PERFORMANCE OF OPTICAL NETWORKS: A SHORT SURVEY

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Abstract:
In the information technology era, there are relentless needs for networks with extremely high capacity. Due to the increasing internet usage and upsurge in users, the end users were longing for the revolution in the network. At this juncture to make the dreams of the network users come true, tremendous research has resulted in optical technology which is a great boon to the world of communication. Optical Packet Switching (OPS) presents new avenues for high speed interconnection networks. There is a rapidly growing demand for high-throughput networks to transmit heterogeneous traffic services such as communication of voice, images and data, multimedia interaction and advanced digital service which warranted OPS. These heterogeneous traffic services in OPS networks require appropriate treatments (e.g. delay or bandwidth guarantees). Quality of Service (QoS) is the only way through which optimization can be attained in the OPS. OPS networks place a particular attention to the QoS provisioning problem from end-to-end perspective. QoS provisioning is therefore a mandatory task in optical packet switching networks. The goal of QoS is to provide guarantees on the ability of a network to deliver predictable results. A network monitoring system must typically be deployed as part of QoS, to insure that networks are performing at the desired level. Definitely, optical networks with improved QoS capabilities are the main goal for the next generation telecommunication infrastructure. One of the proper ways of improving QoS is enhancing the network parameters in each layer. The major parameters that affect the performance of QoS in OPS are: (1) Bit Error Rate (BER), (2) Packet Loss Rate (PLR), (3) Bandwidth, (4) Delay, (5) Jitter, (6) Recovery time, (7) Response time, (8) Reliability, (9) Availability, (10) Fault tolerance and (11) Throughput and so on.

Keywords: BER (Bit Error Rate), Optical Packet Switching (OPS), Packet Loss Rate (PLR), Quality of Service (QoS), WDM (Wavelength Division Multiplexing).

1. Introduction

In order to strengthen the communication bridge among the human society, this paper aims to provide a survey of optical networks. In 18th century, telephone was invented by Alexander Graham Bell and later on telephone network was used to carry voice signals. Afterward IP network was designed for the purpose of carrying data. Since telephone network is used for real time communication system, no queues are present, IP network is a non-real time service, and data could be stored in the network and delivered later. Buffers are used to save the packets, which are placed in the queues. No significant advances in optical communication systems appeared until the invention of the laser in the early 1960s. Before 1980, communication technologies used electrical transmission for sending information. In mid 1990's, telephone networks and IP networks were started to merge for the purpose of carrying voice and data on a single network using optical fiber. The use of optical fiber for communication is only the first step in optical networking. It has grown with tremendous speed and this has impacted millions of lives across the globe.

In communication systems, when copper line is used as a channel, bandwidth is limited because of the speed of electronic processing [Xuehong *et al.* (2003)]. Fiber optic transmission has been well established and dedicated efforts are to be made to increase the transmission speed. Explosive growth of internet has inevitably effected the need to provide not only high unprecedented, accelerating demand for bandwidth requirement and speed, but also requires faster networking infrastructure and different technologies.

Optical networks are high capacity telecommunication networks that use optical technologies. Since light has higher frequencies and shorter wavelengths, greater number of information bits can be transmitted in optical networks. Optical networks operate at a rate of terabits per second; hence they provide higher bandwidth [Rajiv Ramaswami and Sivarajan (1998)]. Very high speed optical networks are required for establishing the next generation broadband data communication systems. Because of the advancements in IP networks and optical communications over the last few years, an increasing level of interest has emerged for using optical components to perform switching functions in high performance packet switches and routers.

This paper has been organized as follows: Section 2 describes the wavelength division multiplexing. Section 3 explains switching mechanisms. Section 4 elaborately introduces the optical packet switching. In section 5, Quality of service is discussed and in section 6, some of the QoS parameters are discussed. Section 7 deals with the conclusion and future work.

2. Wavelength Division Multiplexing (WDM)

To meet the needs of today's networking infrastructure, Wavelength Division Multiplexing (WDM) transmission seems to provide the required capacity. The exponential growth in networks forced to move the users towards multiplexing technique wherein more data is combined and transmitted over a single channel. In the early days, transmission was done using a single wavelength on a fiber by using high speed electronic and optical devices. In optical fiber communication, multiplexing is done using wavelength and is called wavelength division multiplexing.

