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A Smart High Speed Optical Switching Networks for the Optimization of Next Generation Intelligent Networks (NGIN)

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Abstract:
Currently, the growth in the bandwidth capacity of the network enhances the dramatic increase in bandwidth demand by the emergence of a large number of applications with the large number of resource requirements in the upcoming intelligent networks. Since these emerging applications require increased bandwidth capacity, the vision of using optical technology in the communication channel, signal processing, and switching fabric is very promising whose architecture design is based on a optical code division multiple access (OCDMA) technique. The performance evaluation of this switch fabric based on the analytical evaluation of the code and numerical simulations of the optical components which has been used to implement the system. The extension of this system of the Network grids to the Lambda Grids requires the scheduling of lambdas, i.e., end-to-end high-speed circuits that requires high-throughput transfers of large files through the desired intelligent networks using the optical transreciever. This approach in the design of the network has been referred as heuristic i.e. 'Varying-Bandwidth List Scheduling' (VBLS) because the scheduler algorithm returns a Time Range-Capacity (TRC) allocation vector with varying bandwidth levels assigned for different time ranges within the duration of a transfer. Thus, this increase in the data produced by large-scale scientific applications necessitates innovative solutions for efficient transfer of data through the intelligent network. Although, the optical networking technology reached theoretical speeds of about 100 Gbps, the applications are still suffering from the inefficient transport protocols and bottlenecks on the end-systems (e.g. disk, CPU, NIC). Thus, the high-performance systems provide us with parallel disks, processors and network interfaces.

Keywords: Optical Switching, Wavelength Division Multiplexing (WDM), Optical CMDA, Fiber Bragg Grating (FBG), Wavelength Converters, End-to-End Modeling, Throughput optimization, Data-flow Parallelism, Prediction Parallel Streams Striping, Optical Wireless, Personal Communication Systems, hybrid OW/RF systems

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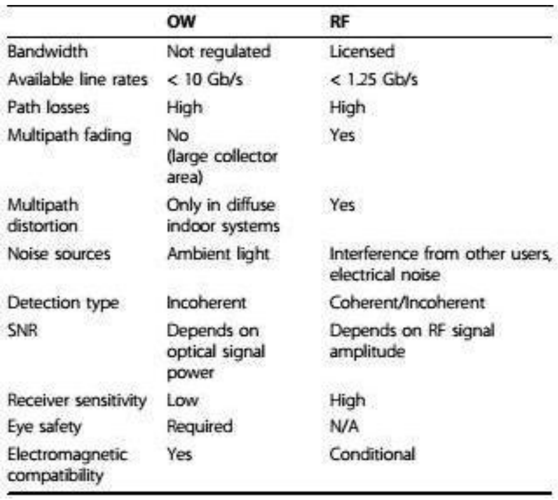
I. INTRODUCTION

It has been more than 30 years since the optical wireless (OW) was proposed as an alternative broadband technology for the wireless data transmission applications. This concept of the OW is very simple i.e. it utilizes the optical beams to carry the data through the atmosphere or vacuum. Due to this reason, the OW link architectures are very similar to the optical fiber communication point-to-point links, with the exception that no optical fibers are deployed as a transmission medium. This topology is also very similar to RF wireless network, but later on the radio waves are replaced with light antennas with free-space optical transceivers. Despite this superficial resemblance between OW and RF links, the OW exhibits several appealing attributes when compared to RF based systems.

The OW links are inherently based on the broadband and optical frequencies in the infrared and visible spectrum are neither regulated nor licensed. On the other hand, the optical components are also quite cheaper and consume less electrical power than the high-speed RF components based network systems. Finally, OW links do not suffer from multipath fading and have much less potential for interference with RF-sensitive electronic systems. These advantages do not, however, imply that OW is a universal replacement for RF communications. The application of OW systems is limited when considering area coverage and user mobility, where RF technologies prove invaluable. In addition, OW systems operate under strict eye safety regulations, while at the same time incoherent OW receivers present lower sensitivity than their RF counterparts because of their photo-electric conversion mechanisms and the impact of ambient light noise sources. Table 1 summarizes the main differences between OW and RF systems.



