Review of Challenges and Standard Research Contribution in Optical Networks

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Abstract- The need of more capacity of the network due to exponential usage of internet by users is the concern of majority of the researchers currently. In line of exploring better solution, it can be said that currently fiber optics has become the core of telecommunication and data networking infrastructures giving birth to optical networking system. These factors have driven the deployment of high capacity optical network and their remarkable rapid transmission from the research laboratories into commercial deployment. However, with the progress of technology taking pace, trade-off is surfaced by the unpredictable traffic situation over the dynamic users situated world wide that is quite challenging to standardize the performance of the existing optical networks. Hence, this paper reviews some of the standard and frequently used techniques for mitigating the traffic issues in Optical networking system.

Keywords- *component; Optical Communication, Wavelength Routing, WDM, network*

INTRODUCTION

Optical communication systems [1] and networks will continue to play a significant role in the development and deployment of emerging network infrastructures. These networks are expected to support the diverse requirements of a broad range of existing and future applications. To accommodate this wide spectrum of applications, network infrastructures are evolving rapidly in terms of technology and architecture towards a more flexible and intelligent optical layer based on Dense Wavelength Division Multiplexing [2] (DWDM) that utilizes new optical switching architectures and technologies as well as advanced control and management protocols. Optical component technology is rapidly maturing, offering cost-effective solutions to a point where optical networks are currently being deployed in core backbone networks, and are gaining increased interest for deployment in metro and access environments. The widespread deployment of optical communication systems and networks introduces many challenges and opportunities, which this special issue aims to address. At present, WDM is preferred over other multiplexing technologies [3] since all of the end-user equipment need to operate only at the peak electronic processing speed where as in TDM and CDM, some part of an end user's network bandwidth can be divided into multiple non-overlapping frequency or wavelength channels. Each WDM channel may be operated at any speed, e.g., peak electronic speed of a few gigabits per second (Gbps). Currently, commercially available optical fibers can support over a hundred wavelength channels, each of which can have a transmission speed of over a gigabit per second (e.g., OC-48, OC-192, and OC-768 [4] in the near future). Optical TDM and CDM are somewhat futuristic technologies today. Under (optical) TDM, each end-user should be able to synchronize to within one time slot. The optical TDM bit rate is the aggregate rate over all TDM channels in the system, while the optical CDM chip rate may be much higher than each user’s data rate. As a result, both the TDM bit rate and the CDM chip rate may be much higher than electronic processing speed, i.e., some part of an end user’s network interface must operate at a rate higher than electronic speed. Thus, TDM and CDM are relatively less attractive than WDM [5], since WDM - unlike TDM or CDM-has no such requirement. Specifically, WDM is the recent favorite multiplexing technology for long - haul communications in optical communication networks since all of the end-user equipment needs to operate only at the bit rate of a WDM channel, which can be chosen arbitrarily, e.g., peak electronic processing speed. Hence, the major carriers today all devote significant effort to developing and applying WDM technologies in their businesses. Research is ongoing to introduce more intelligence in the control plane of the optical transport systems, which will make them more survivable, flexible, controllable and open for traffic engineering. Some of the essential desirable attributes of optical transport networks include real-time provisioning of lightpaths, enhanced network survivability, interoperability functionality between vendor-specific optical sub-networks, and enabling operational protection and restoration capabilities. The research efforts now are focusing on the efficient internetworking of higher layers, primarily IP with WDM layer. The current paper discusses various traits of issues and their existing countermeasures in Optical networking. The paper is expected to brief the most related techniques considered in the studies of Optical network. In section 2, the illustration of issues in Optical network is discussed followed by discussion in Wavelength Division Multiplexing in Section 3. Switching mechanism in Optical networks is discussed in Section 4 accompanied by Section 5 elaborating Optical packet Switching.

Section 6 Discusses about various multiplexing techniques followed by discussion on prior established research work in Section 7. Finally, some concluding remarks are made in Section 8.