Focusing primarily on WDM technology, the introduction of WDM systems increased the bandwidth carrying capacity of multiple virtual fibers, each carrying multigigabits of traffic per second, on a single fiber. WDM allows many channels onto a single fiber without the need for high-speed optoelectronic devices for end-users. In 1970s, WDM techniques were under the scanner of researchers. Many researchers worked on WDM to improve the performance of multiple wavelength operation. WDM came in to commercial use in the mid 1990's; it was simply used to realize high capacity transmission on a strand of fiber. 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 [Uyless Black (2002)].

3. Switching Mechanisms in Optical Networks

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 users increase every minute. At present optical network communication is the most suitable form of communication technology available, which can match the huge requirement of end users in terms of bandwidth and speed. Optical fiber transfer more data at a faster rate than the electrical signals. There is a surge in the users who are attracted towards optical networks, due to its higher bandwidth, faster transmission capacity and lesser attenuation. However, the optical fiber network has a great potential, which has to be upgraded constantly to meet the ever-increasing demands of global society. Optical networks offer an extremely high traffic bandwidth capable of providing communication channels for several hundred nodes. The network traffic requires the network to evolve by increasing transmission capacity of optical fibers as well as switching capability.

Today one cannot imagine the world without optical fiber communication technology. Though numerous researches have been done in the past optical networks, new emerging technologies are continuously opening up new opportunities for the development of optical networks. 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 [O'Mahony *et al.* (2001) and Harald Øverby and Stol (2004)]. 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 [Venkatesh *et al.* (2000)]. 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 [Biao Chen and Jianping (2003)].
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 [Harald Øverby and Stol (2004)]**.** 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. 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 view 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.

4. Optical Packet Switching

An OPS is a powerful and prominent networking technology. A significant advantage of packet switching lies in its bandwidth efficiency and ability to support diverse services. Hence, research is now addressing the advent towards bringing the packet switching concept that is optical packet switching (OPS).
In OPS, user data is transmitted as packets. Specifically, an optical packet is made up of two parts. The first part is the header of the packet, and the second part carries user data, which will be switched. The header carries information about packet forwarding in a network. The header generally has much less data than that of the user data. The process of merging multiple random input packet streams on to common output is called statistical multiplexing. The routers can be designed to handle the packets asynchronously or synchronously. Routers use the dynamic buffering and scheduling to route the packets efficiently. The packet switching process is carried out as follows. When an optical packet arrives at a switch node, the optical header is stripped off from the packet and the user data is untouched. The header is then converted into an electronic format and the information contained in it is analyzed to find the next hop to which that packet should be forwarded. Once the next forwarding hop is determined, new header information is generated, which can be different from the old one. The new header is then forwarded with the user data to form a new optical packet and forwarded to a specific output interface [Harald Øverby (2005)]. Fig. 1 shows a switch for packet arrivals to output fiber, where F is the number of fiber used and N is number of wavelengths used.

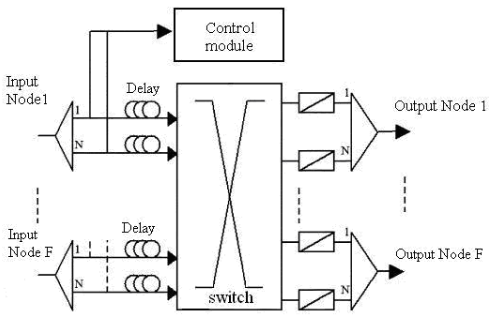

Fig. 1. Architecture of the optical packet switching network

OPS networks operate in either asynchronous or synchronous mode. Synchronous OPS sometimes referred to as slotted OPS [Nord *et al.* (2003)]. 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 [Tanenbaum (1996)].

5. Quality of Service (QoS)

Quality of Service (QoS) refers to the capability of a network to provide better service to the selected network traffic over various technologies. QoS also refers to traffic control and resource management mechanisms that seek to either differentiate performance based on application or service provider requirements [Wei Wei *et al.* (2004)]. Some of the parameters of QoS are packet/burst loss, bit error rate, delay, bandwidth, fault tolerance, recovery time, reliability, availability and response time, etc.

