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PERFORMANCE ANALYSIS OF WDM MESH HIERARCHICAL TIME SLICED OPTICAL BURST SWITCHED NETWORKS

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Abstract. Although Optical Burst Switching (OBS) is seen as the favored switching technology for near-future all-optical networks, this technology still suffers from high burst drops probability as a result of contention at the buffer-less core node. Many variants of OBS have been proposed to address this issue. In this paper, the performance of a newly proposed OBS variant known as Hierarchical Time Sliced OBS (HiTSOBS) is studied. The evaluation aims at comparing the performance of HiTSOBS, in terms of burst loss probability and delay for different bandwidths in different topologies. Simulation results demonstrate that larger topologies experience higher loss and higher delay. Moreover, the simulation results show that our proposed bandwidth sharing model is good for delay sensitive applications especially at lower and medium load.

Keywords: Optical burst switching (OBS); hierarchical time sliced optical burst switching burst loss (HiTSOBS);, contention; burst loss probability (BLP) time slot

1.0 INTRODUCTION

The rapid growth of large bandwidth multimedia applications development has resulted in the search for alternative solutions to transport these applications. Three Wavelength Division Multiplexing (WDM) switching paradigms have been proposed for that purpose. These paradigms are: Optical Packet Switching (OPS) [1] [2] [3], Optical Circuit Switching (OCS) [4] and Optical Burst Switching. (OBS) [5] [3]. Optical Burst Switching technology is seen as the most feasible and realistic solution to satisfy the needs of large bandwidth applications in the near future. However, burst contention in the core network needs more attention. Burst contention occurs when flows from different input lines are sent to the same output port on the same fiber channel (wavelength) at the same time. This

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problem is solved in traditional networks (electronic based), by using electronic memories (RAM) as buffers. OBS paradigm does not assume the use of a buffer in the core network. Therefore burst loss probability became a real hindrance to the deployment of OBS and it is the focus of research in OBS even at the time of this writing. Thus, it is mandatory to solve contention in OBS before this promising technology can benefit its potential users especially, telecom industry. Various architectures of OBS have been proposed in the literature in an attempt to materialize the implementation of OBS. These attempts are based on two principles: non-slotted OBS and slotted OBS. On one hand, non slotted OBS switch burst in wavelength, on the other hand, slotted-OBS switch burst in time domain. The main advantage of slotted-OBS over non-slotted OBS is the elimination of wavelength converters, which are necessary in non-slotted OBS to resolve contention in the core node. However, wavelength converters are not mature technologically, thus they are not cost effective.

In this paper, we focus on time slotted OBS variants and evaluate the performance of Hierarchical Time Sliced OBS proposed in [6] in a mesh network environment. Such analysis has never been done before for this variant of time-slotted OBS architecture. The rest of this paper is organized as follows: Section 2.0 goes through related works; Section 3.0 describes the architecture of HiTSOBS. In Section 4.0, simulation scenarios and results discussed. Concluding remarks are found in Section 5.0.

2.0 RELATED WORKS

Many variants of OBS have been proposed in the literature to reduce burst loss probability so that OBS can really be implemented in real networks and solve the large bandwidth requirements of high definition multimedia applications. The OBS architecture design can be classified into two categories: non-slotted OBS and slotted OBS as shown in Figure 1.0. Examples of non-slotted OBS are: Labeled OBS [7] , Wavelength Routed OBS [8], Dual-Header OBS [9], Reliable OBS (R-OBS) [10] and C^3-OBS [11]. For more details on these architectures, the reader is refereed to respective references. Time variants OBS are reviewed in some details as follows.

The first time variant OBS was proposed by Ramamirtham and Turner in [12]. In this OBS architecture, a wavelength is divided into periodic frames each of which is further subdivided into a number of time slots. The data burst is divided into a number of segments with each segment having duration equal to that of the time slot. Thus, the length of the burst is measured in terms of the number of slots it occupies. Each burst is transmitted in consecutive frames with each segment of the burst using the same slot in every frame. Each incoming link is assumed to have a synchronizer to align the boundaries of the slots with the switch fabric. In this architecture, the Burst Control Packet (BCP) contents the arrival time of the first segment of the burst, the position of the time slot in the frame, and the number of slots required to transmit the burst. If all the frames have free slots in the required position, then the burst is transmitted; otherwise, it is delayed using Fiber Delay Lines (FDLs) for the required number of slots. The maximum delay that can be provided by the FDL is kept the same as the maximum number of time slots in a frame. A burst is dropped if it cannot be scheduled within the maximum delay possible. The drawback of TSOBS is the rigidness of its frame structure. In time variant OBS, the frame size is an important performance parameter that has to be pre-configured at all intermediate core nodes. Using small frame sizes will increase the contention probability due to the fact that the overlapping bursts are more likely to pick the same slot number, while applying large frame sizes will inevitably induce larger end-to-end delays due to each flow having access to a reduced fraction of the link capacity; this will lead to a significant queuing delay at the ingress edge node. This loss-delay trade-off, determined by frame size, is identical across all traffic flows, and cannot be changed in the TSOBS architecture. This architecture was studied and analyzed by many researchers such as [13], [14], [15] and [6].