Approaches in Traffic management

The development of a broadband and ubiquitous Internet is mainly based on optical network technologies for building high capacity transport and access networks, and on wireless network technologies for providing ubiquitous Internet accesses. The various approaches in Optical Network in traffic managements are discussed as follows:

- **Traffic Management**: Minimum-Fiber and Minimum-Conversion optical network wavelength assignment problems [6], dealing with assigning wavelengths to network user demands in a fashion that minimizes the total number of deployed fibers or conversions, respectively. The solution [7] techniques for such issues perform nearly optimally on all assignment problems for which the optimal solution is known. However, today it is widely recognized that the traffic expected to be carried by the public transport networks will be progressively dominated by data, which is growing at explosive rate due to the migration of many applications and services over IP [8]. Measurement methods using direct per link interface monitoring were found to perform worse than methods that aggregate per flow bandwidth information extracted from IP/MPLS ingress nodes in order to derive logical topology link loads. Failure propagation [9] causes if the choice of clear-channels is realized without taking into account the interaction between the two levels.

- **Traffic Protection**: In a wavelength-routed WDM optical network as well as in other networks, the failure of a network element (e.g., fiber link, cross-connect, etc.) may cause the failure of several optical channels [10], thereby leading to large data and revenue losses. Protection schemes can be classified by the type of routing strategy as link-based versus sub-path-based versus path-based, and by the type of backup-resource sharing as dedicated versus shared. Similarly, restoration schemes can be classified by the routing strategy, such as link-based versus sub path-based versus path-based. A brief illustration of the routing aspect for the protection mechanisms is explained by using following example. Consider the topology shown in Figure 4.

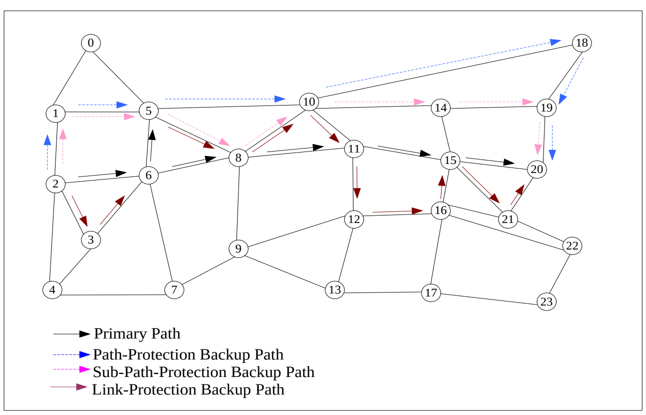

Figure 1 Path Vs Subpath vs link protection

The lightpath from node 2 to node 20 has primary path <2, 6, 8, 11, 15, and 20>. Under path protection, the lightpath can have backup path <2, 1, 5, 10, 18, 19, and 20>. If a link along the primary path (e.g., link <8, 11>) fails, an end node of the failed link (node 8) notifies the source node of the lightpath (node 2) about this failure, and the source node switches traffic path protection, the lightpath can have backup path <2, 1, 5, 10, 18, 19, 20>. If a link along the primary path (e.g., link <8, 11>) fails, an end node of the failed link (node 8) notifies the source node of the lightpath (node 2) about this failure, and the source node switches traffic to the backup path (this is called 1:1 path protection).

- **Traffic Grooming**: Traffic grooming is a term used to describe how different and low-speed traffic streams are packed into higher-speed streams [7]. In a WDM optical network, each wavelength can carry several lower-rate traffic streams in TDM fashion. Regular traffic pattern [11] are considered, as a generalization of the all-to-all traffic pattern and focused on the Unidirectional Path-Switched Ring (UPSR) networks. The concept in [7] proved that the traffic grooming problem is NP-hard for the regular traffic pattern in UPSR networks, and in this paper it was shown that the problem does not admit a Fully Polynomial Time Approximation Scheme (FPTAS). Grooming of the non-uniform traffic on unidirectional and bidirectional rings [12], unidirectional rings were mapped onto a linear topology, and then a two-step approach had been developed to solve the grooming problem, while minimizing the number of the wavelengths and the ADMs, for the mapped topologies. For the first step, an algorithm MIN-STRINGS has been developed that produces the optimal (minimum) number of strings on a linear topology, while compacting each string with traffic streams. For the second step, an effective heuristic has been designed to groups strings for each wavelength such that the numbers of the ADMs used per wavelength are minimized.