	OW	RF
Bandwidth	Not regulated	Licensed
Available line rates	< 10 Gb/s	< 1.25 Gb/s
Path losses	High	High
Multipath fading	No (large collector area)	Yes
Multipath distortion	Only in diffuse indoor systems	Yes
Noise sources	Ambient light	Interference from other users, electrical noise
Detection type	Incoherent	Coherent/Incoherent
SNR	Depends on optical signal power	Depends on RF signal amplitude
Receiver sensitivity	Low	High
Eye safety	Required	N/A
Electromagnetic compatibility	Yes	Conditional

Table 1: Comparative Analysis between RF and OW based Systems

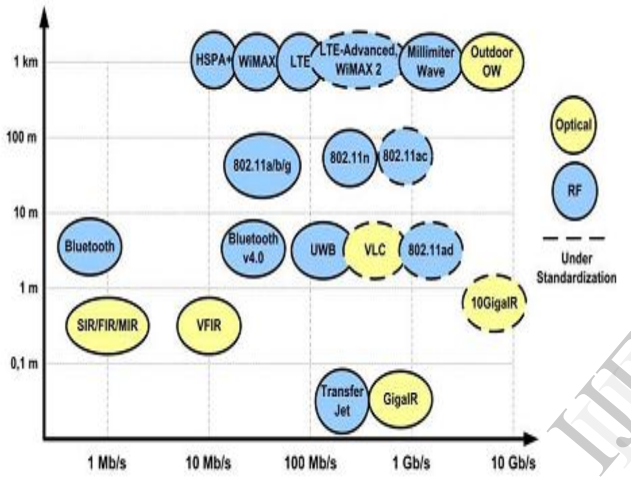


Figure1: RF and OW Technologies Deployed in Commercial Applications

In order to better understand the role and importance of the OW systems in the wireless based end user consumer world, the above figure 1 summarizes the state-of-the art as well as the commercial aspects of RF and OW technologies, in addition to the technologies which are under the standardization process by the major bodies dealing with wireless domain, say, IEEE, 3GPP, Bluetooth and IrDA. These wireless topologies has been discussed in this work with respect to their area of coverage, ranging from a few centimeters in personal communications to over 1 km in outdoor communications, and the data rates they attain, including low rate legacy links under 1 Mb/s (Bluetooth and older IrDA systems). Clearly, contemporary OW links provide channel rates up to 10 Gb/s, which directly compare to the ones of optical fibers. At the same time, commercial OW links operate at link distances that are challenging to attain in RF (3G/4G) and millimeter-wave (60 GHz) broadband communications. OW is a unique technology that provides an attractive alternative in niche application areas, complementing fiber-optic and RF wireless solutions when they are either too costly to deploy, create undesirable interference, or are not feasible at all.

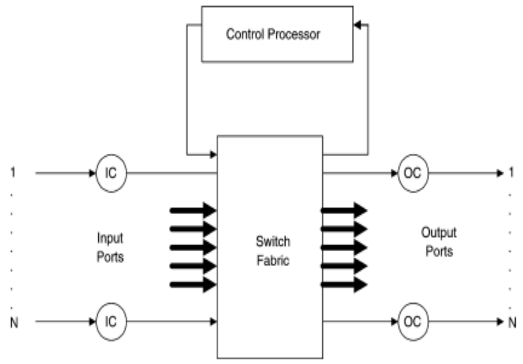


Figure2: Generic switch architecture

Figure 2 illustrates some of the application areas in which OW has been successfully applied. Two mainstream application areas of OW are last-mile broadband access and office interconnection; both are the business objectives of a number of component and system manufacturers. In such applications, state-of-the-art OW systems support 10 Gb/s Ethernet, which equals the bandwidth provided by metro fiber optic systems and is significantly higher than the 1.25 Gb/s Ethernet provided by competing RF wireless systems that operate in the 60 GHz frequency range. At the same time the deployment cost of OW systems is significantly lower than that of fiber optics, which can easily reach $1M/mile in urban areas. OW installation only requires the alignment of two freespace optical transceivers rather than digging trenches and repairing roads.

