Network Layer Performance of Hybrid Buffer-Based Optical Router

Sumit Chandra, Shahnaz Fatima, and Raghuraj Singh Suryavanshi

1 Introduction

Due to the data-centric nature of current applications like TV on demand, the internet, etc., there has been a sharp rise in the demand for more bandwidth. There is a bottleneck in the provision of very high-speed data communication due to present technological technologies. As a result, in the near future, a substitute technology will be needed to accommodate such high data rates (160 Gbps). The optical fiber cable has the capacity to carry a lot of data (Tbps). As a result, optical communication is regarded as the newest technology for data transfer.

Figure 1 displays the optical communication technologies' future plan. Digital Cross-Connect (DXC) was first launched in 1990. An Optical add-drop Multiplexer (OADM) was created 5 years later. Then, Optical Cross-Connect (OXC), passive optical networks (PON) were proposed. The concepts of optical label switching (OLS) where labels are used, Optical Burst Switching (OBS) where packets are transmitted in the form of bursts of packets, and OPS were introduced. Some of these technologies have since been evaluated and implemented in various parts of the world as discussed by Kachris [1]. The biggest barrier to OPS deployment is technology. The steadily increasing speed of electrical circuitry makes gigabit rates unsuitable. Thus, optical technology is a solution that has promise but is still in its

S. Chandra (✉)
Research Scholar, Amity Institute of Information Technology, Amity University Uttar Pradesh, Lucknow Campus, Lucknow, India
e-mail: sumit8842@gmail.com

S. Fatima
Amity Institute of Information Technology, Amity University Uttar Pradesh, Lucknow Campus, Lucknow, India

R. S. Suryavanshi
Department of Computer Science & Engineering, Pranveer Singh Institute of Technology, Kanpur, India

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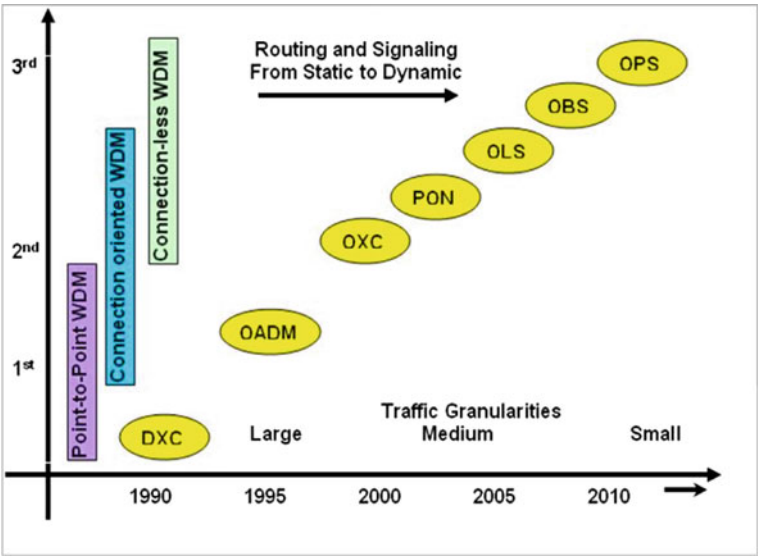

Fig. 1 Roadmap of optical communication

infancy. The three main technological concerns that are crucial to OPS are fast optical packet header processing, routing, and buffering as detailed by Kachris and Tomkos [2].

The speed at which routing may be completed affects OPS deployment. Due to the complex nature of the problem, it is difficult to determine the bare minimum requirements for OPS in routers. The following are the key factors that are essential for OPS systems as discussed by Kachris and Tomkos [3].

Switching Time

Components should be able to be configured for fast optical packet switching in less than 10 ns to maintain minimal overhead.

Throughput

Throughput is the amount of traffic that can move through a network at once without being blocked, and it should be high.

Signal Degradation

It comprises cross-talk, noise deterioration, and optical loss. The transmission distance is constrained by signal degradation. Regeneration of the signal is required to protect it from degradation, but optical 3-Regenration signals don't exist. Due to data-centric applications, internet traffic has dramatically expanded. All optical communication is still impractical as discussed by Kachris et al. [4]. Currently, only the point-to-point interface of optical communication is used, and routing is still carried out in the electrical domain, wasting a significant amount of energy in the

process of switching from electrical to optical and from optical to electrical as detailed by Hemenway et al. [5].