- **Traffic Coloring**: Since lightpath are the basic building block of optical network architecture, their effective establishment is crucial. The wavelengths assigned must be such that no two lightpaths that share a physical link use the same wavelength on that link [13]. Once a path has been chosen for each connection, the number of lightpaths traversing any physical fiber link defines the congestion on that particular link. Wavelengths must be assigned to each lightpath such that any two lightpaths that are sharing the same physical link are assigned different wavelengths. The wavelength assignment problem (also known as the path coloring problem) for a set of lightpaths and their routes, involves assigning a wavelength to each lightpath such that no two lightpaths share the same wavelength (colour) on a given fiber link. One approach to solving this problem is to formulate it as a graph-coloring problem. Once a path has been chosen for each connection, the number of lightpaths traversing any physical fiber link defines the congestion on that particular link [14]. Wavelengths must be assigned to each lightpath such that any two lightpaths that are sharing the same physical link are assigned different wavelengths. Assigning wavelengths to different lightpaths in a manner that minimizes the number of wavelengths used under the wavelength continuity constraint reduces to the graph-coloring problem.

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WAVELENGTH DIVISION MULTIPLEXING (WDM)

There are basically two ways to increase the fiber capacity in transmissions as discussed in viewpoints of multiplexing techniques as shown in Figure 2 [20].

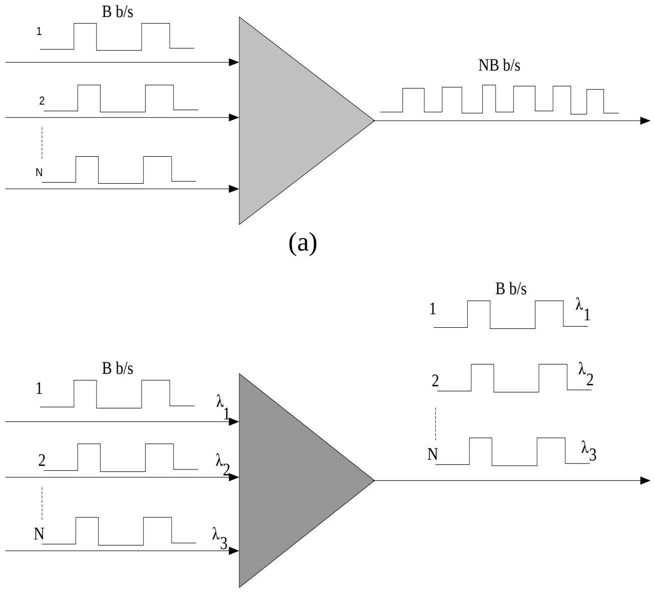


Figure 2 Different multiplexing techniques for increasing the transmission capacity on an optical fiber. (a) Electronic or optical time division multiplexing and (b) wavelength division multiplexing. Both multiplexing techniques take in N data streams, each with B b/s, and multiplex them into a single fiber with a total aggregate rate of NB b/s.

- **TDM (Time Division Multiplexing):** TDM is a method for transmitting multiple digitized data, voice, and video signals at the same time over a single communication medium by interleaving pulses that represent bits from different channels or time slots. Many lower-speed data streams are multiplexed into a higher-speed stream at the transmission bit rate by means of electronic TDM. The multiplexer combines the lower-speed streams to achieve the higher-speed stream.
- **WDM (Wavelength Division Multiplexing):** WDM is basically the same as frequency division multiplexing (FDM), which has been used in radio systems for more than a century. The term FDM is used widely in radio communication, but WDM is used in the context of optical communication, perhaps because FDM was studied first by communications engineers and WDM by physicists. The idea is to transmit data at the same time at multiple carrier wavelengths (or, equivalently, frequencies or colors) over a fiber. WDM allows many channels onto a single fiber without the need for high-speed optoelectronic devices for end-users. Optical networks with WDM arose to endow with added capacity on existing fibers. WDM has become a widely accepted technology for meeting growing bandwidth demands. The advantages of WDM are increased usable bandwidth, reduced processing cost, protocol transparency, and efficient fault handling. WDM systems are beginning to be deployed in both terrestrial and undersea communication links. The deployment of WDM in communications networks has brought solutions to satisfy the rapidly increasing demand for bandwidth capacity introduced by the huge explosion in the public internet. Thus, WDM offers an excellent platform for carrying IP traffic. WDM technology plays a key role in the internet explosion. This situation led to research interest in WDM based optical networks, which become the right choice for the next generation internet networks to transport high-speed IP traffic [15].