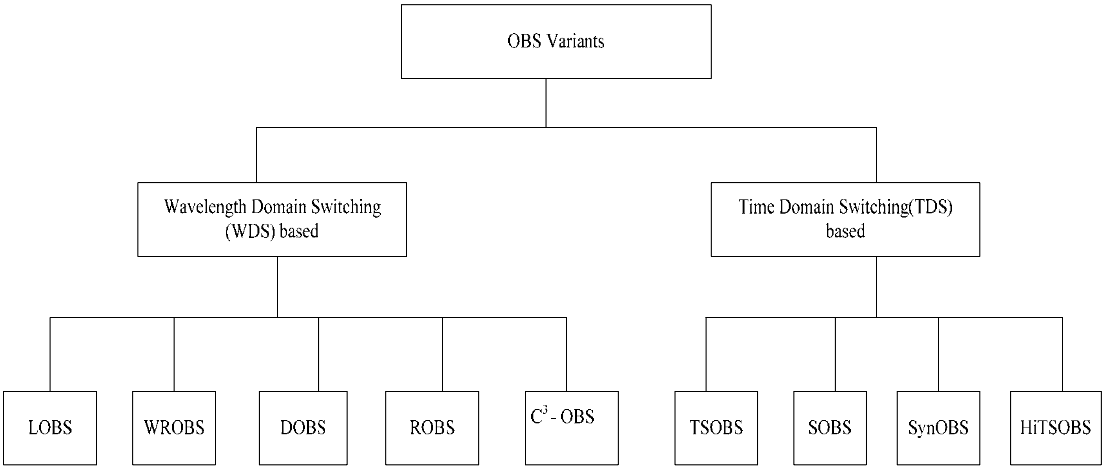


Figure 1 Variants of OBS Architectures

Slotted Optical Burst Switched (SOBS) proposed in [16] is another variant of time slotted OBS. In SOBS, time division multiplexing (TDM) is incorporated into WDM so as to divide the entire λ-bandwidth into smaller base bandwidths. This approach is also referred to as the slotted WDM (sWDM), bursts are then transmitted in the time domain instead of the optical domain as in pure OBS and it eliminates the need for optical buffers and wavelength converters. SOBS uses a synchronizer at the edge node which eliminates the randomness in the burst arrival and thereby losses due to contention. To avoid the wastage of bandwidth, it creates bursts of equal length. Theoretical analysis of SOBS shows that the utilization of the link and the burst delivery ratio are far better than that in the traditional non slotted OBS. Researchers in [17] have studied bandwidth reservation mechanisms in slotted OBS and proposed a solution called soft-state bandwidth allocation for that purpose.

In 2007, Rugsachart defended his PhD thesis in which he proposed a variant of time slotted OBS based on the principles of TSOBS [12]. The proposed architecture is known as Time-Synchronized Optical Burst Switching (SynOBS) [18]. The architecture not only assumes the presence of fiber delay lines, but also considers the impact of full wavelength conversion. Several FDL reservation mechanisms are proposed and analyzed using discrete time Markov chains to compute the burst drop probability. He suggested that, timeslot size must be chosen with care to achieve the best timeslot utilization, which subsequently reduces burst blocking probability, the main issue in any OBS network. This architecture was fully analyzed in [19] by its designer.

To our best knowledge, the latest time slotted variant of OBS is the Hierarchical Time Sliced OBS proposed by Ramamirtham and Turner in [6]. While TSOBS and the other related variants of OBS have achieved good results in term of BLP even without wavelength conversion, these architectures are rigid in term of frame structure. As mentioned earlier, the size of the slot and the frame has been observed to be the main factors to determine burst loss probability in slotted OBS. To overcome the rigidness of frame structure and to provide differentiated service in terms of the loss–delay characteristics, the researchers in [6] have proposed a flexible frame structure. HiTSOBS allows frames of different sizes to co-exist together in a hierarchy in a way that delay-sensitive traffic (voice and video) are supported by frames of higher levels where the frames are of smaller size. While the frames of lower levels support loss-sensitive traffic (email, ftp, web pages and others). Besides, HiTSOBS also allows dynamic changes in the hierarchy of the frames according to the mixture of traffic classes thus obviating the need for any other changes in the network. As in TSOBS, a burst header packet carries the information about the number of slots required to transmit the burst as well as the level at which the burst has to be transmitted and the bursts are scheduled atomically rather than slice-by-slice to serve the entire burst in a frame at the desired level. This keeps the control plane scheduling scalable and reduces the number of operations in the data plane to the number of levels in the frame hierarchy.

Theoretically HiTSOBS is a good architecture. However, this architecture has not been fully studied and analyzed neither by its architects nor by other researchers. In [6] the architecture was not tested in multi-core nodes environment, such as mesh WDM OBS networks. There, HiTSOBS was tested with a very simple topology consisting of only one core node and one wavelength per link. Such network model is not sufficient to generalize the results obtained by the scientist.