Another major application area of OW is in personal communication systems. The rapid progress in optical technology over the past 30 years, driven mainly by fiber-optic systems and display technologies, has enabled the mass production of high volume, low cost, and fast optical components that are suitable for short range OW. During the 1990s OW emerged as a candidate technology for data transmission in personal communications systems using protocols developed by the Infrared Data Association [2]. The result of this study was the standardization and commercialization of OW ports that have been extremely popular since the late 1990s and may be found on all kinds of mobile phones and portable computers. The current state-of-the-art in personal communications is Gigabit Infrared (Giga-IR) that operates at link speeds of 512 Mb/s and 1.024 Gb/s. This short-range interconnection is among the highest speed wireless interconnection media available and is easily integrated into portable and consumer devices. At the Expo Comm Wireless Japan in 2008 and 2009, KDDI Corporation demonstrated Giga-IR, which is envisioned as an interconnection medium for future cellular phones. Networking requirements of the current scientific applications are not all met by current network infrastructure. For instance storage area network (SAN) implementations explore alternatives using iSCSI over Gigabit Ethernet over DWDM and other technologies using Infini Band over DWDM [1]. Many differing networking technologies has been developed and deployed to support a growing and diverse array of services and application requirements. Recently, a lot of research has focused on optical networking to provide transparent optical communication infrastructure. Although many switching techniques for voice and data communications have been studied, new switching techniques for the optical layer such as wavelength routing and burst switching are still being developed [2,3].

Optical switching takes advantage of the techniques developed for voice and data especially in the waythe switching is accomplished. These switching techniques use mainly Time-Division (TD), Wavelength-Division (WD), Space-Division (SD), or CodeDivision Multiple Access (CDMA). However, the design and implementation of all optical switching introduced new design parameters and performance criteria [4]. The parameters include optical nonlinearity, loss/gain imbalance, signal to noise ratio, chromatic dispersion and polarization mode dispersion effects. The ability to measure and model the effects of these parameters is essential to build all-optical switches and networks. In this paper, we review the progress and proposals made in photonic switching techniques and architectures proposed to solve optical switching problems. We begin by classifying switching paradigms and examining different types of optical switching techniques. We introduce proposals in photonic switches and then describe an optical CDMA multicasting switch architecture. Finally, we present several examples of network experiments and test beds that show applications of optical switches.

II. SWITCHING PARADIGMS

Over time, two distinct networks have been developed, circuit-switched networks and packet-switched networks. Each network support different type of applications. Consequently, switches (switching fabrics) can be broadly classified into two categories in terms of how connections are established within these two types of networks. There are circuit oriented switches and packet-oriented switches. Here a

switch refers to the generic function of mapping inputs to outputs and it includes systems such as, routers, cross-connects and add-drop multiplexers (ADM). An optical switch performs switching in the optical domain without converting the data to the electrical domain (O/E/O), although the switch may be controlled electrically. In circuit-oriented optical switches, inputs and outputs are connected for a certain period of time, resources are used for that period of time (wavelength, time slot, etc.) and then these resources are released when the connection is released. In packet-oriented switches, regardless of the particular photonic technology used, the following functions are performed:

- read the packet address header;
- synchronize the packets at the input port with the control processor;
- route optical packets from input to output by setting the appropriate switch configuration;
- resolve contention of packets.

Figure 2 shows a generic architecture for a switch. It consists of four basic building blocks: the input controller (IC), the control processor, the switch fabric, and the output controller (OC). The input controller terminates the incoming signal, reads the header, and synchronizes the signal with the switch controller. The control processor is responsible for connection establishment and management of the switch. In circuit-oriented switches, the control processor also receives signaling messages from the network for circuit connection requests. These requests may be in-band with the data signals and received by the input controller or out-of-band on a separate network. The switch fabric enables packet routing, connection establishment and provides buffering functions. Output controllers transmit signals to the destination in the appropriate format for the external network. There are different ways for implementing switches to support these switching functions. Section 3 describes how these switching techniques are classified.

III. CLASSIFICATION OF OPTICAL SWITCHES

Significant advances have been made in designing switching fabrics using different technologies including space, time, wavelength, and code division multiplexing [5]. Several excellent reviews are available that cover various aspect of switching including computer communication structures, interconnection networks, circuit switching architectures, and

phothics switching systems [3,6,7]. This section focuses on fundamental photonic switching characteristics and particularly switches that support WDM services. Photonic switching architectures can be classified in two categories, shared medium (shared links) and interchanger (dedicated links). Figure 2. Two type of switching architecture: shared medium and interchanger. Figure 2 depicts a generic example of these two classes. In a shared medium, signals from the input stage are multiplexed into a shared channel (using a star, bus, or ring topology) and are broadcast to the output stage. An input port signal is demultiplexed at the appropriate output port using a multiple access protocol (TDMA, WDMA, CDMA). In interchanger switching architecture, switching is performed by a mapping operation, using separate links. Both categories can use four types of techniques:

- Space-division switches, where signals enter the switch on physically disjoint inputs and are mapped to physically disjoint outputs. The purpose of space-division switching is to be able to connect every input to every output with minimum control and few cross-points. Space-division switches can be classified according to their connectivity blocking property. They include blocking, re-arrangeably non blocking, wide-sense non-blocking, and strictly non blocking switches.
- Time-division switches, where inputs from the same link are mapped by interchanging time slots. Photonic Time Division (TD) switching systems are based on the same principles as conventional digital switching systems. TD switching involve the sharing of a cross-point for a specific period of time. Thus, individual cross-points are assigned to multiple users and each user uses the resources for its assigned period of time. The main features are scalability and

small physical size. TD Multiplexed (TDM) signals in the optical fiber transmission line are switched by interchanging the time slot in the switching network. However, it requires significant rapid operating speed and memory manipulation to accurately align and order data signals in the appropriate time slots.

- Wavelength (Frequency)-division switches, where inputs from the same link are mapped by interchanging wavelengths. The purpose of wavelength-division (WD) switching is to interchange channels (wavelengths) from inputs to outputs. There are two types of wavelength switching; one is interchanging signals from one path to another path by changing the WDM routing in the network (without wavelength conversion). The other type of wavelength switching is wavelength conversion, where the information is converted from one wavelength λ_i to another wavelength λ_j, where $\lambda_i \neq \lambda_j$. The main advantage of wavelength-division (WD) switching is that it is bit rate independent of the individual channels. Each channel can transfer at the maximum electronic modulation speed. The other advantage is that high-speed multiplexing and synchronization are not required in switching the channel. Because the wavelength tuning mechanisms are relatively slow, the WD switches are more appropriate for circuit oriented switching.
- Code-Division Multiple Access, where inputs from the same link are mapped by interchanging orthogonal codes. Code-Division Multiple Access (CDMA) is a technique that originated from spread spectrum communication and is conventionally used in wireless communications. Recently, it has been applied to fiber optic networks to provide asynchronous access [8,9]. Because of its asynchronous access and star topology, OCMDA was originally developed for local area networks [10]. Since the mid-90's, OCDMA has been considered for future telecommunications applications. For instance it has been considered for broadband applications such as ATM switching networks [11]. Salient features of OCDMA include transparency to the overlaid transport protocols; the ability to support asynchronous access; the potential for improved security and capacity; and support for QoS

IV. FLOW MODEL OF END TO END THROUGHPUT

The end-to-end data transfer throughput including the end-system factors could be modeled as a specialized version of maximum flow problem. In a maximum flow problem, the goal is to send as much flow as possible between two special nodes, without exceeding the capacity of any arc [6]. In Fig.8, the path of a data transfer between two multi-node clusters is presented. In this model, disk and multi-core nodes of the cluster are considered as nodes with capacities. The memory to-memory transfer is modeled with two dummy nodes as source and destination connected to the cluster nodes with infinite capacities.

The parallel disk system is linked with one arc instead of multiple arcs for each disk, because how many parallel disks are installed and the actual parallelism level of the file system may not be known. While all of the capacities could be measured in terms of throughput unit, the CPU has only usage percentage, in other words utilization. However there is a positive correlation between the CPU utilization and the throughput gained and we provide a model that could convert between throughput and utilization percentage.