WDM and TDM both are methods that increase the transmission capacity and are complementary to each other. Consequently, most networks today use a combination of TDM and WDM. The critical question today is determining what combination of TDM and WDM should be used in carriers.

SWITCHING MECHANISMS

Network users are increasing day by day and they can transmit not only data but also multimedia applications. It is essential that the bandwidth and speed of the network have to be enhanced as the number of network user's increase every minute.. To cope with the enormous pace of development of optical networks, switching technologies are introduced. Recently many researchers have proposed new switching technologies in optical domain. They are Wavelength Routed (WR) networks, Optical Burst Switching (OBS) networks, Optical Packet Switching (OPS) networks [16]. In an OBS network, various types of client data are aggregated at the ingress (an edge node) and transmitted as data bursts (Figure 3(a)) which later will be disassembled at the egress node (Figure 3(b)). During burst assembly/disassembly, the client data is buffered at the edge where electronic RAM is cheap and abundant.

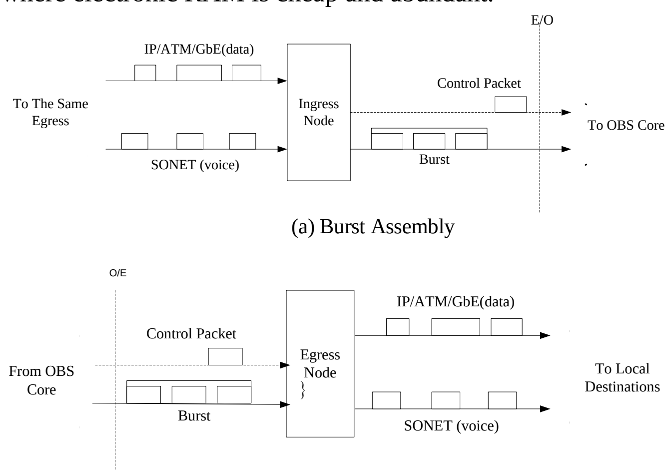


Figure 3: Burst Assembly/Disassembly at the Edge of an OBS Network

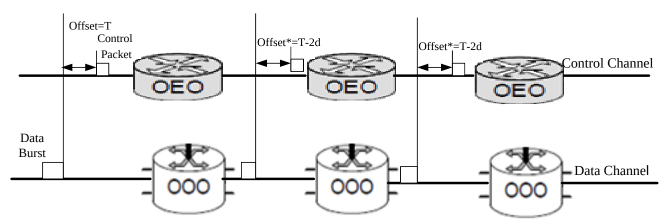


Figure 4: Separated Transmission of Data and Control Signals

Figure 4 depicts the separation of data and control signals within the core of an OBS network. For each data burst, a control packet containing the usual "header" information of a packet including the burst length information is transmitted on a dedicated control channel. Since a control packet is significantly smaller than a burst, one control channel is sufficient to carry control packets associated with multiple (e.g., hundreds of) data channels. A control packet goes through O/E/O conversion at each intermediate OBS node and is processed electronically to configure the underlying switching fabric. There is an offset time between a control packet and the corresponding data burst to compensate for the processing/configuration delay. If the offset time is large enough, the data burst will be switched all-optically and in a “cut-through” manner, i.e., without being delayed at any intermediate node (core). In this