Therefore, more work needs to be done in terms of evaluation and analysis before this architecture can be generalized and pretend to be the choice of the OBS architecture in the near future. This paper is aimed to achieve such objectives.

3.0 Architecture and Operation of MCN-Hierarchical Time Sliced OBS

In this section, the frame structure of the multi-core node HiTSOBS is described. Also, the control and data plane operations are discussed.

3.1 Frame Hierarchy

In Mesh-HiTSOBS, time-slots are numbered serially, starting at 1. The frame size known as radix and denoted by r represents the number of slots in each frame in the HiTSOBS hierarchy. i represents the time slot at which current burst transmission starts and B is the burst size in time slots as shown in equation (1) according to [6] and time slots are reserved according to the same equation.

$$i, i + r, i + 2r, \ldots\ldots i + (B - 1)r \tag{1}$$

Figure 2.0 depicts the frame structure of HiTSOBS. In this paper, it is assumed that a slot in the level-1 frame may expand into an entire level-2 frame and so on but not more than 3 levels. Beyond three levels, network performance is expected to degrade especially for delay sensitive applications.

Bandwidth occupation per slot in a given level is determined by equation 2 which is a modified version of similar equation in [6]:

$$S_c = \left(\frac{1}{kr}\right) W_c \tag{2}$$

Where S_c represents the capacity occupied by a slot out of the total bandwidth (W_c) of a particular wavelength of a fiber link; k represents frame level and r is the frame size in time slots.

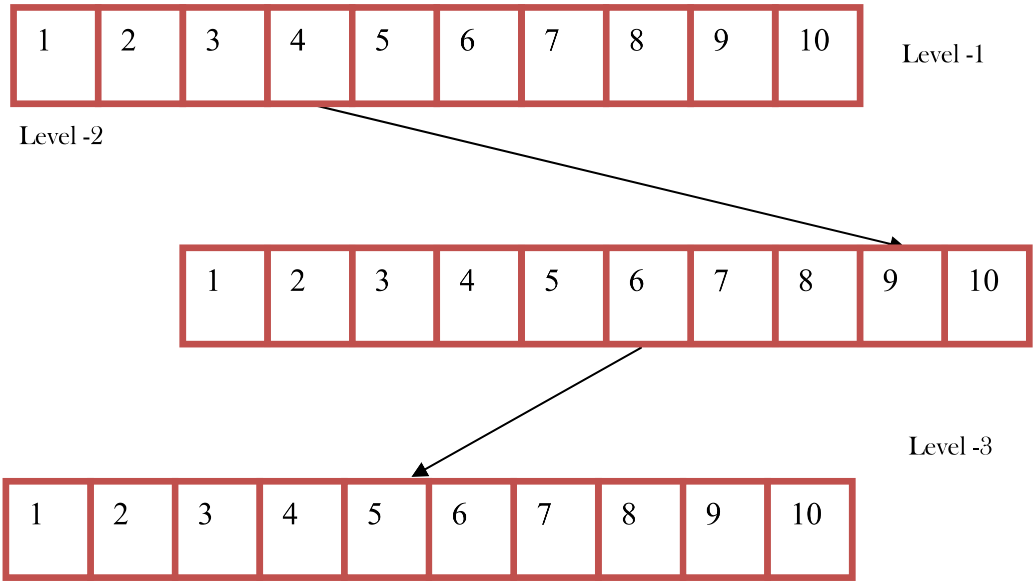


Figure 2 Frame hierarchy in mesh-HiTSOBS

3.2 Control Plane Operation

Similar to conventional OBS, in Mesh-HiTSOBS ingress edge node accumulates data from different client networks (IP, ATM, and SONET/SDH, etc...) into bursts, and classifies them into one of the following QoS classes: Class 0 for Bandwidth greedy applications. These bursts are transmitted at level -1. Class 1 for Delay sensitive bursts and they are transported by level-2 frames and finally Class 2 for loss sensitive data which are carried by level-3 frames.

Prior to the transmission of a burst, a burst header packet (BHP) is sent to reserve necessary resources. The BHP contains four types of information as depicted in Figure 3.0: QoS requirements of a burst, the start slot, and the burst length. Moreover, the BHP carries the initial routing information. Such information is not available in the BHP of [6] because routing was not studied.

Figure 3 Control packet

A core node receiving this control packet would first deduce the outgoing link for the bursts and its QoS requirements and then determine where the slot lies in its hierarchy corresponding to that output link. There are three possible outcomes:

- A frame does not exist at the requested level in the Hierarchy. If this is a high priority burst, the burst is delayed using Fiber Delay Line (FDL) if it is not full. If the burst is of a lower priority, it is dropped.
- A frame exists at the requested level but the required slot is unavailable. In this case, again if the FDL is not full, a high class burst will be delayed while low class bursts will be dropped.
- A frame exists and the requested slot is available throughout the entire route: In this case the burst is assigned the requested slot and passes through the switch in a cut-through manner without any delays.