Due to the complexity of the optical system and the lack of optical counterparts for electrical components, the shift from electrical to optical technology is not seamless as discussed by Proietti et al. [6]. Currently, wavelength division multiplexing is used to build point-to-point networks. It is anticipated that optical routers will take the place of the present electronic routers in the following phase. Due to the lack of optical processors, all-optical router implementation is still not conceivable. As a result, hybrid optical router designs incorporating electrical processors to perform data control functions are anticipated in the upcoming phase.

Packets arrive at the inputs of the switch randomly for any output, so they may select a common output for the exit of the switch. This phenomenon is known as contention. Contention resolution procedures are employed to prevent this collision. The deflection route is currently not chosen because of the high delay. The other two processes, wavelength conversion and contesting packets' buffering, are thought to be the better options. However, it's also crucial to remember that for efficient conflict resolution, wavelength conversion and buffering should be combined.

In a similar context, many optical packet router designs have evolved with time and depend on buffering requirements as summarized in Table 1. The optical router design study was proposed by Srivastava et al. [7] and since then, several other router designs have undergone a similar analysis (Fig. 2).

Table 1 Comparison between different switch designs

References	Novelty
Bari et al. [8]	Realization of optical DCs
Xu et al. [9]	Passive optical DCs
Segawa et al. [10]	AWG-based switch design
Sato et al. [11]	Wavelength routing in DC
Srivastava et al. [12]	AWG-based switch design
Srivastava et al. [13]	Optical switch design analysis
Srivastava et al. [14]	Re-circulating type switch design
Srivastava et al. [15]	Concept of optical memory
Singh et al. [16]	Concept of hybrid memory
Srivastava et al. [17]	Concept of dual buffers
Shukla et al. [18]	Re-circulating type switch design
Singh et al. [19]	Hybrid buffer with add-drop
Singh et al. [20]	Optical buffer with add-drop
Chandra et al. [21]	Hybrid switch

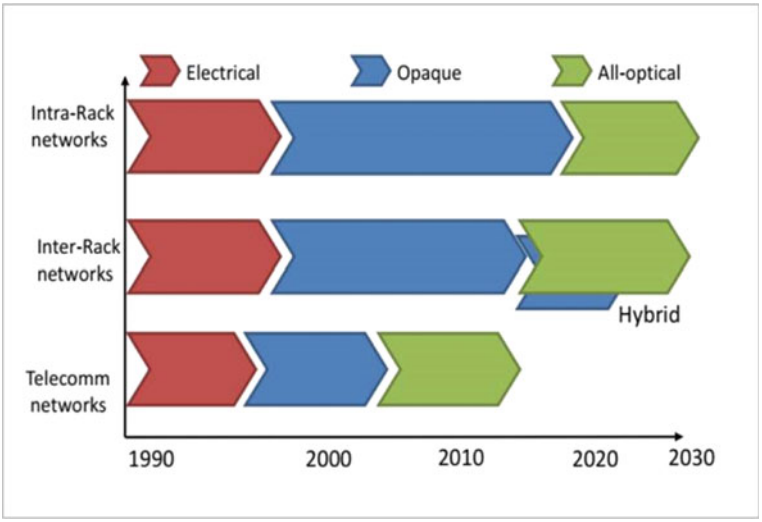

Fig. 2 Timelines for various technologies

2 Literature Survey

A variety of switch designs and buffering methods have been proposed, with the majority of modern work relying on OFC technology. Some of the notable switch designs are highlighted in Table 1. In total, 14 papers are detailed wrote by nine authors. An optical data center was suggested and created by Bari et al. [8]. A passive optical data center design was put up by Xu et al. in [9]. A Data Center design based on an arrayed waveguide grating was proposed by Segawa et al. [10]. A wavelength-routed DC architecture that is easily adaptable to WDM was proposed by Sato et al. [11]. For the storing of competing packets, Srivastava et al. [12] presented an optical core switch system based on AWG and fiber delay lines. An optical switch that is a broadcast and select type switch was introduced by Srivastava et al. [13], and a thorough mathematical analysis of the optical switch is presented to determine the operation window. A re-circulating type buffer was the foundation for the numerous optical switch designs that Srivastava et al. [14] presented and compared. According to Srivastava et al.'s [15] proposal, optical memory based on FDL has both benefits and drawbacks. A hybrid buffer with optical and electrical memories was suggested by Singh et al. [16]. Mathematical analysis has been done for the purpose of optimizing memories. The idea of a dual buffer was put forward by Srivastava et al. [17] to improve buffering storage for contention resolution. An AWG-based re-circulating type optical buffer design was put out by Srivastava et al. By incorporating WDM inside the buffer, Shukla et al. [18] expanded on Srivastava et al. [17]'s approach. An add-drop-based optical switch with hybrid buffering was introduced and its advantages over more contemporary designs by Singh et al. [19]. A network router-capable add-drop optical switch with optical buffering was presented by Singh