way, no optical RAM or fiber delay lines (FDLs) is necessary at any intermediate node. Nevertheless, the burst-level granularity leads to a statistical multiplexing gain which is absent in optical circuit switching. Furthermore, it allows a lower control overhead per bit than that in optical packet switching. Wavelength Routed networks is also referred as Optical Circuit Switching (OCS) networks. In OCS, a dedicated end-to-end light path is established for each connection. There is no loss in data in this technique. However, there will be considerable delay during transmission and less wavelength utilization by using this technique [17]. OBS networks are characterized by a separation of data and control channels. At first, a control packet is sent to support intermediate nodes configuration and resource reservation; meanwhile the source node builds the corresponding burst aggregating incoming packets with the same characteristics; when intermediate node is ready, the burst is sent optically switched across the network. This means that only control packets are converted to electrical domain at each hop to take reservation decisions, while the bursts always remain in the optical domain. There are two major deficiencies in OBS. They are the delay offset between a control message and its corresponding data burst is based on the diameter of a network and OBS adopts one-way resource reservation scheme. The delay offset affects network efficiency, quality-of-service, and network scalability. This one-way resource reservation scheme causes frequent burst collision and, thus, burst loss.

On the other hand, in OPS, messages are transmitted as packets. Here, control and data information travels together in the same channel. At each switching node, the packet header is processed in the electrical domain for routing purpose and the packet data is kept in the optical domain. Based on the destination, information extracted from the packet header and the control module decides to which output the packet is to be switched and configures the switch accordingly. Fig. 5 shows a switch for packet arrivals to output fiber, where F is the number of fiber used and N is number of wavelengths used.

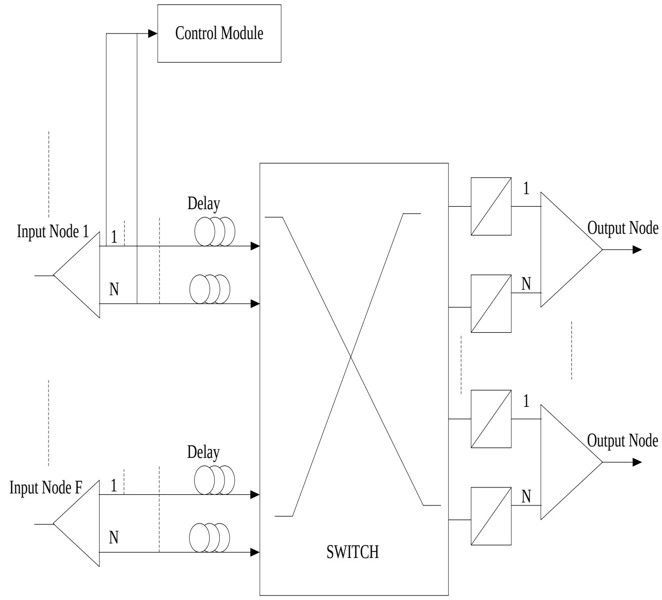
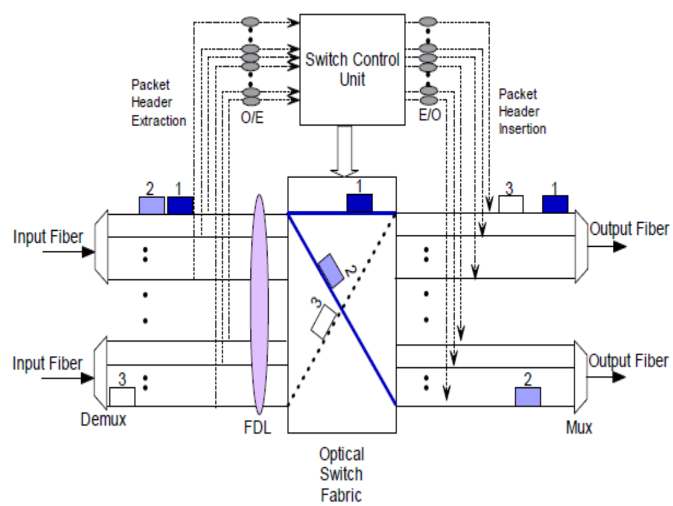
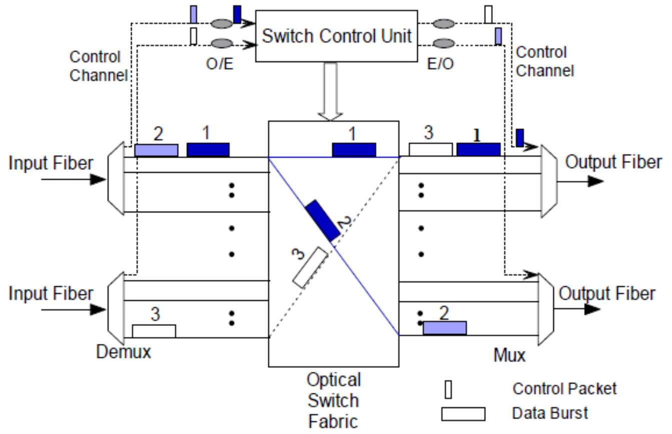