Since we have assumed very limited buffer size (Table 1), streamline effect [20] is taken into account in order to reduce burst loss rate. In the streamline phenomenon, bursts transported by a common link are streamlined and do not contend with each other until they diverge. This happens because of the absence of buffers inside an OBS core node. Therefore, once contention among the streamlined bursts is resolved at the first link where they merge, there will be no intra-stream contention thereafter. However, there can be inter-stream contention (i.e., streams from different links may contend). The streamline effect is illustrated in Figure 4.0

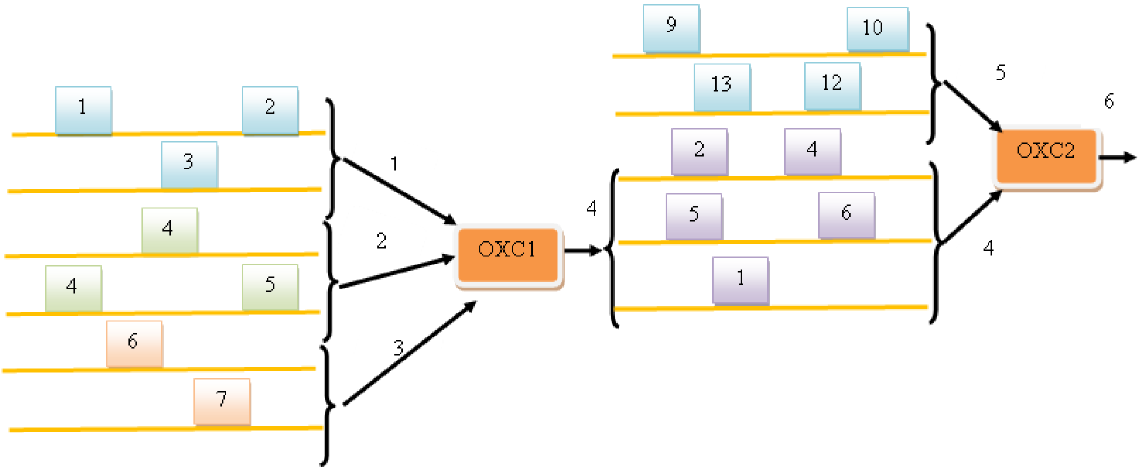


Figure 3 Streamline effect in OBS packet

In the above Figure, burst streams 1, 2 and 3 merge at core node 1 (OXC1) known as optical cross connect. After any burst loss that might happen at this core node due to contention, the remaining bursts are streamlined in output stream 4 and no further contention will happen among them. Nevertheless, these bursts may still experience contention when they merge at downstream nodes with other burst streams. In the depicted figure, the bursts in link 4 merge with those in link 5 at core node (OXC2) and are streamlined in output port 6.

The streamline effect helps reduce burst loss rate in two ways [20]. The first reduction is based on the fact that bursts transported by the same link within an input stream do not contend among themselves. Therefore, their loss probability/rate is lower than that obtained when M/M/k/k queuing model is assumed. The second possible way of burst loss reduction by streamline effect consideration is attributed to the fact that burst loss probability is not uniform among the input streams. The higher the burst rate of the input stream, the lower its loss probability. Consequently, if traffic within an OBS network is encouraged to form major flows with fewer merging points, the overall loss rate will be reduced.

3.3 Data Plane Operation

Based on the routing information and the hierarchy constructed by the control plane, the data plane processes the incoming burst and sends them to the reserved output link. A counter is maintained for each frame in the hierarchy, corresponding to the slot last served in that frame. Each time-slot, the counter for the level-1 frame is incremented by one, and the corresponding slot entry checked. If it is a leaf entry containing a burst, the optical crossbar is configured so that the input line corresponding to that burst is switched to the output link under consideration. If on the other hand, the slot entry points to a lower level frame, the counter for the lower-level frame is incremented, and the process recourses. A very limited size of FDL is used. HiTSOBS is scalable and can support high data rate because the complexity of the data plane operation per time slot at most equals the number of levels in the frame hierarchy, which can be limited to a small constant.

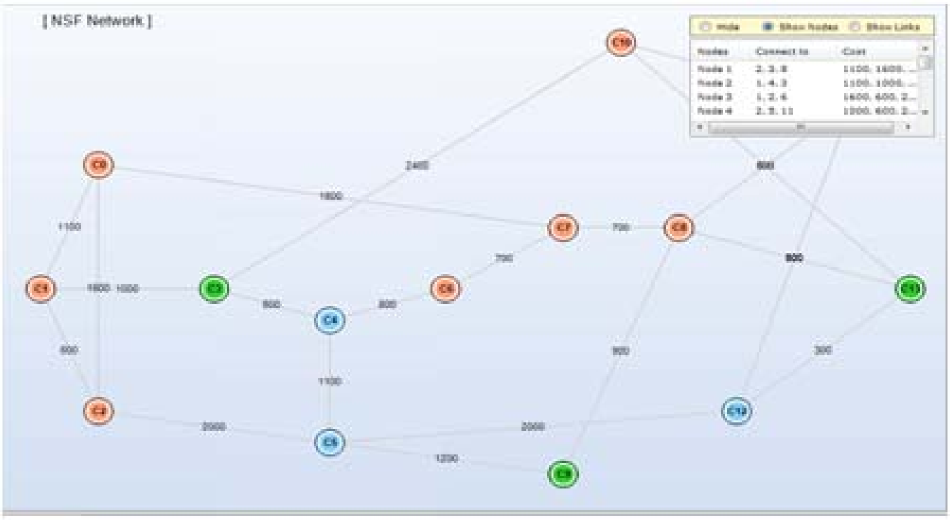
4.0 Simulation Parameters, Scenarios and Results Analysis