et al. Additionally noted are the problems with switch placement in the network [20]. Chandra et al. presented a hybrid optical switch, which is considered in this paper [21]. This switch design consists of electronic and optical buffer along with the inclusion of negative acknowledgment scheme to avoiding excess dropping of packets. The presented optical switch designs have their own advantages and dis-advantages.

3 Description of the Optical Packet Switch

Figure 3 depicts an optical packet switch based on FDL and an electronic buffer with negative acknowledgment. It is important to note that the buffering time in FDL is of the order of μs while in electronic buffers the buffering time is of the order of ms. Thus, in the case of a longer stay in the buffer (~ms), the electronic buffer will be used. The main problem associated with the buffering of electronic buffering is the first conversion of data from optical-to-electrical (O/E) and for the retrieval from electronic buffer electrical to optical conversion. However, the All-Optical Negative Acknowledgement (AO-NACK) scheme prevents this O/E and E/O conversion, but AO-NACK is sent back to the sender, thus increasing downlink traffic (Fig. 4a). To decrease the AO-NACK packets sent back to the sender, an input buffer was proposed by Chandra et al. [21], which AO-NACK packets are temporarily stored in the input buffer for a single slot only, using the buffer structure shown in Fig. 4b. The complete operation of the switch is detailed in [21]. The switching optical buffer will be used to store competing packets first, followed by the input buffer if the optical buffer is full, and the electronic buffer if the switching optical buffer and the input buffer are both full. Due to the sluggish read and write speeds of electronic random access memory, electronic buffers should be avoided. However, since they are very inexpensive compared to the cost of switches overall, they can be added to switches. It is important to keep in mind that the input buffer is only functional when there are no packets waiting at the input line. The input buffering strategy can only be advantageous under low and moderate loading circumstances. In the part after, simulation results are shown to demonstrate the utility of the input buffer.

4 Simulation Results

A computer simulation is used to demonstrate the suitability of the suggested design. The quantity of inputs, the size of the buffer, and the quantity of outputs are crucial variables from the perspective of simulation. A discrete event simulator is developed for computer simulation, and random numbers are applied to the traffic creation. As the simulation develops over time, evaluations of the number of created packets and the number of packets that successfully traversed the switch are made. A Monte Carlo simulation is run [19] to estimate average performance.