Figure 5 Architecture of the optical packet switching network

The burst in OBS and the packets in OPS can travel at their freewill by using wavelength while in OCS, data should travel only in the allocated light path. Hence, wavelengths are efficiently utilized by OPS and OBS. OPS and OBS are the technologies, which use WDM to transfer the data in optical domain. Both OPS and OBS can be used to transport IP traffic and ATM traffic. OPS and OBS are optically switched network architectures that aim to serve higher layer packet based communication protocols. Introduction of OPS and OBS became popular because they have improved their performance by using WDM, reduction in network capital and operational expenses.



a) OPS node



b) OBS node

Figure 6: Comparison of Different Switching Node Architectures

Basic switching node architectures used by various switching paradigms are illustrated and compared in Figure 6. At an optical circuit switching (OCS) node shown in Figure 6(a), once a lightpath is setup, all data carried by one input λ will go to a specific output λ. Since no O/E/O conversion of data at any intermediate node is needed, multi-hop transparency (in terms of the bit rate, protocol and coding format used) can be achieved. On average, the connection duration should be on the order of minutes or longer as setting up or releasing a connection takes at least a few hundreds of milliseconds. Shorter duration connections needed to accommodate sporadic data transmissions will result in a prohibitively high control overhead. A major difference between OCS and the other three approaches depicted in Figure 6 is that in OCS, no statistical multiplexing of the client data can be achieved at any intermediate node. More specifically, in the core, bandwidth is allocated by one λ at a time, which is a coarse granularity. In practice, however, most of today's applications only need the sub- λ connectivity. In addition, high-bit rate computer communications often involve "bursts" that last only a few seconds or less. To overcome the above deficiency of the OCS approach, O/E/O conversion can be introduced above an OCS network in the IP and SONET layers for example. The electronic switching node used in such an O/E/O approach is depicted in Figure 6(b). Here, statistical multiplexing of the client data at the sub- λ granularity is possible with electronic processing and buffering (not shown in Figure 6(b)). Since every data unit needs to go through O/E and E/O conversion, this approach is not scalable enough to support hundreds of wavelengths, each working at 40Gbps or beyond (the need for which is anticipated in the near future). In addition, electronic switches are known to suffer from problems such as limited capacity and huge power/space consumption and heat dissipation in addition to requiring expensive O/E/O conversions. Note that, although not shown, either an optical cross connect or optical add-drop multiplexor may also be used in conjunction with an electronic switch for wavelength granularity traffic that does not need to go through the electronic switch. A hybrid, multi-layer network consisting of such nodes, each consisting of both an electronic switch/router and an optical cross connect, is one way to combine the strength of the optics and electronics, but certainly not the only way to do so, and in fact may not be the ultimate long-term solution.