4.1 Simulation Parameters and Scenarios

To test the efficiency of HiTSOBS in a mesh WDM OBS network environment, we have modified the discrete-event simulator model developed by the researchers in [6] to integrate Shortest Path (SP) algorithm for routing purposes. Time slots are reserved based on equation (1). The First-Fit algorithm was used for wavelength assignment. The new simulator is called Time Slot OBS network simulator (TS_OBSns). Two network topologies were simulated. These topologies are the 14 nodes NSFNET topology and the proposed 11 nodes Mali Intranet topology (MaliNet) as depicted in Figures 5.0 and 6.0 respectively. We assumed that, the nodes are interconnected with fiber links of 4 wavelengths each. Bursts for flow j arrive as a Poisson process at rate λ_j / B_{avg} bursts per timeslot where B_{avg} represents the average burst size. The timeslot was chosen to correspond to $1 \mu s$, which is consistent with the switching speeds of solid-state optical switching technologies available in the industry [21] and [22]. Three wavelength capacities were simulated (10, 20 and 100 Gbps) as shown in table 1. Different burst sizes (9 KB, 12 KB and 125 KB) were also simulated. The number of levels was chosen to be 3. Three classes of burst were assumed: class 0 (High Definition Multimedia Video/audio), class 1 (High Definition Multimedia streaming) and class 2 (normal data: FTP, email, telnet, etc...). Each flow is assigned to a level depending on its class. Upon arrival of a flow's burst at the edge node, the following processing happens: if the arriving burst encounters a non-empty queue, the burst is queued in the buffer if it is not full and awaits service. If on the other hand the arriving burst encounters an empty queue, the edge node reserves a time slot in a way similar to that in [6]. Time slots are reserved over a number of frames equal to the burst length and the burst is transmitted on to the core node. As in [6] the slot positions for burst slices for any given flow vary each time the flow becomes newly backlogged; this is important because it helps prevent synchronization and phase locking which complicates the implementation of OPS. Simulation parameters are summarized in Table 1.

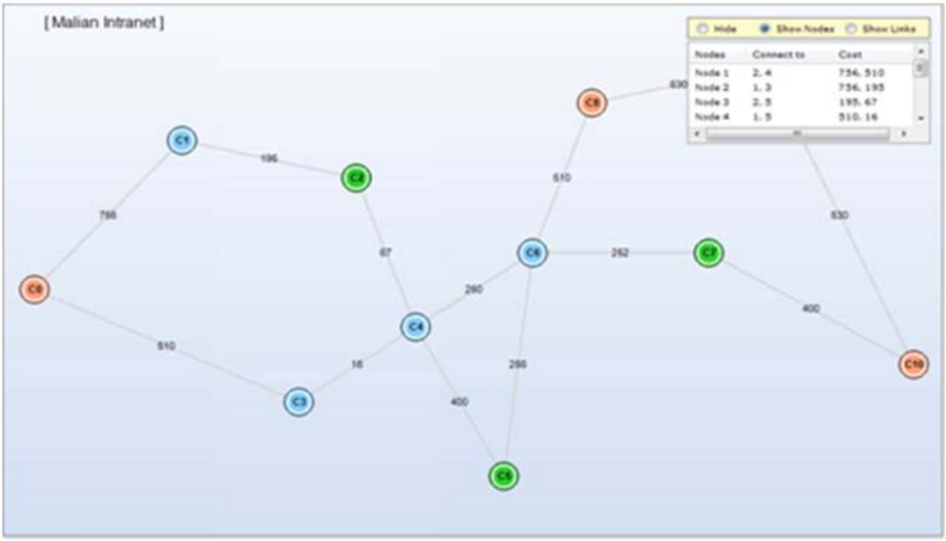
Table 1 Simulation factors and level

Factors	**Levels**
Wavelengths per link	4
Wavelength Capacity (Gbps)	10, 20, 100
Frame Size (Time slot)	10
Burst Size (KB)	125
Switching Time (µs)	1
Number of levels	3
Buffer Size, FDL (Time slot)	10
Number of Edge Nodes	20
Number of time slots simulated (k)	1000
Number of core nodes	11, 14
Number of Fiber Links	13, 21
Train size, Z (Time slots)	2,3
Number of Simulations	5



Nodes	Connect to	Cost
Node 1	2, 3, 8	1100, 1600, ...
Node 2	1, 4, 3	1100, 1000, ...
Node 3	1, 2, 6	1600, 600, 2...
Node 4	2, 5, 11	1000, 600, 2...

