An Opportunistic Burst Cloning Scheme for Optical Burst Switching over Star Networks

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***Abstract*— In optical burst switched (OBS) networks, burst loss is mainly due to contention that occurs at both edge and core node. At edge node, contending burst may be electronically queued. Whereas at core node, which lacks of optical memory and wavelength conversion capability, contending burst will be dropped. Burst cloning prevents burst loss at core nodes by sending multiple copies of the same burst through OBS network simultaneously in order to enhance probability that at least one copy will reach destination. However, at high load, burst cloning leads to a significant burst loss at edge nodes, which become unable to schedule new bursts at earliest tolerable departure time. In this paper, we adopt burst cloning scheme with star topology and we propose an opportunistic burst cloning scheme, which aims to control the extra load of burst cloning in order to reduce burst loss at both edge and core node. We perform both analytical and simulation analyses on conventional OBS, basic burst cloning scheme and opportunistic burst cloning scheme over star networks. We observe that opportunistic burst cloning scheme achieves better overall network performance than the other approaches.**

***Index Terms*—** basic burst cloning, opportunistic burst cloning, optical burst switching, optical star network.

I. INTRODUCTION

Optical Burst Switching (OBS) has become a mature technology to support the current and next generation Internet over bufferless wavelength division multiplexing networks [1]. It can be considered as intermediate solution between optical circuit switching, which has a low complexity but it suffers from low bandwidth utilization, and optical packet switching, which has advantage of high bandwidth utilization but at the cost of high complexity [2], [3]. In OBS networks, a data burst, which consists of multiple packets, is created at ingress node and switched by one or more core nodes along the network all-optically until it reaches its destination egress node. Before the start of the burst transmission, the ingress node sends a control packet to reserve a wavelength for the burst at each core node, where the control packet is subject to optical-electric-optical conversions. If the wavelength reservation fails due to the contention with another burst at a core node, which lacks of optical memory and wavelength conversion capability, then the burst is lost.

Loss recovery represents one of the major challenges that face researchers. Loss recovery

Brazilian Microwave and Optoelectronics Society-SBMO received 24 Feb 2013; for review 1 May 2013; accepted 21 June 2013
Brazilian Society of Electromagnetism-SBMag *ISSN 2179-1074*

mechanisms have been classified into two categories, called reactive and proactive; reactive mechanisms are better suited when burst loss is rare and bandwidth utilization needs to be optimized, however proactive mechanisms are better suited when contention loss is high and delay needs to be optimized [4]. Burst cloning is a proactive loss recovery mechanism; the idea is to replicate a burst and send duplicated copies of the burst through the network simultaneously; if the original burst is lost, the cloned burst may still be able to reach the destination [5].

To our knowledge, burst cloning is studied only in mesh topologies whereas star OBS networks have received considerable attention from researchers and industrials [6]-[10]. In this paper, we adopt the burst cloning scheme with star topology and we demonstrate that the burst cloning scheme can lead to a significant burst loss at edge nodes, which become unable to schedule new bursts at earliest tolerable departure time especially at high load. In order to overcome this shortcoming, we propose an enhanced scheme, called opportunistic burst cloning scheme, which aims to control the extra load of burst cloning. We analytically analyze the conventional OBS, basic burst cloning scheme and opportunistic burst cloning scheme over star networks. The precision of our analytical model is verified through simulation and the both analytical and simulation results confirm that opportunistic burst cloning scheme can achieve better overall network performance than the other approaches.

The remainder of this paper is structured as follows. In Section II, we present the network under study. In Section III, we describe and analyze the conventional OBS over star networks. In Section IV, we adopt and analyze burst cloning scheme with star networks. In Section V, we propose and analyze opportunistic burst cloning scheme over star networks. In Section VI, we show the analytical and simulation results. Finally, we conclude this paper in Section VII.

II. THE NETWORK UNDER STUDY

We focus on a class of OBS networks that use an overlaid-star topology (also called composite-star topology) [6]-[10]. The overlaid-star topology, as shown in Fig. 1, forms a logical mesh, where each edge node is a member of two or more stars in order to have at least one recovery path in the event of core or fiber link failure. A burst traversing the network only passes through one core node, resulting in a major simplification of the control problem of ensuring that contention is rare; furthermore, each of the stars can be managed independently of the others [10].