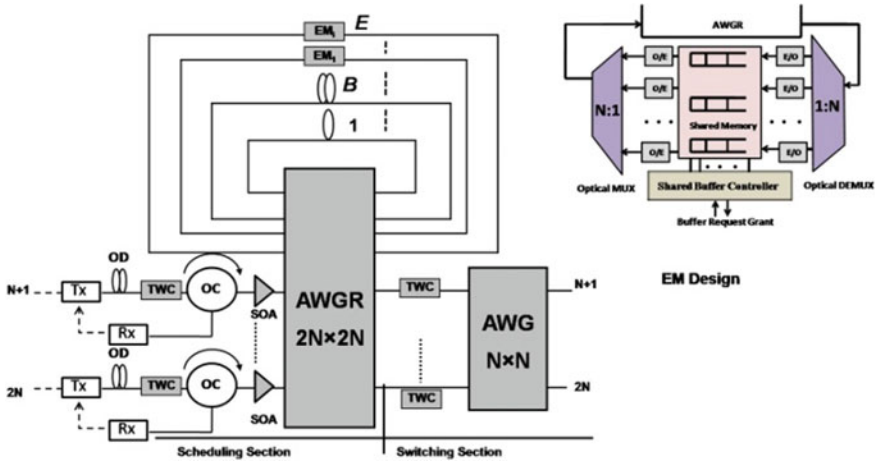

Fig. 3 Illustrative diagram of proposed switch design

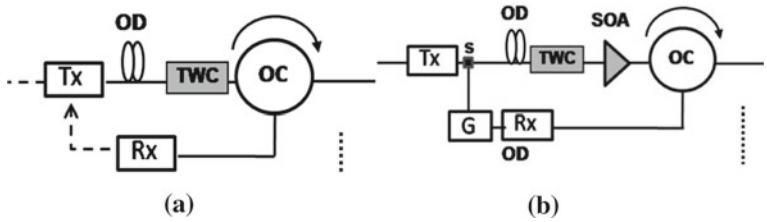

Fig. 4 **a** AO-NACK scheme **b** Input buffer scheme

The simulation steps are detailed in Algorithm 1. In Figs. 5 and 6, results for step 1 are shown while considering two loads value of '0.2' and '0.8', respectively. The load refers to the fraction of nodes generating data in a time slot. The load can be defined as the traffic that is arriving on the switch inputs, i.e., '0' load means no traffic while load '1' indicate continuous traffic on each load. For the illustration point of view, only 1000 slots are shown while considering the switch size of 4.

Algorithm 1

Input: Size of switch (N), buffering capacity (B),
MS = maximum slot for simulation
do j=1: MS
For load = ρ,
Step 1: Packet generation
With probability ρ
If packet is generated
P=P+1 (Packet count (P))
else
P=P
Step 2: Destination assignment
With probability ρ/N
Step 3: Buffer allotment
First fill optical buffer
If optical buffer is full
Fill input buffer
If input buffer is full or input line is busy
Fill electronic buffer
If electronic buffer is full
Count lost packet (L)
Step 4: Packet Loss Probability (L/P)
end
end

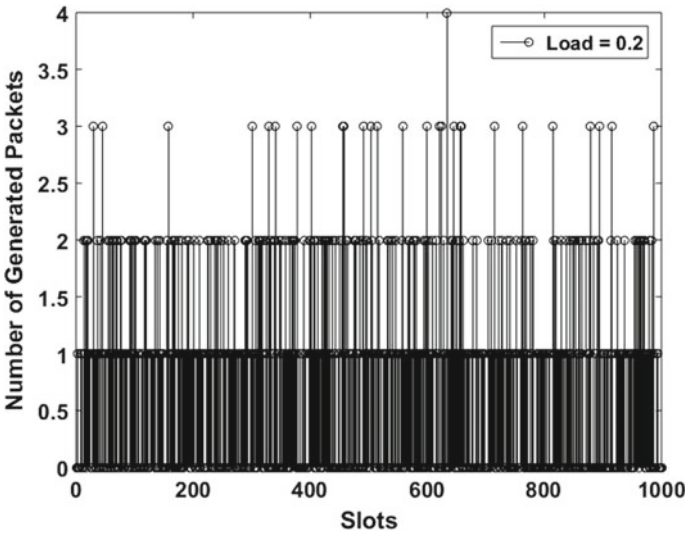

Fig. 5 Number of generated packets versus slots (load = 0.2)

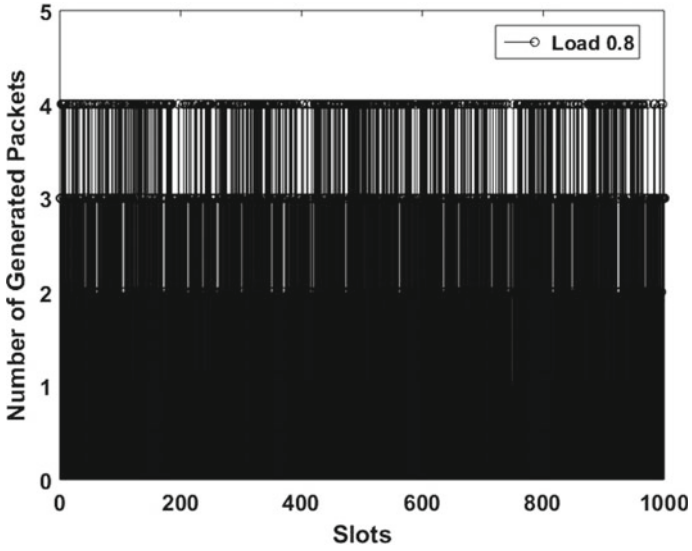

Fig. 6 Number of generated packets versus slots (load = 0.8)

Thus, the maximum number of packets that can be generated is 4. It is clear from Fig. 5. that the out of 1000 slots only once four packets are generated some slots are vacant and most of the times only one packet is generated.