Figure 5 NSFN topology



Nodes	Connect to	Cost
Node 1	2, 4	756, 510
Node 2	1, 3	756, 195
Node 3	2, 5	195, 67
Node 4	1, 5	510, 16

Figure 6 MaliNet topology

4.2 Results Analysis

In this section, different simulation results are discussed. Figure 7.1 shows the burst loss ratio (BLR) against load for different topologies with a wavelength capacity of 10 Gbps. While Figure 7.2 shows the burst loss ratio (BLR) against load for different topologies with a wavelength capacity of 20 Gbps. From these figures it is observed that larger topology produce higher BLR. This can be attributed to the fact that, in large networks, a BHP has to reserve resources for its corresponding burst through many nodes. Since buffer size is limited, and only the shortest path is used for routing, bursts contention is high and this will naturally lead to a high burst drop.

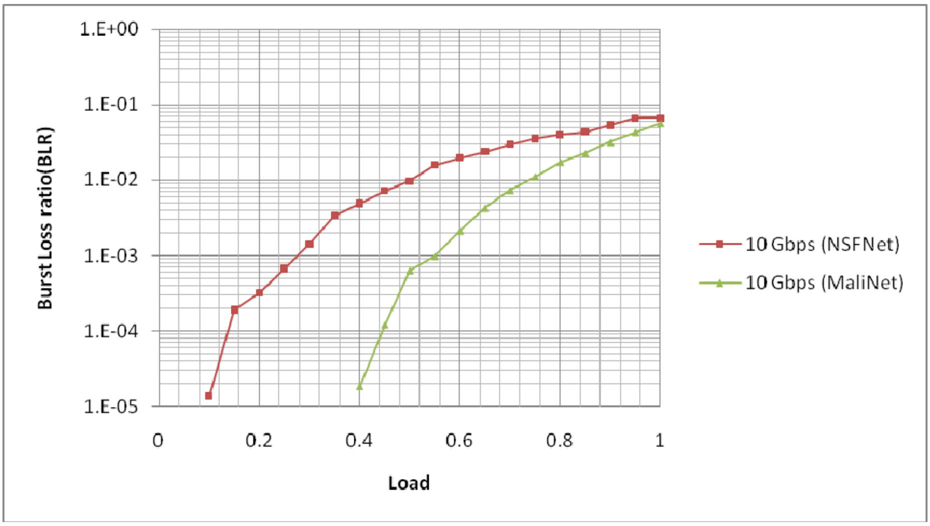


Figure 7.1 Loss vs. load for 10 Gbps

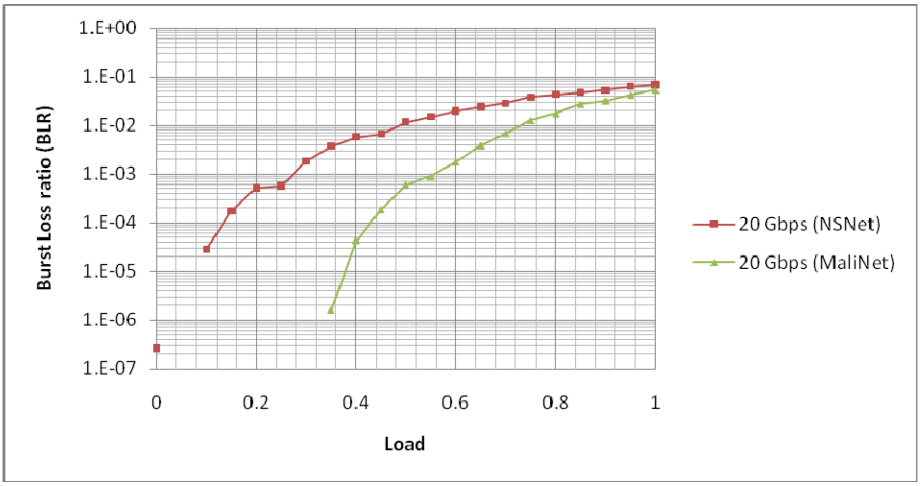


Figure 7.2 Loss vs. load for 20 Gbps

The delay results of the same simulation are plotted in Figures 8.1 and 8.2 respectively. As in Figures 7.1 and 7.2, bursts experience larger delay in big networks than small networks. The reason for this is the time taken to process the control packet at each core node and propagation delay which is proportional to network size.