Since OPS and OBS are still in preparatory stage and in experimental phase, the full benefits of these switching technologies are still to be exploited. OPS and OBS are highly aggressive technologies and OPS technology is undertaken for study with a viekw to explore the avenues of performance improvement. OPS technology seems to be more feasible when compared to OBS. In recent times, the optical packet switching has emerged as one of the most promising technologies for future telecommunication networks. OPS networks operate in either asynchronous or synchronous mode. Synchronous OPS sometimes referred to as slotted OPS [18]. In slotted OPS network, all the packets have the same length. Header is placed inside the packet with fixed timeslot and packet is having a longer duration than the header. In slotted OPS networks, packets with the fixed length are aligned together with equally spaced timeslots before they enter the switch in each node. Packet alignment requires the design of optical synchronization stages. So, there is a pre-stage for the packet synchronization before they are switched by the following optical packet switching stage. This synchronization stages increase equipment cost. Hence, it requires complex and expensive synchronization hardware at each node. In addition, packet chopping and combining for a consistent packet length can be another disadvantage. This type of network generally achieves a good throughput since the behavior of the packets is regulated. In asynchronous OPS network, optical packets can have variable lengths. The packets are not aligned and they are switched one by one 'on the fly'. Here, the node must be able to handle packets of variable length with variable inter-arrival times and asynchronous arrivals. The advantage of this technique is that a pre-stage for packet synchronization can be saved and no packet chopping and combination is required due to its flexibility in optical packet length. Asynchronous OPS networks generally have lower cost, better flexibility, and robustness. The asynchronous technique can have a much lower switching throughput than synchronous OPS networks due to higher chance of collisions between unsynchronized packets. The impact of contention is generally less in slotted OPS compared to asynchronous OPS. This is because the contention window is smaller in slotted OPS [19].

PRIOR STUDIES

Optical networking, like all of the other networks, has many problems. The objective of this section was to provide an overview of the research and development work in the area of optical networking that has been conducted in the past. Peng et al. [21] have propose a BP matching method to characterize the overflow traffic from one layer to another, resulting in an improved model to calculate the blocking probabilities for fixed routing in WRON with arbitrary topologies and without conversions. As the moment matching method only considers the mean moment of the overflow traffic, but ignores the second overflow traffic moment—variance Their approach is more accurate, which is showed by the final results. Xin [22] have demonstrated an analytical model is developed for dynamic traffic grooming, allowing heterogeneous data rates for sub-wavelength connections, arbitrary alternate routing in both logical and physical topologies, and arbitrary wavelength conversion. The accuracy of the model has been verified by numerical results from simulation.

Shen et al. [23] have developed the virtual nodal degree ranked algorithm for opaque node placement and the novel MILP-based models for sub-wavelength traffic grooming for translucent optical networks. The models maximize served sub-wavelength traffic demand and minimize required wavelength capacity. Figueiram et al. [24] have studies the behavior of two algorithms developed for scheduling multiple light paths requested by advance reservation. To assess the benefit of each algorithm, they compare the blocking probability introduced by each of them. The blocking probability is obtained by simulating their behavior on different topologies. This simulation is based on traces of requests generated by FONTS, their Flexible Optical Network Traffic Simulator, which provides on-demand and advance-reservation requests with different characteristics.

Nakajima et al. [25] have developed a connector for connecting optical fibers in an aerial optical closure. They achieved an easy procedure by designing support devices and introducing them into the assembly process. Moreover, they eliminated the need to re-cut the optical fiber during switching work, and the required working time was greatly reduced. These technologies are needed to support the future age of large scale optical network construction. Tian et al. [26] have proposed a wavelength-division-multiplexed (WDM) passive optical network (PON) to provide conventional unicast data and downstream multicast function. At the optical line terminal (OLT), for each WDM channel, a dual-drive Mach-Zehnder modulator (DDMZM) is used to generate a sub-carrier double-sideband differential-phase-shift-keying (DPSK) signal. All the central carriers are separated and subsequently modulated to deliver the multicast data, while the remaining sub-carrier DPSK signals carry the downstream uncast traffic.

