On the Simulation of Optical Burst Switched Networks with Self-Similar Traffic Sources

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Abstract — This paper is focusing on the performance evaluation of optical burst switched (OBS) networks. More specifically we present a simulation framework based on OPNET modeler developed to evaluate the performance of an OBS network in the presence of self-similar traffic. The effect that the self-similar traffic sources and specific design parameters have on the network performance is examined. The network performance is assessed in terms of burst assembly delay, burst assembly delay jitter, and burst loss ratio. Our work has shown that the performance metrics under consideration have a strong dependency on parameters such as number of packets per burst, assembly timeout, number of available wavelengths and the degree of the traffic self-similarity. The scenario under study is that of an OBS star network.

Keywords — Optical Burst Switched Networks, Network Performance Evaluation, Self-Similar Traffic.

I. INTRODUCTION

The rapidly-growing Internet is driving the demand for higher transmission capacity and high-speed networks. The advances in optical networking and particularly dense wavelength division multiplexing technology have made it possible to exploit the huge potential bandwidth of optical fibers (exceeding 10 Tb/s). Although telecommunication applications have been the original driver in developing high-speed optical networks, demanding applications such as Storage Area Networks (SANs), high energy particle physics, and Grid computing in general that fuel continued networking researches [1],[2] are emerging rapidly.

It has become evident that the requirements imposed by this type of applications can only be satisfied by advanced optical network solutions based on novel transport schemes such as Optical Burst Switching (OBS) and Optical Packet Switching (OPS) [3], [4].

OBS offers an emerging and promising solution to the ongoing challenges for higher network bandwidth [5],[6]. OBS combines the benefits of circuit and packet switching transport schemes while taking into account the limitations of the current optical networks technology. In OBS the user data (including but not limited to IP packets) with the same destination and other common attributes such as Quality of Service (QoS) parameters are assembled into larger bursts and forwarded through a buffer less network as one entity. A burst overhead packet, which records the information of the burst, like the source and destination information, the burst length, and the starting instance of the burst, is also formed for the switching of this burst. The burst overhead packet is sent towards the destination in order to set up a buffer less optical transmission path for its corresponding burst. After an offset delay time, the data burst is transmitted. In general all OBS proposals include an offset time between the transmission of a burst overhead packet and its corresponding burst. This offset allows the control packet to reserve the needed resources along the path towards the destination prior to the burst arrival. Thus the data burst remains in the optical domain while traversing its path across the network from source to destination [5], [7].

Fig. 1 illustrates a typical OBS network architecture. We consider an OBS network consisting of edge routers, which are responsible for burst assembly and disassembly and core routers, which are mainly responsible for header processing and burst routing.

It has been extensively demonstrated that the traffic pattern in today’s Internet is Self-Similar [8], [9]. In this paper we intend to analyze the performance of a typical OBS network in the presence of self-similar traffic sources. The most straightforward way to investigate the network performance is through simulations, which can be used independently, or jointly with the analytical methods. However, there are no existing tools specially designed for the analysis of OBS networks. The OPNET Modeler [10] is a powerful and modular simulation tool that can be used for network simulations. We have especially designed some OPNET models to simulate the behavior of the edge and core routers in a typical OBS network. These models, exploiting the OPNET kernel, are capable of simulating different process models to implement specific protocols.

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and algorithms. The rest of this paper is organized as follows. Section 2 gives the design of the OPNET models for different types of nodes in an OBS network. In Section 3 we present our simulation results and illustrate the performance of the OBS network scenario that we focus on. We have also examined the effect of some parameters and algorithms on the overall network performance. Finally the paper is concluded in Section 4.

II. THE OPNET MODELS OF AN OBS NETWORK

Based on our description of the OBS network in the previous section, we will model and use three essential components, i.e., the edge router, the core router and the source nodes. Each component implements the OBS related algorithms and protocols.