We consider a star OBS network topology with N edge nodes, as shown in Fig. 2, where each edge node functions as both the ingress and egress node and it is connected to a core node using two fibers, one in each direction. All the fibers have the same number of transmission wavelengths W_t, W_b of them are used for burst transmission, called data wavelengths, while the remaining wavelengths W_c are used to transmit control packets, called control wavelengths:

$$W_t = W_b + W_c\,. \tag{1}$$

 ISSN 2179-1074

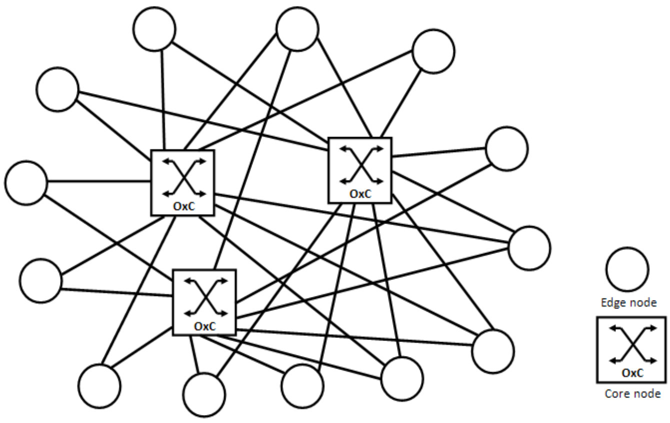

Fig. 1. Overlaid-star topology

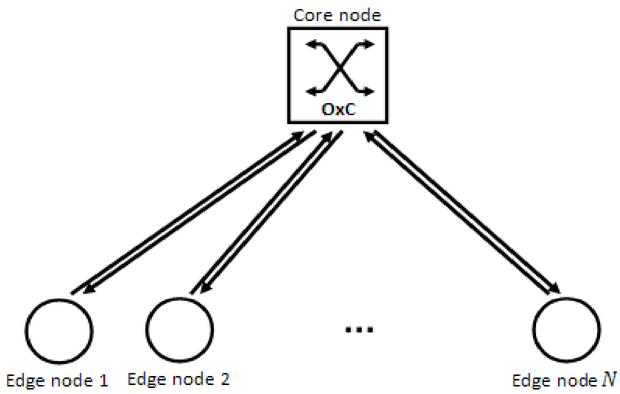

Fig. 2. Star OBS network

III. CONVENTIONAL OBS

Packets arriving from clients are classified according to destinations and assembled into variable-length bursts according to hybrid (time and length) assembly algorithm. When a burst is ready, the edge node schedules it by using Earliest Possible Minimum Void with Void Filling (EPMV-VF) [11]. Where, the edge node tries firstly to reserve a data wavelength at offset time using Latest Available Unscheduled Channel with Void Filling (LAUC-VF) scheduling algorithm [12]. If there are no available data wavelengths at offset time, then the edge node reserves using FIFO scheduler a data wavelength at the earliest time available after the offset time that leads to increase the waiting time at edge node by an additional delay, called queuing delay. Many studies consider that burst queue of edge node is infinite which is unrealistic and can lead to unreasonable queuing delay when the load is heavy relative to link capacity [13]. In order to keep that queuing delay is less than a *maximum tolerable burst queuing delay*, we consider that burst queue is finite and, consequently, a new arriving burst can be lost if the burst queue is full. If the data wavelength reservation success, the edge node sent a control packet to core node with the duration of the burst, the offset time and the data wavelength. After the propagation delay between the edge node and the core node, the core node receives the control packet and it tries to reserve the same data wavelength, and if the data wavelength reservation fails due to burst contention, the burst is finally lost. If the destination receives a burst, it disassembles the burst into individual packets and then forwards them to appropriate clients. We refer to this scheme in the rest of paper as Conventional OBS (COBS).

A. Modeling the edge node

In the studied network, the edge node sends bursts to the other edge nodes using the uniform distribution. We assume that the new burst arrival from burst assembler is Poisson process with rate λ bursts per second and the duration of burst is exponentially distributed with a mean of $1/\mu$ seconds. We model burst queue of the edge node with $M/M/W_b/K$ queue, where the number of system places K is greater than the number of servers W_b. Therefore, the maximum tolerable burst queuing delay is $K(W_b\,\mu)^{-1}$. Let p_n be the equilibrium probability of n bursts in the system. p_n is expressed in terms of p_0 as follows:

$$p_n = \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n p_0 \text{, for } n = 1,\ldots, W_b, \tag{2}$$

$$p_n = \frac{W_b^{\;W_b}}{W_b!}\left(\frac{\lambda}{W_b\mu}\right)^n p_0 \text{, for } n = W_b+1,\ldots,K . \tag{3}$$

The normalization condition of the total probability is expressed as follows:

$$\sum_{n=0}^{K} p_n = 1 . \tag{4}$$

Consequently, p_0 is given by:

$$p_0 = \left(\sum_{n=0}^{W_b} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n + \frac{W_b^{\;W_b}}{W_b!}\sum_{n=W_b+1}^{K}\left(\frac{\lambda}{W_b\mu}\right)^n\right)^{-1} . \tag{5}$$