Lee et al. [27] have design a two-step scheduling algorithm to support multiple bandwidth allocation policies for Upstream channel access in an Ethernet passive optical network. The proposed scheduling algorithm allows us a simultaneous approach for multiple access control policies: static bandwidth allocation for guaranteed bandwidth service and dynamic bandwidth allocation for on-demand dynamic traffic services. Zhang et al. [28] have generalized the basic structure and the construction scheme of Wavelength Routed Optical Network (WRON). They also generalized the routing scheme of WRON and proposed solutions for routing problems based on the two of the three parameters source node address, destination node address, and routing wavelength. Future work includes study of fault-tolerance variant of the WRON.

Soares et al. [29] have proposed a new wavelength converter placement scheme called First Load Priority - FLP, useful for designing and planning of optical networks with sparse partial wavelength conversion architecture. A performance evaluation of FLP working in different scenarios is provided. Comparing to other wavelength converter placement schemes like MBPF, TOT and XC, FLP achieved better performance results in all scenarios studied, very close to that achieved from full complete wavelength conversion architecture. Yupapin et al. [30] have proposed a new system of a continuous variable quantum key distribution via a wavelength router in the optical networks. A large bandwidth signal is generated by a solution pulse propagating within the micro ring resonator, which is allowed to form the continuous wavelength with large tunable channel capacity. Two forms of solution pulses are generated and localized, i.e. temporal and spatial solutions. The required information can be transmitted via the spatial solution while the continuous variable quantum key distribution is formed by using the temporal one.

Lee et al. [31] have proposed and experimentally demonstrate a novel network architecture and wavelength assignment scheme for multi-wavelength passive optical networks with protection capability. Fiber failure can be protected and the bidirectional traffic can be restored promptly. Lackovic et al. [32] has aimed was to compare the topologies using two mentioned categories. The modeling procedure for network dimensioning with demand CLR constraint has been proposed and applied to the topologies. Basic statistics for the topologies has been made, and the traffic model used for calculating traffic demands was described. Simple switch architecture with tunable converters and output buffering has been used. Luo et al. [33] have presented a network architecture to provide cloud computing using Passive Optical Networks (PONs). It promotes a new application model of PON, especially for the design and development of next generation PONs. The attractive features include data-plane provisioning in addition to traditional transmission-pipe functionality, a new way to subsidize access network deployment investment, as well as high-speed fiber optic resource virtualization.

Conclusion

Due to the recent progress and development of WDM technology, increasing traffic demands can be readily accommodated in the next-generation optical networks. In spite of the huge amount of capacity provided by a WDM channel, enhanced network services and network performance improvement can only be achieved with efficient traffic-engineering mechanisms. The fault tolerant function is essential in order to provide seamless services to users by protecting their traffic against failures in the optical network because many connections can be carried on a fiber. Because the capacity of a WDM channel is very large, its bandwidth may not be efficiently utilized by a single connection. Hence, low-rate user connections need to be efficiently aggregated through the traffic grooming scheme. The prime objective of this paper was to provide an overview of the research and development work in the area of optical networking. It can be seen that the bandwidth used can be shared by many resources and also in the passive optical network system real time live broadcasting can be possible and the same type of service quality can given to many number of users. However, there is no issue of heavy load and with GPON that can provide data rate of up to Gbps. It was also witnessed that cable is harder to splice and OLT ONU control messages consumes valuable bandwidth. In application it is used in broadband video connection, peer to peer connection and local web hosting. Traffic engineering issues regarding network survivability, traffic grooming, impairment aware routing, virtual-topology engineering, and coordination among multiple layers of network architecture need to be reviewed for next generation optical networks based on Wavelength-Division Multiplexing. An intelligent routing algorithm is especially necessary in the optical network where signal impairments due to device imperfections might degrade the signal quality. In addition, the virtual network connectivity (topology) should be flexibly maintained such that dynamic changes to the traffic demands can be easily absorbed, which can be implemented by the virtual topology engineering method in a WDM network.

Due to the ever-increasing speed of optical access networks, the bandwidth bottleneck will move from the first/last mile toward Metropolitan and wide area networks. To provide higher bandwidth efficiency, current optical metro and core wavelength switching networks based on reconfigurable optical add-drop multiplexers (ROADMs) could be required to resort to more efficient switching techniques at the sub wavelength granularity in the near- to mid-term.

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