A. Edge router

An edge node is responsible for two tasks. The first one is the packet aggregation, burst assembly and burst overhead generation, wavelength assignment (round robin approach) and burst data transmission. The second task is burst receiving. The edge router receives the bursts from the core router, disassembles them into packets and sends the packets to their destinations. The burst assembly mechanism can be timer-based, threshold-based, or mixed timer/threshold-based [11], [12]. In a timer-based burst assembly approach, a burst is created at periodic time intervals; hence the network may have variable length bursts. In a threshold-based approach a limit is placed on the number of packets contained in each burst. Our edge router model is based on a hybrid approach, i.e., a burst can be sent out when either the burst length exceeds the threshold or the timer expires. When the assembly timeout expires or the number of packets in a burst reaches the threshold, the edge router generates the burst overhead packet to record the burst information and sends it out. After a certain offset interval the data burst is also transmitted.

B. Core Router

The core router model is responsible for processing the incoming burst overhead packet, allocating required resources based on the overhead packet information and adjusting the switching fabric to switch the corresponding burst upon its arrival. There are several reservation protocols and techniques used in OBS networks with the main two being, Just-in-Time (JIT) [13] and Just Enough Time (JET) [14]. Our model exploits the JET protocol. In JET protocol, when the burst overhead packet arrives at a core router it carries the offset time information and the actual reservation starts at the expected arrival time of the burst data. The core router maintains a routing table to schedule and route data bursts according to their destination and wavelength channel. Since our model does not consider wavelength conversion, a data burst can either be fully transmitted or discarded. Based on this decision the related statistics of the model is also updated.

C. Source nodes

The source nodes in our simulation model are standard raw packet generator (RPG) workstations available in OPNET Modeler that can generate self-similar IP traffic. More precisely, superposition of fractal renewal point process (Sup-FRP) can be used for describing the session or application level fractal behavior characterizing the web requests generated by a group of users. The Sup-FRP model has three parameters $\gamma, A, M$ and is built as the superposition of $M$ independent identically distributed FRPs where each FRP is characterized by the following power-law probability density function for inter-arrival times:

$$p(t) = \begin{cases} \gamma A^{-1} t^{\gamma-1} & 0 \leq t \leq A \\ \gamma^{-\gamma} A^\gamma t^{-\gamma} & t > A \end{cases}$$

with $1 < \gamma < 2$ [15]. The generated packets are sent to the edge router that is connected to the source nodes.

The above models are general building blocks of our simulation framework that are suitable for different network topologies. By modifying the parameters of the edge and/or core router process models, we can easily investigate the performance metrics of our OBS network.

III. SIMULATION RESULTS

Using the components and process models introduced in the previous section, we will present the simulation results of a star OBS network. Fig. 2 gives the sample network topology for our simulation. The network topology is a star network consisting of one OBS core router, which is connected to eight edge nodes by WDM links.

![Image](https://via.placeholder.com/150)

Fig. 2. A star OBS network in OPNET Modeler

There are five wavelengths on each link and the link speed is 10 Gbps. Each edge node is connected to four sources. The source nodes are self-similar packet generators, which continuously generated packets based on the simulation parameters. In order to generate different self-similar traffic streams, we have gathered the simulation results for different values of arrival rate, Hurst parameter and the fractal onset time scale. Each packet has the same probability to be routed to any destination node in the network. For each port of the edge router, there is a dedicated self-similar traffic source to generate IP packets following an exponential IP packet length distribution with mean value of 375.5 bytes. This mean value reflects the fact of predominance of small packets in IP traffic peaking at 44, 552, 576, and 1500 bytes [16].
algorithm in each edge node is a hybrid timer/burst length-based algorithm. The maximum number of packets in a burst is 100 and the timeout for a burst assembly is set to 300 ms. Each newly generated burst will select an output wavelength channel in a round robin manner. In the core node, the switching time of the all-optical switching fabric is 1 µs and the time for header processing is 800 ns.

The results of the simulations are focusing on the average burst assembly delay, burst assembly delay jitter, and burst loss ratio in core router.