The burst Loss Probability at Edge-node (*LPE*) is the probability that the system is saturated. It can be computed by:

$$LPE = p_{\mathrm{K}} . \tag{6}$$

The utilization of each outgoing data wavelength (ρ) is given by:

$$\rho = \frac{\lambda(1-p_{\mathrm{K}})}{W_b\mu} . \tag{7}$$

The Queuing Delay (*QD*) is given based on Little's law [14]:

$$QD = \frac{\sum_{n=1}^{K} n p_n}{\lambda(1-p_{\mathrm{K}})} . \tag{8}$$

B. Modeling the core node

The core node has not wavelength conversion capability, therefore we can consider that the data wavelength number per input/output port of the core node is one. In order to model the fact that burst transmission takes time and it is not instantaneous, we associate the IDLE-ON process with each input port [15], [16]. The input port stays in ON state for the duration of the burst $1/\mu$ then it moves to the IDLE state and vice-versa. We assume that IDLE state period is exponentially distributed with a mean of $1/\alpha$. We can express α in terms of μ and ρ as follows:

  ISSN 2179-1074

$$\alpha = \frac{\mu\rho}{1-\rho}. \tag{9}$$

Since there are N edge nodes, the burst arrival process from all input ports is the superposition of N single IDLE-ON process. The burst arrivals are only possible from the input ports that are currently in the IDLE state. Therefore, the core node model will consider that the arrival rate of new bursts to an input port may be influenced by the number of bursts currently being switched to all output ports. Also, since there is no buffering in the core node, the model does not contain any queues. One of the arriving bursts through the N input ports can be switched to an output port OP_i ($1 \le i \le N$) among of the N output ports, the remaining bursts are dropped or switched to the other output ports OP_j ($1 \le j \le N$ and $i \ne j$). We model the core node with a two-dimensional loss system, as shown in Fig. 3. Let (m, n) be the tuple of possible states. If a burst is currently being switched to the output port OP_i, then $m = 1$ else $m = 0$. However, n represents the number of bursts currently being switched to the all output ports OP_j and the following constraints hold:

$$0 \le n \le (N-1). \tag{10}$$

The number of bursts currently being switched by the core node is $(m+n)$, which means that $(m+n)$ input ports are in the ON state and the remaining $(N-(m+n))$ input ports are in the IDLE state. We can estimate the arrival rate of new bursts from the $(N-(m+n))$ input ports to the output port OP_i by:

$$\lambda_1(m,n) = \left(1 - \frac{m+n}{N}\right)\alpha. \tag{11}$$

The departure rate from the output port OP_i is given by:

$$\mu_1(m,n) = m\mu. \tag{12}$$

The arrival rate of new bursts to all output ports OP_j ($j \ne i$) is:

$$\lambda_2(m,n) = (N-1)\lambda_1(m,n). \tag{13}$$

The departure rate from all output ports OP_j ($j \ne i$) is:

$$\mu_2(m,n) = n\mu. \tag{14}$$

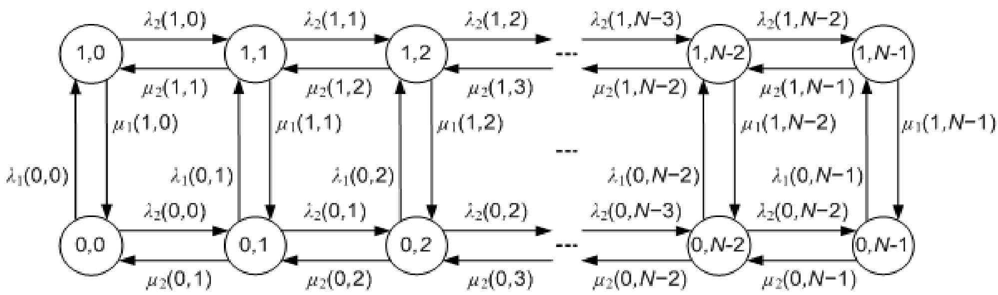

Fig. 3. Two-dimensional state transition diagram for the loss system

Since the following two flows are equal: clockwise: $\lambda_2(m,n)$ $\lambda_1(m,n+1)$ $\mu_2(m+1,n+1)$ $\mu_1(m+1,n)$, counter clockwise: $\lambda_1(m,n)$ $\lambda_2(m+1,n)$ $\mu_1(m+1,n+1)$ $\mu_2(m,n+1)$. Thus, according to Theorem (Kolmogorov's criteria) [17], the underlying state process of the loss system is a reversible process. We denote the probability of the state (m, n) with $P(m, n)$, then we can apply the following equations locally between any two connected states:

Brazilian Microwave and Optoelectronics Society-SBMO *received 24 Feb 2013; for review 1 May 2013; accepted 21 June 2013*
Brazilian Society of Electromagnetism-SBMag *ISSN 2179-1074*

$$P(m+1,n)=\frac{P(m,n)\lambda_1(m,n)}{\mu_1(m+1,n)}, \tag{15}$$

$$P(m,n+1)=\frac{P(m,n)\lambda_2(m,n)}{\mu_2(m,n+1)}. \tag{16}$$

Therefore, we can express $P(0,n)$ and $P(1,n)$ in terms of $P(0,0)$ as follows:

$$P(0,n)=\left(\left(1-\frac{1}{N}\right)\frac{\alpha}{\mu}\right)^n C_N^n P(0,0), \tag{17}$$

$$P(1,n)=\frac{N-n}{N}\frac{\alpha}{\mu}\left(\left(1-\frac{1}{N}\right)\frac{\alpha}{\mu}\right)^n C_N^n P(0,0). \tag{18}$$

The burst Loss Probability at Core node (*LPC*) is the probability of the data wavelength reservation failure at core node. Since the burst arrivals are state-dependent, we can obtain the *LPC* based on the state probabilities in combination with the appropriate arrival rate:

$$LPC=\frac{\sum_{n=0}^{(N-1)}\lambda_1(1,n)\cdot P(1,n)}{\sum_{m=0}^{1}\sum_{n=0}^{(N-1)}\lambda_1(m,n)\cdot P(m,n)}. \tag{19}$$

Using Newton's binomial formula, we can simplify (19) that becomes:

$$LPC=\frac{\alpha(N-1)}{\mu N+2\alpha(N-1)}. \tag{20}$$

C. Overall network performance

The network performance metrics of interest here are the Burst Loss Probability (*BLP*) of network, the Normalized Throughput (*NT*) of network and the Burst Delay (*BD*). The *BLP* is given by:

$$BLP=LPE+(1-LPE)LPC. \tag{21}$$

The *NT* defined as the absolute throughput divided by the total available bandwidth and we can calculate the *NT* by the following formula:

$$NT=\frac{\lambda(1-BLP)}{W_b\mu}. \tag{22}$$

The Burst Delay (*BD*) depends on offset time (*OT*), *QD* and end-to-end Propagation Delay (*PD*). *BD* is given by:

$$BD=OT+QD+PD. \tag{23}$$

IV. BASIC BURST CLONING SCHEME

The idea of burst cloning scheme is to send multiple copies of the same burst through the OBS network simultaneously in order to enhance the probability that at least one copy will reach destination [5]. In this scheme, which is proposed for mesh networks, the both edge and core node can do cloning. Each copy can traverse the mesh network along an independent path, which leads to send a control packet for each copy. The edge node can receive multiple copies of the same burst but one copy of them will be considered. In this paper, we adopt the burst cloning scheme with star networks and we refer to the new scheme as Basic Burst Cloning Scheme (BBCS). The implementation of

BBCS is less complex. The cloning can be done only at the edge nodes in electronic or optical domain. The data wavelength reservation at edge node for each copy is processed as in COBS; therefore, the copies of the same burst can be transmitted with different data wavelengths at different departure times. The edge node sends only one control packet for all copies of the same burst with the duration of the burst, the offset time of each copy and the data wavelength of each copy. When the core node receives the control packet, it tries to reserve the data wavelength for first arriving copy; and if the reservation fails, then it tries for second arriving copy; and if the reservation fails, then it tries for third arriving copy and so on until a successful reservation. Then the core node disables the other reservations in order to ensure that one copy can leave the core node to its destination edge node. If all reservations fail, then the burst is finally lost.

A. Modeling the edge node

We shall now propose the queueing model of the burst queue of an edge node in BBCS. To arrive at this model, we first make a simplifying consideration, which is the both W_b and K are divisible by the number of copies of the same burst (R). Consequently, we can model the burst queue of edge node with $M/M/V/Q$ queue with the same parameters λ and μ, where the number of server V is W_b /R and the number of system places Q is K/R. The equilibrium probability p_n is given as in COBS. Here, the LPE is given by:

$$LPE = p_{\mathrm{Q}}, \tag{24}$$

ρ is computed by:

$$\rho = \frac{\lambda(1-p_{\mathrm{Q}})}{V\mu}, \tag{25}$$

QD is expressed as follows:

$$QD = \frac{\sum_{n=1}^{Q} np_n}{\lambda(1-p_{\mathrm{Q}})}. \tag{26}$$

B. Modeling the core node

Let f be the probability of a data-wavelength reservation failure. Since the nth reservation will be considered only after the $n-1$th reservation failure. Therefore, the load (l) may be considered as:

$$l = \frac{(1-f^R)\rho}{(1-f)R}. \tag{27}$$

We model the core node as in COBS such as α is given by:

$$\alpha = \frac{\mu l}{1-l}. \tag{28}$$

Therefore, we can express f as follows:

$$f = \frac{\alpha(N-1)}{\mu N + 2\alpha(N-1)}. \tag{29}$$

It is clear, that to obtain f we need l and to obtain l we need f, which leads to an iterative algorithm. We propose the following iterative algorithm. In the initialization step, we assume that f is null. In the