QoS is defined from two points of view viz. QoS experienced by the end user and QoS from the point of view of the network. End user perception of QoS is how the quality of particular service is received from the network provider in the network. The end users' perception of QoS is necessitating bandwidth guarantees, minimum delay, less PLR, controlled jitter and etc. Network's perception of QoS is how the network capabilities are fully and efficiently utilized by the end user and they are best effort service, differentiated service (soft QoS) and guaranteed service (hard QoS).

There is no guarantee in PLR and delay in today's Internet service, because it offers only the best-effort service. Today's network handles each packet equally and utilizes the available resources. Invariably, when network resources are inadequate and scarce, all traffic in the network will be degraded since there is no differentiation between the traffic. Thereby, improving the performance of QoS in OPS will be achieved.

Facing explosive growth of users, providing good Quality of Service is essential for successful development and implementation of the next-generation optical network applications. Introduction of diffusive and interactive services has dramatically increased the telecommunication traffic in the last few decades [Johnson (1985) and Piero Gamini Renaud *et al.* (1998)]. Channel capacity (bit rate), channel occupancy (continuous or bursty) and connection duration (connection set up time and frequency) will determine the range of future services in optical communication [Piero Gamini Renaud *et al.* (1998)]. Thus, QoS is an important and necessary parameter in real time applications. World Internet traffic has been growing at an exponential rate. The prevailing best effort mechanism does not provide any service differentiation or guarantee the new commercial infrastructure. There is an urgent demand for the promising QoS guarantees with the evolution of the internet [O'Mahony *et al.* (2001) and Chen, Y. and Qiao (2003)].

Now days, due to increased application and service integration, multifaceted challenges are being faced. The next generation telecommunication infrastructure will definitely comprise of optical networks with improved QoS.Though optical fibers are attractive for their higher bandwidth, to optimize the utilization of bandwidth fully; it is inevitable to improve the parameters that affect the QoS of the networks. OPS technology utilizes very high bandwidth in the optical fiber using WDM. Thus, the researchers are focusing on the optical packet switching networks to improve the quality of services using WDM. The immediate need is to improve the performance of QoS of the optical packet switching networks.

Though there are many challenges in optical packet switching, we have made concerted efforts to improve the QoS in optical packet switching networks. There is a surge in growth of network users accompanied by the explosive growth of internet. In recent years, the importance of QoS technologies for packet networks has increased rapidly. Some believe that QoS is not needed because increasing bandwidth will suffice to provide good QoS for all applications. They believe that implementing QoS is complicated, but adding bandwidth is simple. If all network connections had infinite bandwidth such networks never become congested, then one would not need to apply QoS technologies, which is a utopia.

Today, network traffic is highly diverse and each traffic type has unique requirements in terms of bandwidth, delay, loss and availability, because of which, QoS technologies play a crucial role in optical packet switching networks. It is imperative to note that the focus of optical packet switching technology is to improve QoS, because it lacks features to provide added facilities to the end users in the existing optical networks.

If QoS requirements are not addressed, the traffic will experience unpredictable behavior. In view of the fact that we have not made optimum utilization of the existing optical networks, improving QoS helps us to reduce the disparities in the prevailing networks. The most important metrics that characterize the performance of an optical packet switching technology and the most significant factors that influence the end-end quality of an application are bit error rate, packet loss and delay.Ways and means to improve QoS are to provide overprovision of network capacity and to enhance QoS in terms of parameters. QoS performance may be specified in the layers. The QoS parameters are to be modified suitably towards their corresponding layers.

6. QoS Parameters

In order to accomplish the enhanced performance of optical packet switching networks, quality of service parameters such as Bit Error Rate (BER), Packet Loss Rate (PLR), Bandwidth, Delay, Jitter, Recovery time, Response time, Reliability, Availability, Fault tolerance and Throughput and so on are to be improved in OPS and to place OPS in its proper context among the current research avenues in optical networks.