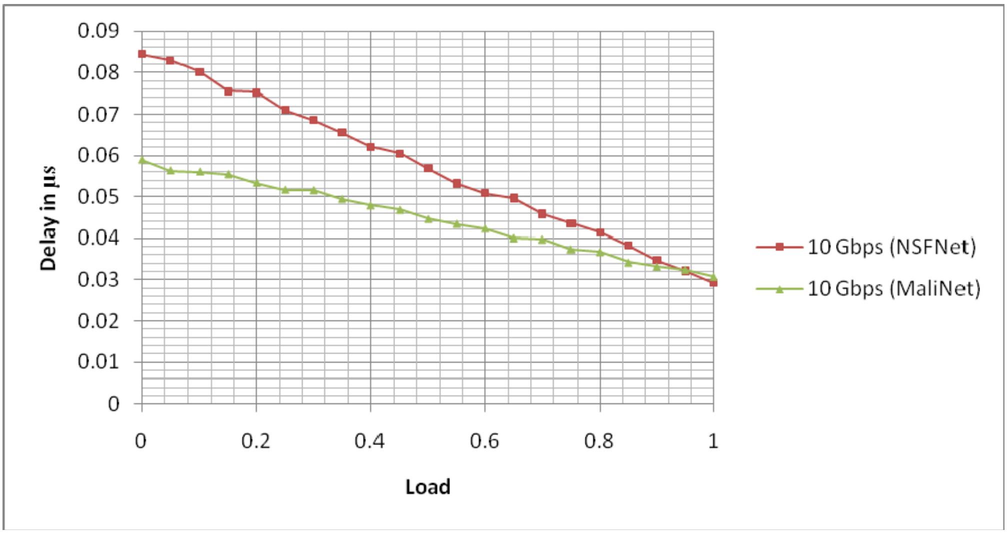


Figure 8.1 Delay vs. load for 10 Gbps

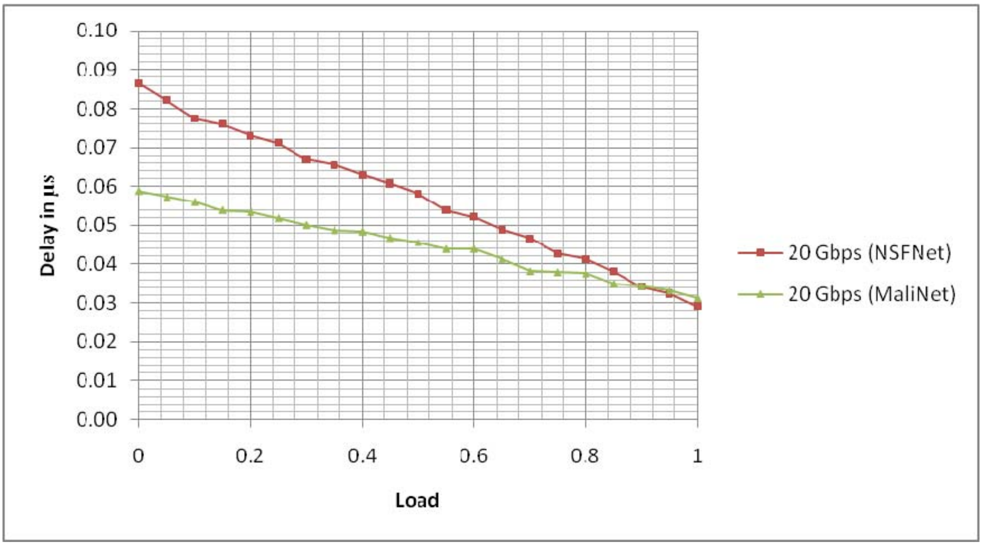


Figure 8.2 Delay vs. load for 20 Gbps

Figure 9.1 and 9.2 shows the burst loss ratio (BLR) against load for different bandwidths (10 and 20 Gbps) in NSFNET topology. From these graphs, one notices that a higher bandwidth produces a lower loss ratio and a lower delay especially at lower loads. However, as load increases the effect of bandwidth shrinks for loss and broadens for delay due to resource scarcity and the increase in looking for resource to be reserved respectively.

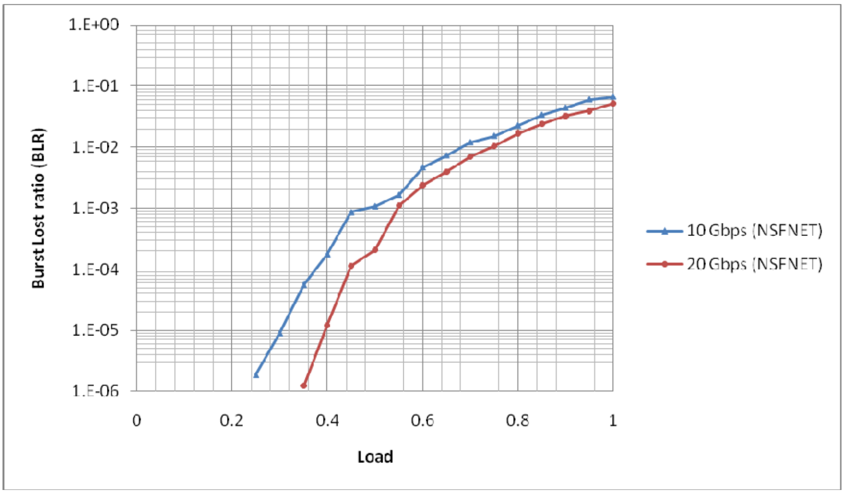


Figure 9.1 Loss vs. load NSFNET with the same bandwidth (10 Gbps)