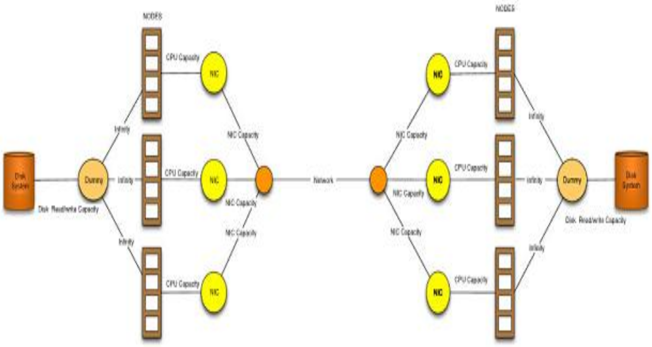


Figure 3: Flow Model Graph

The graph in Fig.8is a bipartite graph, hence it makes the application of a maximum flow algorithm very easy and there is no need to keep a residual network. It is enough to extract the value of a flow (stripe) each time the flow amount is increased. The outcome of this model will be the number of parallel streams per stripe, the number of stripes per node and the number of nodes. The amount of a throughput flow will be the maximum achievable throughput of parallel streams. However when end-system nodes present a bottleneck, additional number of stripes, each of which will be multiple parallel streams, is going to be used. In our model, the parallel stream number should be the same for all the stripes to enable the implementation of the model easier. The following variables are used to define the model:

- U_{ij}: Total capacity of each arc from node i to node j (e.g. 100 % is the average utilization of all the CPUs of a node and could be related to throughput through regression model)
- U_f: Maximal (optimal) capacity of each flow (stripe) (e.g. each GridFTP flow has an optimal throughput of 7.5 Gbps with 15 % CPU utilization for internode setting)
- N_{opt}: Number of streams for Uf
- X_{ij}: Total amount of flow passing i–>j
- X_{fk} Amount of each flow (stripe)
- N_{Si}: Number of streams to be used forX_{fkij}
- S_{xij}: Number of stripes passing i–>j
- N_n :Number of nodes

The following inequalities must hold for any algorithm that will be devised:

$$0 \leq X_{ij} \leq U_{ij}$$
(1)

$$0 \leq X_{fk} \leq U_f$$

(2)

The biggest challenge to apply this model lies in finding the capacities of each arc. The easiest one is the capacity of the NIC, which could be found by some system command. Also our tests show that the capacity of NIC can not be utilized 100 % but gives a value between 90 and 95 %. It is obvious that no matter how large the stream number is, only one core can be utilized at its maximum due to the non-threaded version of Grid FTP.

However, we have seen that threaded version of Grid FTP provides unstable throughputs which we will explain in detail in our experimental study (Section6) In that case, in addition to using the capacity of all of the CPUs, a flow (stripe) capacity is also defined that should not be exceeded (Uf) which can be dominated by NIC capacity, single disk access capacity or single CPU core capacity.

The hardest part of the problem at hand is to find the available bandwidth of the disk and network which is considered to be unknown and can only be found by doing sampling by increasing the stream and stripe number in a specific methodology considering the capacities of the nodes. In our previous work [31], a prediction model (Newton's Iteration Model) that calculates the optimal parallel stream number to achieve the maximum throughput between two end points is provided. The model is based on the Mathis Throughput Equation which is presented in (3). According to this equation, throughput depends on Maximum Segment Size (MSS), round-trip time (RTT) and packet loss rate (p). c is a constant.

$$Th <= \frac{c \times MSS}{RTT \times \sqrt{p}}$$

(3)

The throughput of n parallel streams is n times the throughput of a single stream in uncongested networks (4).

$$Th_n <= n\frac{c \times MSS}{RTT \times \sqrt{p}}$$

(4)

However, opening too many streams may congest the network, causing p and RTT values to change. An increase in these variables will also cause a drop down in throughput. So it is important to find the optimal level of parallelism that will give us the peak throughput. After several substitutions, the throughput of n streams is formulated as in (5). The details of the substitution can be found in our previous work [31].

$$Th_n = \frac{n}{\sqrt{a'n^{c'} + b'}}$$

(5)

This equation has 3 unknown variables: a', b' and c'. Therefore, 3 sampling throughput measurements (Th_1, Th2, Th3) of different parallel stream numbers (n_1, n_2, n_3) are needed to calculate those variables. Once the values of these variables are known, the throughput of any parallelism level can be calculated. An exponential sampling selection strategy is used in which the selected parallel stream numbers are powers of 2(1,2, ..,2 n). It is started with 1 stream and samplings are done until throughput starts to drop down or increase only slightly comparing to the previous level. 3 points are selected from the available samplings which give the best accuracy in prediction curve and calculate the optimum stream number.