Bit Error Rate (BER) measurement is one of the prime considerations in determining signal quality [Poompat Saengudomlert and Murie Médard (2002)]. BER is the digital equivalent of signal to noise ratio in an analog system. In digital data transmission systems, a small percentage of transmitted bits to be corrupted and produces BER. For example 1×10^{-5} would indicate that 1 bit is in error out of 1,00,000 bits that are transmitted. Considering BER as the key performance parameter to quantify reliability of a transmission system, the accuracy of the BER is estimated and reduction of PLR has been measured by reducing BER in the optical networks [Carolina Pinart (2007)].

In networks, there is the possibility of transmitted packets fail to reach their destination, resulting in packet loss. Packet loss is the failure of one or more transmitted packets to arrive at their destination. This event can cause noticeable effects in all types of digital communications. There are so many reasons for the occurrence of packet loss such as signal degradation, packets corruption, faulty networking hardware, faulty network drivers, distance between the transmitter and receiver and so on. Packet loss is one of the major factors which affect the quality of service in networks.

Network delay is a vital and integral characteristic of a network. Delay of a network relates as to how long it takes for a bit of data traveling across one endpoint to another measured in fractions of seconds. Delay differs depending on the location of the specific pair of communicating nodes. Thus, engineers usually report both the maximum and average delay, and they divide the delay into several parts: processing delay, queuing delay, transmission delay and propagation delay.

When a packet is sent from one node to other, the following delays occur: (1) transmission delay (time required to send all bits of packet into the wire), (2) propagation delay (the time taken by the packet to travel through the wire), (3) processing delay (the time taken to handle the packet in the network system), and (4) queuing delay (the time taken to buffer the packet before it can be sent). Packet processing delay is the sum of processing time of an application for specific packet length and additional memory access delay. In order to achieve 100% throughput, processing delay should be reduced. To find delay in the network, propagation delay and queuing delay are only considered, but the processing delay is ignored because of its negligible values [Ramaswamy *et al.* (2004)].

Network reliability refers to the reliability of the overall network to provide communication in the event of failure of a component or components in the network. Reliability is a technique that how long the particular component is functioning without any malfunctioning. It does not relate to the time it takes for its repair and back to restoration. Survivability, the ability of a network to withstand and recover from failures, is one of the most important requirements of networks. Thus, we understand that quality of service parameters involved in optical packet switching networks and how QoS parameters affect the performance of optical packet switching networks.

7. Conclusion

This, the paper aims at providing a better Quality of Service in optical packet switching network to the end user by enhancing its performance by appropriately analyzing QoS parameters such as Bit Error Rate (BER), Packet Loss Rate (PLR), delay, reliability and etc at different layers.

7.1. *Future Work*

In order to make OPS commercially viable, further inroads in developments are to be made. Since the developments in OPS technology are in the stage of research, this field provides wide opportunity to the researchers to make OPS cost effective and a more practical phenomenon.

World internet traffic has increased exponentially necessitating QoS in optical networks. There is an urgent need to introduce optical fiber technology, which has high bandwidth that is required for high quality of transmission. Apart from bandwidth, QoS of optical OPS can be improved in the ensuing key areas.

Optical networks offer challenging opportunities at several levels. At architectural level, it will require leveraging new or improved components for both optical and electronic processing. Efficient network architectures are required for dispersion compensation and combating fiber non-linearities. At the networking layer, the opportunity is in developing protocols and algorithms.

Implementing buffer is the most important and challenging task in OPS. Employing optical random access memory in optical domain is still in its preparatory stage. Active research is going on in the field of optical buffering. Optical buffering can be realized using optical delay lines (FDL). Implementing buffer(s) in the optical packet switch can be studied as cost effectiveness in additional ports.

In the present scenario, 128 to 160 wavelengths are used as the operating wavelengths of WDM and it can be increased to higher values. To increase the operating wavelengths, laying of new fiber is not absolutely necessary, wavelengths can be increased by a factor of 16 or 32.

In future, emphasis should be made in creating on-demand high-bandwidth optical network services.

There is tremendous room to enable applications, which we have discussed so far the development of optical networking systems. Innovations exist at all levels. The operated wavelengths of WDM can be increased to higher values. Improved high-speed optical memories in the optical switch can be developed for high data traffic and electro-optical conversion can be eliminated in the switch. Due to the ever-increasing network users, introduction of gigabit network architecture will improve its performance in the future decades by connecting more than hundreds of thousands of end users simultaneously.

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