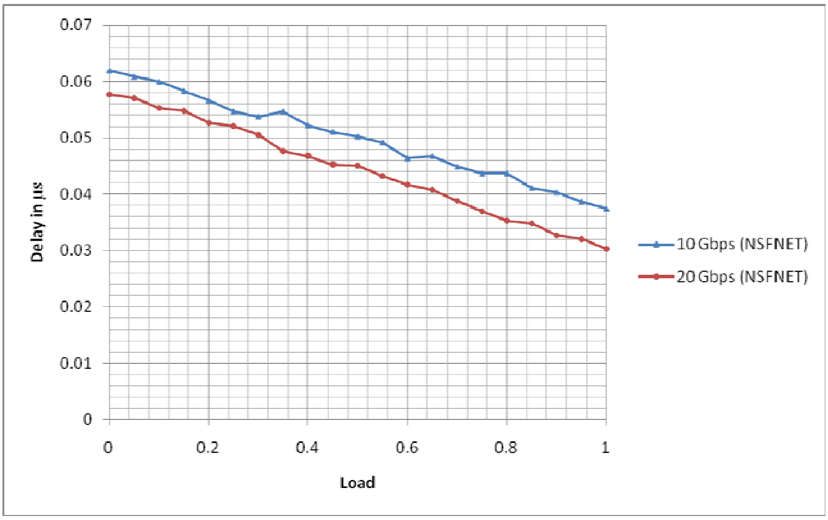


Figure 9.2 Delay vs. Load

The results depicted in Figures 10.1 and 10.2 compare the performance of our bandwidth sharing model and that of the original HiTSOBS. Figure 10.1 shows that, as for burst loss ratio, the original model performs better at lower and medium loads, but as load approaches its peak, both models perform alike.

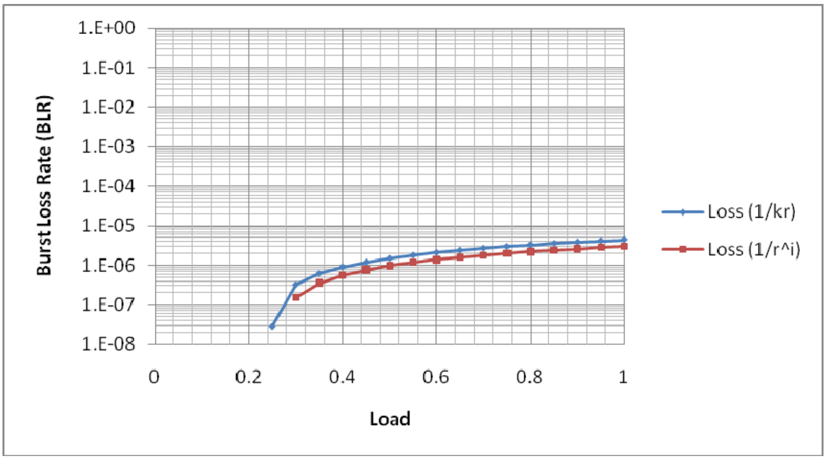


Figure 10.1 Loss vs. load

In Figure 10.2 it is clear that, at lower load, the proposed model outperforms the original model; however, at higher load, the two models have similar results, this is due to the fact at high load time slots are less available.

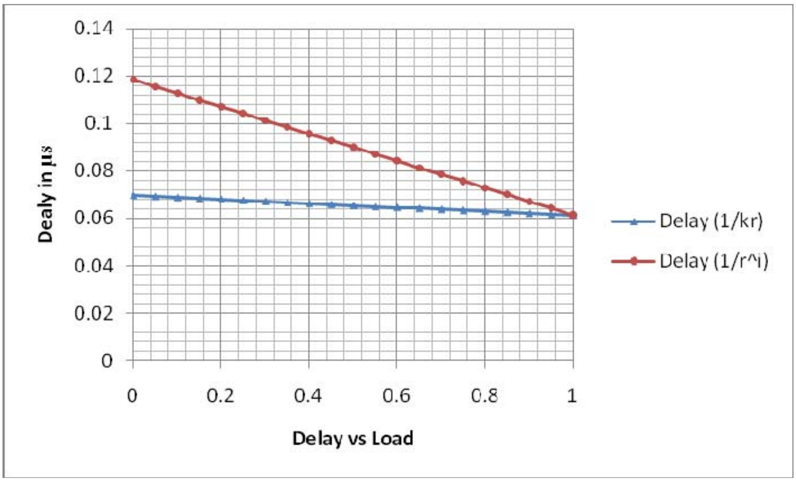


Figure 10.2 Delay vs. load

5.0 CONCLUSION AN FUTURE WORKS

In this paper, we have demonstrated, through simulations that HiTSOBS as a technique could improve OBS network performance and thus it is a promising candidate for future OBS networks. However, more comparisons and analysis are needed. Thus, we have developed a a complete route, wavelength and time slot allocation (RWTA) algorithm for that purpose. In this algorithm route selection and wavelength assignment are based on AntNet algorithm. Results obtained here are to be compared with those expected from the newly developed RWTA algorithm.

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