In Fig. 6, the number of generated packets versus slots is shown at a load of 0.8. Here, a minimum of two packets are generated and a significant number of three and four packets are also generated. This is expected as the load increases the number of generated packets will also increase.

In Fig. 7, packet loss performance of electronic and optical buffers is shown at a load of 0.8. The packet loss probability is higher in electronic buffers as compared to optical buffers, and to maintain the same packet loss performance in electronic buffers as in optical buffers, comparatively buffer space will be required.

In Fig. 8, the number of generated packets, lost packets without buffer, lost packets with optical buffer, and lost packets in the presence of both input and optical buffer are shown. The index 1–1000 represents the performance at a load of 0.2 and, similarly, for other loads, an index of 1000 is chosen. At a load of 0.2, the number of generated packets is 792, the number of dropped packets without a buffer is 50, and with an optical buffer, the number of lost packets is zero. It is also clear that as the load increases, the number of generated and lost packets both increases. At the very high load of 1, the number of dropped packets is not zero.

In Fig. 9, packet loss probability (PLP) versus load is shown. Here the packet loss probability is very high in the case of no buffer, which is around 7.1% at the load of 0.2 and nearly 32% at the load of 1. With the use of an optical buffer, PLP is zero till the load of 0.8. While at a load of 0.8, the PLP is 1.1×10^{-4}. Finally, in the case

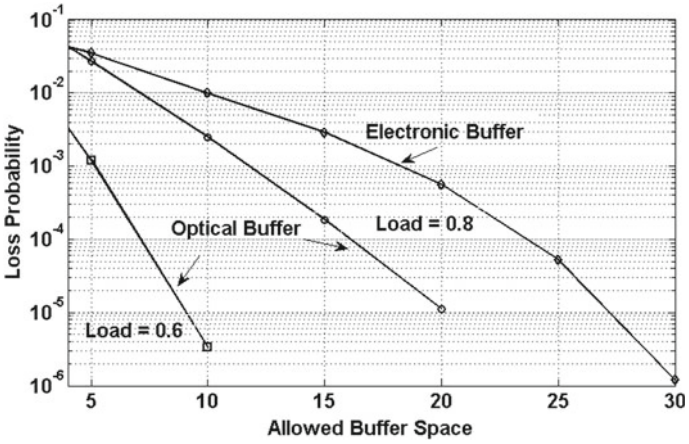

Fig. 7 PLP versus Allowed buffer space

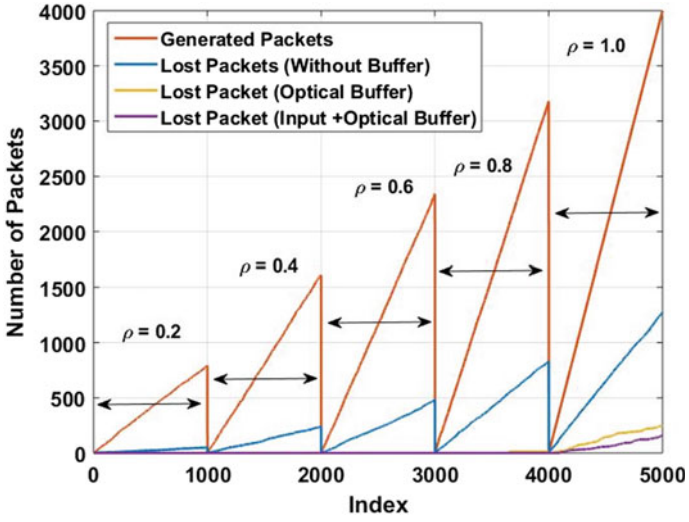

Fig. 8 Number of packets versus index

of input and optical buffer, the PLP is as low as 2.12×10^{-5}. Thus, using the input buffer, the PLP can be further reduced to 1/5.