Brazilian Microwave and Optoelectronics Society-SBMO received 24 Feb 2013; for review 1 May 2013; accepted 21 June 2013
Brazilian Society of Electromagnetism-SBMag ISSN 2179-1074

iterative step, we calculate l using (27); we calculate α using (28); and then we calculate f by (29). We repeat the iterative step until f converges. The burst is lost only if all reservations fail. Therefore, *LPC* is given by:

$$LPC = f^{R}. \tag{30}$$

C. *Overall network performance*

BLP, *NT* and *BD* are given as in COBS. If original load $\lambda(W_b\mu)^{-1}$ is less than R^{-1}, then BBCS can reduce burst loss at the core node with very low loss at edge nodes; else, BBCS can lead to saturation state of burst queue of edge node and, consequently, a significant burst loss at edge nodes.

V. OPPORTUNISTIC BURST CLONING SCHEME

When the load is low, the most bursts are expected to reach their destination; consequently, the burst loss at the core node can be minimized sufficiently by just sending two copies of the same burst. When the load is high, the cloning mechanism leads to a significant burst loss at edge nodes even if the number of copies of the same burst is only two. Instead of cloning all new arriving bursts as in BBCS, our Opportunistic Burst Cloning Scheme (OBCS) aims to control the extra load due of burst cloning mechanism in order to avoid the problem of burst queue saturation. In OBCS, no more than two copies of the same burst can be sent through the network. Furthermore, the edge node either enables or disables the cloning of a new burst according to the current state of its burst queue. When the burst queue size is less than a preset threshold, the edge node enables the cloning mechanism and sends two copies of the same burst; however, when the burst queue size reaches the preset threshold, the edge node disables the cloning mechanism and sends only one copy. This technique is similar to the concept of Early Random Drop (ERD) [18], which used for congestion avoidance in packet switched networks. When the queue size reaches a drop level, the source in ERD begins to drop all new arriving packets with a fixed probability. In OBCS, when the burst queue size reaches the preset threshold, the edge node drops also all new arriving copies with a fixed probability of 0.5 but in a fairly manner because it keeps an opportunity for each burst to reach its destination. If the burst cloning is enabled, the edge node sends a control packet for two copies as in BBCS; else, it sends a control packet for one copy as in COBS. The core node processes the control packet for two copies as in BBCS and processes the control packet for one copy as in COBS.

A. *Modeling the edge node*

We model the burst queue of edge node queue with the Markov chain shown in Fig. 4, where T denotes the threshold. Based on the global balance equation for the cut between states $(n-1)$ and n, we can express p_n for $n \geq 1$ as follows:

$$p_1 = \frac{\lambda}{\mu} p_0, \text{ for } n = 1, \tag{31}$$

$$p_n = \frac{\lambda}{\min(W_b, n)\mu}\left(p_{n-1} + p_{n-2}\right), \text{ for } n = 2,\ldots,T, \tag{32}$$

$$p_n = \frac{\lambda}{\min(W_b, n)\mu} p_{n-1}, \text{ for } n = T+1,\dots,K. \quad (33)$$

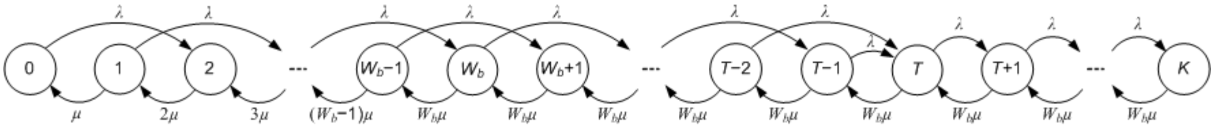

Fig. 4. State transition diagram for burst queue of an edge node in OBCS

Based on (31), (32), (33) and the normalization condition of the total probability, we can calculate any state probability p_n. We propose the following way for computing all state probabilities of the system: we denote the un-normalized probability of the state n with u_n; we initialize u_0 to one; for $n \geq 1$, we calculate u_n as in (31), (32) and (33); finally, we calculate p_n as follows:

$$p_n = \frac{u_n}{\sum_{i=0}^{K} u_i}, \text{ for } n = 0,\dots,K. \quad (34)$$

LPE is given by:

$$LPE = p_K, \quad (35)$$

ρ is given by:

$$\rho = \frac{\sum_{n=1}^{K} \min(W_b, n) p_n}{W_b}, \quad (36)$$

if the burst is not lost at edge node, then it will be cloned with the probability (c):

$$c = \frac{W_b \mu \rho}{\lambda(1 - p_K)} - 1. \quad (37)$$

QD is given based on Little's law as follows:

$$QD = \frac{\sum_{n=1}^{K} n p_n}{W_b \mu \rho}. \quad (38)$$

B. Modeling the core node

We calculate the data-wavelength reservation failure (f) as in BBCS except that the load (l) may be considered as:

$$l = \frac{(1 + cf)\rho}{1 + c}. \quad (39)$$

If the burst is cloned, then it is lost only when the both data wavelength reservations are failed. However, if the burst is not cloned, then the burst is lost when one data wavelength reservation is failed. Therefore, *LPC* is given by:

$$LPC = (1 - c) f + c f^2. \quad (40)$$

C. Overall network performance

BLP, *NT* and *BD* are given as in COBS. OBCS can reduce burst loss at the core node without leading to saturation state of burst queue of edge node even at high load. Consequently, OBCS can improve significantly the normalized throughput while maintaining a small queuing delay through a simple technique to disable/enable burst cloning mechanism.

VI. NUMERICAL RESULTS

In order to evaluate the precision of our analytical model, we implemented COBS, BBCS and OBCS over Optical Burst Switching - network simulator (OBS-ns) that developed at the Optical Internet Research Center (OIRC) [19] on the basis of ns-2 [20]. In performing the simulations, we consider a star OBS network with 15 edge nodes (i.e. $N = 15$). A dual-fiber was established between each edge node and the core node. We assume that all the dual-fibers are 200Km in length, in other words, the Propagation Delay (*PD*) of each dual-fiber is 10^{-3}s. The number of data wavelengths is 8 per single fiber (i.e. $W_b = 8$). We assume that there are no control packet losses. The capacity of each wavelength (*C*) is 10Gbps. The core node has not wavelength conversion capability and has not fiber delay lines. The initial offset time between the control packet and its corresponding burst is 10^{-5}s. The burst assembler generate bursts with an average burst length of 1Mbytes (i.e. $\mu^{-1} = 0.0008$s). Consequently, we can set the load (*L*) generated by each burst assembler by adjusting the rate λ:

$$L = \frac{\lambda}{W_b \mu}. \tag{41}$$

The maximum tolerable burst queuing delay $K(W_b\mu)^{-1}$ is 0.0024s (i.e. $K = 24$).

In Figures 5, 6, 7, 8 and 9, we plot respectively the results of *LPE*, *LPC*, *BLP*, *NT* and *BD*, which are obtained from analytical model and simulation, as function of *L* for COBS, BBCS with $R = 2$ and OBCS with $T = 16$. The results shown in Figures 5, 6, 7, 8 and 9 demonstrate that, the precision of our analytical model is good.

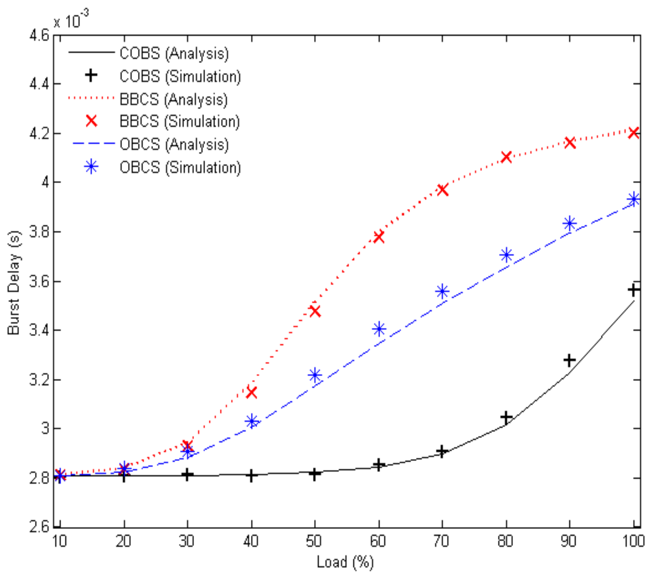

Fig. 5. Burst delay (*BD*)

In Fig. 5, we observe that, the end-to-end burst delay (*BD*) of the COBS remains less than that of both BBCS and OBCS for every load. It remains close to 0 until the load reaches 0.5; after this point, the *BD* of COBS begins to increase as we increase the offered load. However, when the load is below 0.3, the *BD* of the OBCS is similar to that of the BBCS and increases slowly. When the load is above 0.3, the *BD* of BBCS continues to increase more rapidly than that of OBCS. The above results can be interpreted based on equation (23). Since *OT* and *PD* remain constant, the variation of *BD* is due to

  ISSN 2179-1074

QD. For BBCS, as the load increases the extra load, due to burst cloning mechanism, increases, however, OBCS reduces the ratio of the extra load as the load increases. Thus, OBCS can also reduce *QD* and, consequently, *BD* more than BBCS.

