 2.0 applications. This change in content has an enormous impact on both the volume and reliability of the traffic, which means that carriers are required to provide huge amount of traffic with managed quality and reliability. There is wide consensus today that we need a network infrastructure that will support packetized bandwidth transport in quality in quantity mentioned above.

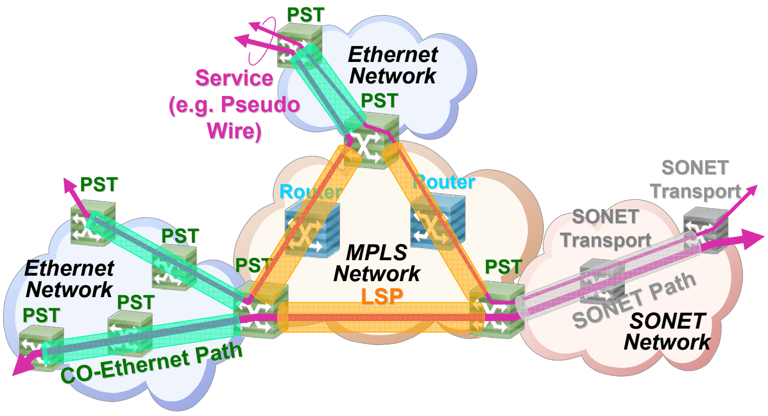

Figure 4. Deployment of PST in heterogeneous networks.

It appears that connection oriented features imprinted into packet/Ethernet technologies paired with 100 Gb Ethernet bandwidth pipes is the way to go as carriers shift their attention to building next generation network infrastructure [5]. In order to enhance the connection management, new approaches, such as MPLS-TP or PBB-TE have been proposed to avoid un-managed distributed of IP traffic. They are expected to be the cost effective means to carry huge amount of data. Therefore, the future transport networks are going to be optimized for data traffic and to have carrier grade centralized management scheme. It is essential to have an efficient interworking of Layer 2 and Layer1/0 in any packet transport infrastructure, which will accommodate mix and match of legacy services such as SONET/SDH in addition to newly introduced Ethernet services. The so called Packet Switched Transport (PST) network elements will play a key role in providing a connection oriented packet transport, as illustrated in Figure 4. These network elements will also provide a multi-layer cross-connect feature and deloading of IP router through traffic [5,6].

From high bandwidth transport perspective, 100Gb Ethernet is needed sooner rather than latter. The need for 100GbE includes development of server interconnects, definition of the Media Access Control (MAC) layer parameters and LAN physical interface specifications for the 100GbE PHY, and definition of transport parameters that would allow communications over 100GbE across the Wide Area Networks (WAN) and nationwide networks [7,8]. Future transport network will provide interoperability between two key technologies Ethernet and OTN (Optical Transport Network). Data wrapping into so-called optical transport units (OTU4) containers, which will be transported over wavelengths, will become the way to design optical transport networks. The OUT-4 is an extension of OTU units, or containers, recognized by ITU-T [8] for the following bit rates: OUT-0 for 1.25 Gb/s, OTU-1 for 2.5 Gb/s, OUT-2 for 10 Gb/s, OUT-3 for 40 Gb/s, and OUT-4 for 100 Gb/s.

There is a requirement for transmission of 100GbE signals (wrapped in OUT-4 frame) over distances that far exceed 1000 km. For that purpose, multilevel modulation schemes, usually recognized through multi-level quadrature-amplitude-modulation (M-QAM) techniques, or by multi-level phase shift key modulation (M-PSK) should be combined with polarization multiplexing to improve the spectral efficiency and relax the requirements with respect to both chromatic and polarization mode dispersion. Selection of a modulation format is related to its complexity (or cost effectiveness) and performance (through optical signal-to-noise ratio-OSNR) that can be achieved. The general rule is, however, that any merit from spectrum reduction perspective will have a negative impact to OSNR that can be achieved at the receiving side. In order to increase the receiver sensitivity, coherent detection with heavy digital signal processing has been applied [9-16].

There was a number of experiments during last several years where multilevel modulation schemes have been used, often in combination with polarization multiplexing shown in Table 1, aimed to increase either transmission capacity or distance or both. Just recently, the record spectral efficiency of 4.2 b/s/Hz, and a record bandwidth transmission have been demonstrated with 114 Gb/s DWDM transmission over 600 km by using 8-PSK modulation scheme combined with polarization multiplexing [5].

Table1. DWDM spectral efficiency and bandwidth distance product for100 Gb/s transmission.

Bit rate (Gb/s)	Total capacity (Tb/s)	Distance (km)	Modulation format	Reference
107	1	480	NRZ-OOK	OFC 2007, PDP23
107	1	160	VSB NRZ-OOK	OFC 2007, OWE3
100	0.1	50	NRZ-DQPSK	OFC 2006, PDP36
107	1	1200	NRZ-DQPSK	OFC 2007, PDP24
107	1	2000	RZ-DQPSK	ECOC 2006, Th4.1.3
111	20	240	PDM RZ-DQPSK	OFC 2007, PDP20
111	1	2375	PDM RZ-DQPSK	OFC 2007, PDP22
111	13.4	6248	PMD-OFDM	OFC'09, PDPB5
114	32	580	PMD-RZ-8PSK	OFC'09, PDPB4
Spectral Efficiency (b/s/Hz)	**Total capacity (Tb/s)**	**Distance (km)**	**Modulation format**	**Reference**
2	1.2	1000	PDM-OFDM	OFC 2008, PDP2
2	16.4	2550	PDM-QPSK	OFC 2008, PDP3
3.2	25.6	240	PDM-RZ-DQPSK	OFC 2007, PDP19
4.2	0.9	640	PDM-RZ-8PSK	OFC 2008, PDP1
6.2	1.1	630	PDM-RZ-16QAM	OFC'09, PDPB8
7	0.52	240	PMD-OFDM	OFC'09, PDPB7

4. CONCLUSIONS

The most important aspects of next generation optical networking have been discussed. There are several key technologies that are well suited to bring connection to practice oriented end-to-end packet transmission.

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