The reason an exponential sampling strategy is selected is that the increase in throughput is steep while the stream numbers are small. However there is a logarithmic trend in the throughput curve. As the stream number increases, the throughput difference between two stream level decreases. Therefore sampling by exponential parallel stream numbers gives us good characteristics of the throughput behavior by using minimal number of samplings. The sampling is done once and the optimal number is calculated. However if the data size is too large and the network throughput varies dramatically over time, the samplings can be repeated over periodic intervals to adjust the optimal parallelism number. But it is important to keep in mind that opening and tearing down connections is costly therefore it is better to keep the sampling with different stream numbers to minimal.

That is why a back-pressure approach will not work with parallel streams. CPU utilization. To present the maximal achievable end-to-end throughput problem as a flow problem, the CPU Utilization Capacity has to be defined in terms of the throughput. Henceforth by using the correlation between these entities, a regression model is provided that will give us the predicted CPU Utilization curve from the predicted throughput curve. Since there is a linear relation between them, it is defined as follows:

$$U_{cpu} = a + b \times Th$$

(6)

$$a = Mean(U) - b \times Mean(Th)$$

(7)

$$b = \frac{\sum ThU - (\sum U \sum Th/size)}{\sum Th^2 - (\sum Th)^2/size}$$

(8)

It is mentioned in the previous sections that theend-system bottlenecks could also affect the characteristics of the throughput curve. The Newton's iteration model is used to predict the maximum throughput value of a flow (stripe) and in the following sections, algorithms are presented that calculates the flow numbers going through each arc in the flow model presented above. Newton's Iteration model can also be used to predict the peak point of throughput curve for different stripe values given all end-system bottlenecks are removed according to the algorithms presented in the following section.