A. Average assembly delay and jitter

Fig. 3 presents the simulation results for the average assembly delay and assembly delay jitter of different arrival rates and burst level of traffic sources indicated by various Hurst parameters.

![Fig. 3. Average assembly delay and its jitter vs. arrival rates](image)

The first observation is that by increasing the arrival rate, higher traffic load would accelerate the burst assembly process, thus reducing the waiting time of the packets in the assembly buffers at edge routers. In spite of observing the same reducing trend in Fig. 3.a, the self-similarity effect of the traffic sources is more pronounced in Fig. 3.b. In other words, by increasing the level of self-similarity or burstiness of the traffic sources, the assembly delay jitter will also increase as expected.

B. Burst assembly parameters

The burst size is affected by two parameters: the timeout value and the maximum number of packets in a burst. Fig. 4 depicts the effect of the burst building methods on the average assembly delay and its jitter.

![Fig. 4. Effect of the maximum number of packets in a burst](image)

By increasing the Hurst parameter of traffic sources the assembly delay jitter will also increase. However, the timeout parameter also affects the assembly delay metric and the assembly delay jitter.

As depicted in Fig. 5, the timeout parameter of the burst assembly algorithm also plays a key role in the burst assembly delay and its jitter.

![Fig. 5. Effect of timeout parameter](image)

By increasing the timeout parameter, intuitively we increase the amount of time that packets should wait in the assembly buffers. However after some value another parameter, which is the maximum number of packets in a burst, comes to the play. Thus the average assembly delay and its jitter have some upper bounds.
Another observation is the differences in the jitter value for different Hurst parameters. It is observed that in case of \((H=0.9)\) the assembly delay and its jitter are not flattened as opposed to other traffic sources and Hurst parameters.

### C. Loss ratio vs. Arrival rate

Fig. 6 shows that the burst loss ratio increases almost linearly with the increase in the packet arrival rate. It is the result of the increasing traffic load, which generates higher loss. Although, this figure presents a single Hurst parameter \((H=0.7)\) for the traffic sources, the same trend is also observed for other traffic sources. For this result the timeout is set to 300 ms, and maximum number of packets in a burst is set to 100.

![Fig. 6. Burst loss ratio vs. arrival rate](Image)

**Fig. 6. Burst loss ratio vs. arrival rate**

### D. Loss ratio vs. number of wavelengths

Fig. 7 demonstrates the change of loss ratio with respect to the increasing number of wavelengths. Since one wavelength is dedicated for the transmission of the burst overhead packet, we only refer to the change of the number of wavelengths for burst data transmission. For this result the arrival rate is set to 1400 packet per second, the time out is 300 ms, and the maximum number of packets in a burst is set to 100.

![Fig. 7. Loss ratio vs. number of wavelength](Image)

**Fig. 7. Loss ratio vs. number of wavelength**

It is observed that the increase in the number of used wavelengths would decrease the burst loss ratio. This is expected as the higher number of wavelengths can be translated to higher probability that a burst finds a free wavelength to use for its transmission in the OBS network.

### IV. Conclusion

This work included the development of the necessary OPNET models to analyze an OBS network consisting of edge and core nodes. The performance results can be used as guidelines for the network design, resource allocation and the investigation of the effect of various parameters in the algorithms and protocols used. The model takes into consideration self-similar traffic sources describing realistically today’s Internet traffic pattern. It is shown that in spite of decreasing trend of average assembly delay due to increasing arrival rate, the self-similarity level of the traffic sources has significant effect on assembly delay jitter. The main burst assembly parameters, the timeout and the number of packets in a burst, and their effect on assembly delay and its jitter are also affecting these two metrics. It is also observed that increases in the arrival rate almost linearly increase the burst loss ratio. The more available wavelength can also reduce the burst loss ratio. The OPNET modules used and developed in the framework of this work can potentially be incorporated in larger and more complex OBS network scenarios.

### References