In Fig. 10, average delay (AD) versus load is shown. Here, the AD till load of 0.8 is nearly two slots. Thereafter, it rises very sharply. In the case of the optical buffer, it is around six slots, while in the case of the input and optical buffer, the average delay is around five slots. The difference of one slot is evident due to the single slot delay at the input buffer.

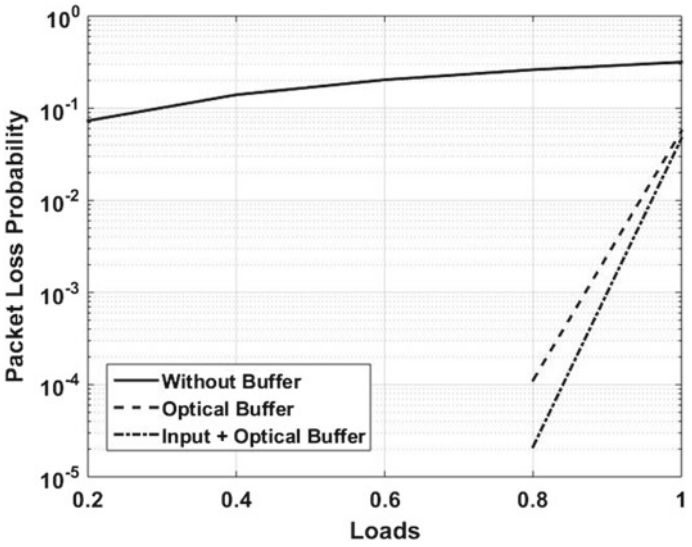

Fig. 9 Packet loss probability versus loads

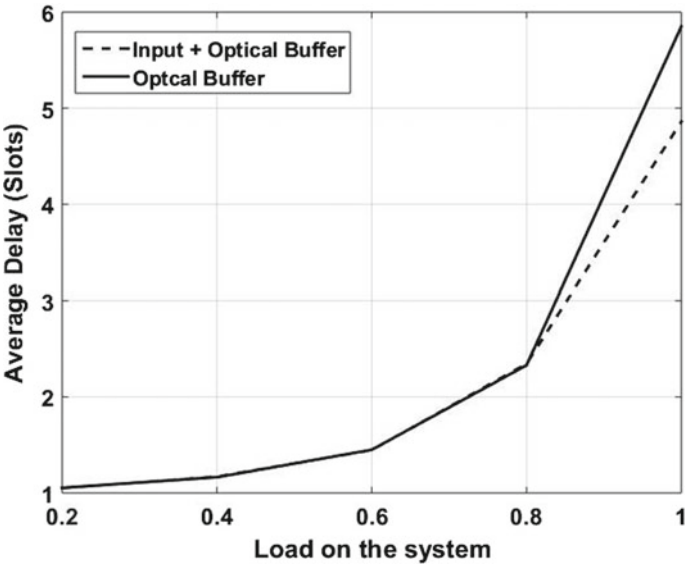

Fig. 10 Average delay versus loads

Table 2 Comparison with state-of-the-art switch designs

Reference	PLP
Singh et. al. [19]	1×10^{-4}
Singh et. al. [20]	1.28×10^{-4}
Proposed (2022)	8×10^{-5}

In Table 2, a comparison with the state-of-the-art method is shown; in the comparison, two papers are considered. In Table 2, switch size N = 4 is considered. The PLP, for Singh et al.'s [19] work is 1×10^{-4}. In the considered design, PLP is as low as 8×10^{-5}. As a result, the considered switch design outperforms current state-of-the-art technologies.

5 Conclusions

Optical routers are the main component in the designing of the OPS system, this paper discusses an optical router design, and to lessen the need for repeated transmission of the packets, inclusion of optical buffer of unit slot is introduced at the input of the switch. However, packet can only be stored in the input buffer when no other packets are present at the input line. By using a Monte Carlo computer simulation, the findings are achieved. It has been discovered that the electrical buffer performs worse than the optical buffer in terms of packet loss. The switch optical buffer has a significant effect on the PLP as a whole. The presence of an optical buffer at the switch's input can further reduce PLP, and the average delay of the switch is very less of 6 slots. In the future work, packet loss performance can be further evaluated using bursty traffic modeling.

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