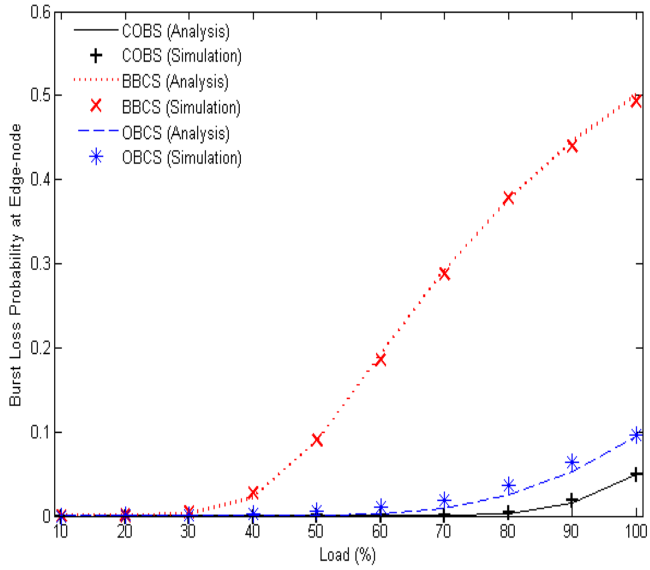

Fig. 6. Burst loss probability at edge node (*LPE*)

In Fig. 6, we observe that, the burst loss probability at edge-node (*LPE*) of BBCS remains close to 0 until the load reaches 0.3; after this point, the *LPE* begins to increase rapidly as we increase the load. The LPE for the OBCS remains close to 0 until the load reaches 0.5; after this point, the *LPE* begins to increase slowly as we increase the load. The *LPE* for the COBS remains close to 0 until the load reaches 0.7; after this point, the *LPE* begins to increase slowly as we increase the load. The above results can be interpreted as follows. For the BBCS, as the load increases the extra load increases until burst queue of edge node is almost full which leads to a significant burst loss at edge node. However, the OBCS disables burst cloning mechanism when the burst queue is near to saturation state. Consequently, the OBCS can keep very reasonable *LPE* relative to that of COBS even at very high load.

In Fig. 7, we observe that, the burst loss probability at core-node (*LPC*) of COBS remains greater than that of both BBCS and OBCS for every load. When the load is below 0.4, the *LPC* of the OBCS is very similar to that of the BBCS and increases slowly. When the load is above 0.4, the *LPC* of BBCS continues to increase slowly until the load reaches 0.6, after this point, it remains almost constant. However, when the load is above 0.4, the *LPC* of OBCS becomes greater than that of BBCS and continues to increase as we increase the load. The above results can be interpreted as follows. For the BBCS, as the load increases the burst loss at edge nodes increases which means that the load to the core node is reduced in addition to almost all incoming bursts to core node are cloned and, consequently, BBCS achieves better *LPC*. For the OBCS, as the load increases the extra load, due to the burst cloning mechanism, reduces that explains that when the load is low the *LPC* of OBCS is near to that of BBCS and when the load is high the *LPC* of OBCS becomes near to that of COBS.

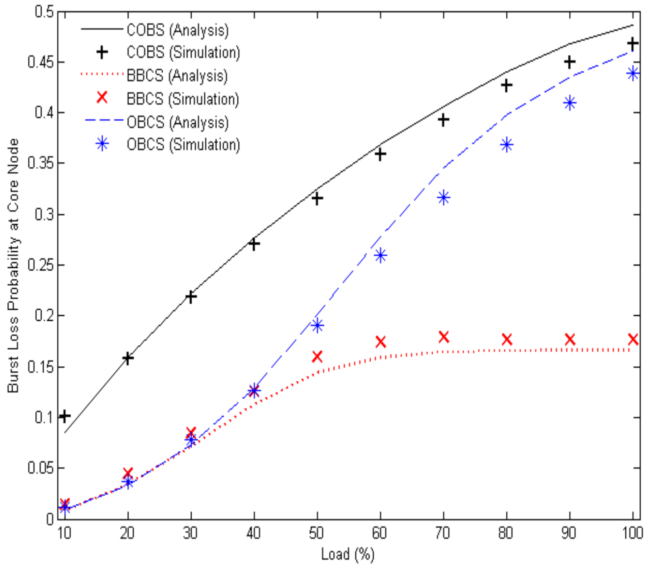

Fig. 7. Burst loss probability at core node (*LPC*)