V. EXPERIMENTAL ANALYSIS AND RESULT DISCUSSIONS

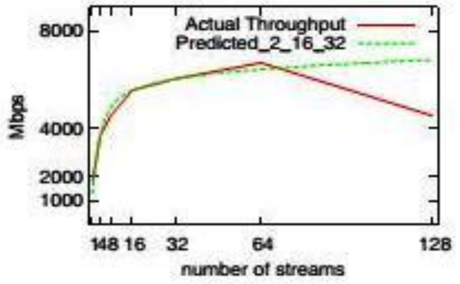


Figure 4: Data Transfer Analysis of Dynamic Model of LONI-GridFTP

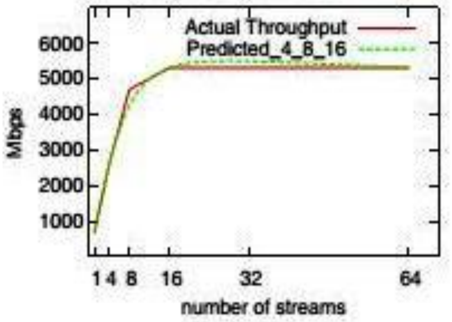


Figure 5: Data Transfer Analysis of Dynamic Model of Teragrid - GridFTP

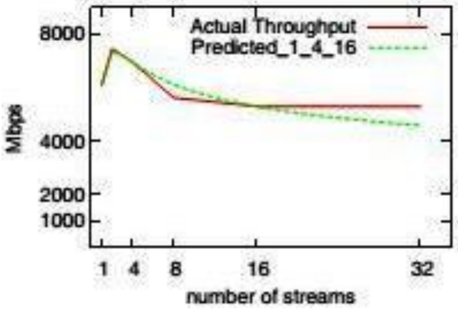


Figure 6: Data Transfer Analysis of Dynamic Model of Inter-Node GridFTP

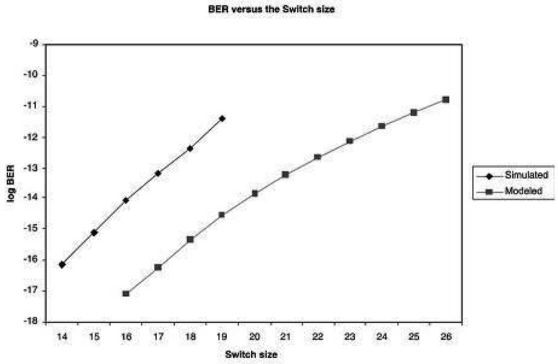


Figure7: OTDM Interconnect Architecture Based Switch Size

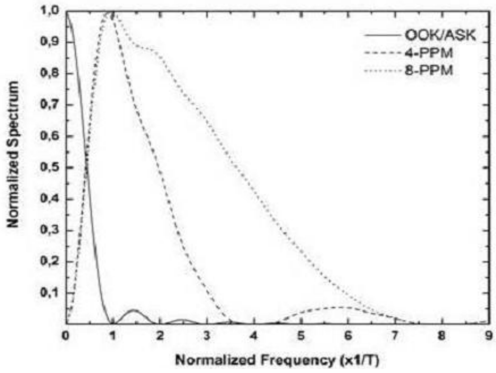


Figure 8: Spectral properties and BER performance of PPM System

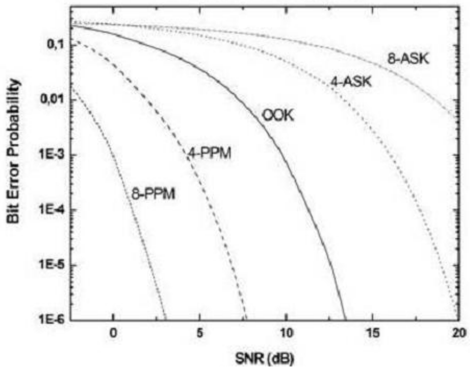


Figure 9: Spectral properties and BER performance of OOK/ASK systems

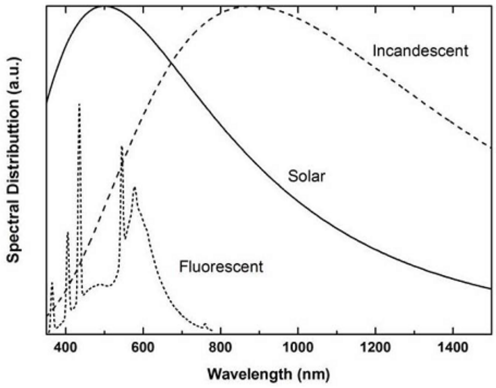


Figure 10: Spectral distribution of solar radiation and emissions from incandescent/fluorescent lamps in the visible and near-infrared wavelength range

The experimental work has been carried out with the desired graphical analysis of the dominant parameters which in turn provides the outcome that has been shown in the figures from 4 to 10. The figure 4 shows the analysis of the number of streams that has been plotted against the data rate speed for the dynamic model of LONI-GridFTP, the figure 5 6 depicts the same performance for the dynamic models of Teragrid – GridFTP and Inter-Node GridFTP respectively. The figure 7 gives the performance of an OTDM interconnects switch architecture when plotted against a standard spectrum with respect to normalized switch size. And the figures 8, 9 & 10 shows the performance of the data transmission capability i.e. spectral distribution of the PPM and OOK/ASK systems, when the analysis of the spectral densities are done with respect to BER performances.

CONCLUSION

The requirements for high-speed and high-capacity network elements in future networks justify the increasing interest in photonic switching techniques. Optical switches are likely to be used for a wide range of applications. The future of photonic switching and their deployment depends mostly on network architecture evolution, application requirements and the reliability they offer to build the confidence of carriers and service providers to be able to deploy it in a commercial net work. The economic factors and the cost-effective evolution of the photonic technology play important roles as well. Numerous photonic switches have been developed to provide switching at the optical layer. They differ in their metrics in terms of scalability, switching speed, loss and cross-talk. Each one of them may be suitable for specific application such as optical add-drop multiplexer (OADM), Optical Cross connect, Automatic protection switching, Network monitoring, or Fiber optic component testing. All-optical switches offer several advantages such as reduced capacity bottleneck, reduced cost, and dynamic network provisioning. However, electronic switches play a fundamental role in grooming at the sub-lambda level (STS-1). They handle bandwidth smaller than one wavelength and fit in access networks, metro-access networks and customer distribution. Without the development of optical buffering and header recognition technologies, it is difficult to use optical switches to route data packets in packet-switched networks. The issues that are still needed to be addressed are optical transient effects, photonic buffering, and packet and burst header recognition. Among various solutions, those based on WDM transport networks with electronically controlled switches are the most mature. Implementation and further progress in this area depends on the development of more advanced optoelectronic devices, such as tunable lasers, filters, fiber Bragg gratings, and wavelength converters. The end-to-end transfer throughput in high-speed networks could be improved dramatically by using data parallelism that takes into account the ends ystem capacities such as the cpu load, disk access speed and NIC capacity over the nodes.

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