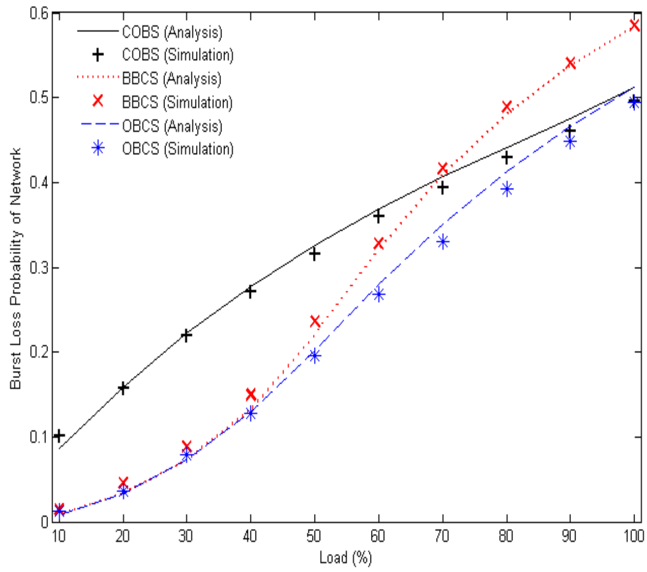

Fig. 8. Burst loss probability (*BLP*) of network

In Fig. 8, we observe that, the burst loss probability (*BLP*) of network of OBCS remains less than that of both BBCS and COBS for every load. When the load is below 0.4, the *BLP* of OBCS is very similar to that of the BBCS and increases slowly. When the load is above 0.4, the *BLP* of BBCS continues to increase rapidly and becomes greater than that of COBS when the load is 0.7. However, when the load is above 0.4, the *BLP* of OBCS becomes less than that of BBCS and continues to increase slowly as we increase the load. In Fig. 9, it is clearly that the OBCS can achieve better normalized throughput (*NT*) of network than both COBS and BBCS for every load. When the load is below 0.4, the *NT* of the OBCS is very similar to that of the BBCS and increases as we increase the offered load. When the load is above 0.4, the *NT* of BBCS continues to increase slowly and becomes less than that of COBS when the load reaches 0.7, after this point, it remains almost constant. However, when the load is above 0.4, the *NT* of OBCS becomes greater than that of BBCS and continues to increase as we increase the load. We can explain the above results as follows. The COBS have better *LPE* but worse *LPC*. The BBCS have worse *LPE* but better LPC. The OBBS can be considered as an intermediate solution between COBS and BBCS; it can get the optimal solution for equation (21). Consequently, the OBCS achieves better *BLP* and *NT*.

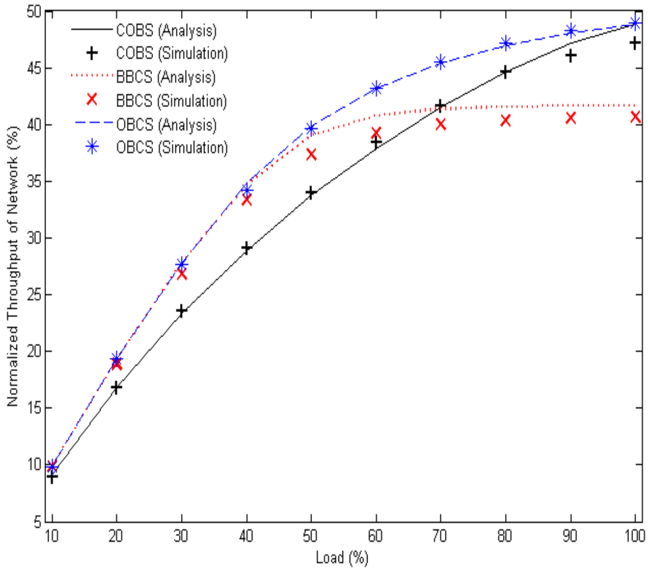

Fig. 9. Normalized throughput (*NT*) of network

VII. CONCLUSION

In this paper, we adopted the burst cloning scheme with star topology and we demonstrated that the burst cloning scheme can lead to a significant burst loss at edge nodes, which become unable to schedule new bursts at earliest tolerable departure time especially at high load. In order to overcome this shortcoming, we proposed an opportunistic burst cloning scheme, which aims to control the extra load of burst cloning. We analytically analyzed the star topology with conventional OBS, basic burst cloning scheme and opportunistic burst cloning scheme. The precision of our analytical model was verified by simulation and the both analytical and simulation results confirm that opportunistic burst cloning scheme achieves better overall network performance than the other approaches.

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