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Unequal Load Balance Routing for OBS Networks Based on Optical Parameters Dependent Metric

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Abstract
Based on a detailed simulation analysis in optical burst switching (OBS) networks, a proposed new routing protocol metric is driven based on the Burst loss ratio (BLR). It takes into account many optical parameters in its dependency as number of channels, load and link bandwidth. Depending on this new metric, an unequal load balance routing technique is proposed. It is shown that, in some examples, more than 50 % of the drop rate is avoided when using load balance routing rather than single best path routing.

I. Introduction
At the beginning of the new millennium, several trends can be observed in the field of communications. First, convergence as a dream starts to be a fact with bandwidth requirement growth without limit for accessing unlimited resources. Internet protocol (IP) based data networks and mainly the internet plays a central role in network convergence. This is not only due to the fact that data traffic has surpassed voice traffic but even more as both of them plus many other services like video will rely on this IP cloud. Second, any increase in the network access bandwidth leads to exponential bandwidth increase needed in the core of the network to deliver this traffic from source to destination. Third, optical technology continues to provide a huge bandwidth at the physical layer which is not utilized due to problems in switching and routing layers.

In this paper, we elaborate on these trends and show how they motivate OBS as a new switching paradigm for future transport networks [1]. Then, we discuss briefly routing protocol concepts and routing metrics. After that, a detailed simulation analysis for various optical parameters that affect BLR in OBS networks is described. A new unequal load balance routing based on the new discussed optical parameters dependent metric will be shown. The remaining sections focus on a complete load balance routing algorithm and some examples showing the benefits of the new routing technique.

A. Photonic Network Evolution
In the late 70s of the 20th century, the first fiber based optical transmission systems were installed. Today, most wide area traffic in communication networks is carried via fibers. Until a few years ago, most systems used a single high speed optical channel and multiplexing was done in the electrical domain.

In 1995, a new technology entered the market in the USA: wavelength division multiplexing (WDM). This optical multiplexing technique allows a better exploration of fiber capacity by simultaneously transmitting multiple high-speed channels on different wavelengths [2]. WDM spans from today's point-to-point transport links over add/drop multiplexers (ADM) for ring and mesh networks to networks with higher reconfiguration speeds.

Due to low utilization factor for circuit switching, optical packet switching (OPS) seems to be a promising technology. But, due to its complexity it is expected to remain a research topic for some more years. Recently, OBS is proposed as a new switching paradigm for optical networks requiring less complex technology than OPS while conserving better utilization than circuit switching networks.

B. IP Network Evolution

The Internet is a packet-oriented network based on IP, a connectionless networking protocol. Recent years have seen an increasing demand for bandwidth mainly due to new applications, communication convergence, an increasing number of users, traffic volume and growing commercial interest in network services. The Internet traffic is bursty in nature making it a typical case for applying OBS.

C. OBS Definition and Motivation

OBS is, in some way, a combination of OPS and circuit switching (CS). One can describe its main characteristics as:

1. OBS granularity is between CS and OPS.
2. There is a separation between control information (header) or setup message and data. Header and data are usually carried on different channels with a separation in time as illustrated in Fig. 1.
3. Resources are allocated without explicit two-way end to-end signaling, instead so-called one-pass reservation is applied.
4. Bursts may have variable lengths.
5. Burst switching doesn't require buffering.

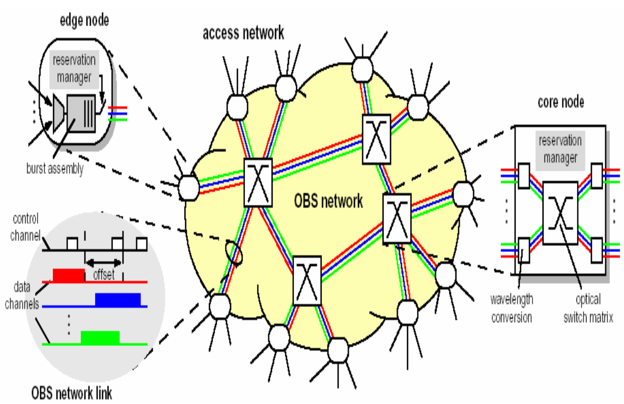

Fig. 1 OBS network

OBS keeps data in the optical domain and avoids optoelectronic conversion while processing data in electronic domain. On the other hand, all-OPS is still too complex to perform all processing in the optical domain. Therefore, a hybrid approach like burst switching seems very promising. It keeps data in the optical domain but separates control information which allows sophisticated electronic processing of this control data. Figure 1 shows some of the main characteristics of an OBS network.

There are two types of nodes. In edge nodes, traffic is collected from access networks and assembled into larger data units, so-called bursts. Core nodes serve as transit nodes in the core network. Their main task is switching bursts without extensive processing. To achieve this, some control information containing reservation requests is necessary ahead of every burst's transmission time [3].

These reservation concepts are based on a separation of control information and data. A reservation request is sent in a separate control packet on a different channel while the actual transmission of the data burst is delayed by a certain basic offset. This basic offset enables the intermediate nodes to process control information and set up the switching matrix, thus having a complete established path from source edge node to destination edge node all in optical domain without buffering the data burst in each core node along the path [1]. There are several possibilities to perform reservation of data channel bandwidth. A reservation request is sent in a separate control packet on a different channel while the actual transmission of the data burst is delayed by a certain basic offset, as shown in Fig. 1. This basic offset enables the intermediate nodes to process control information and set up the switching matrix. In contrast to systems with immediate transmission, which send control information together with the burst, the network can do without buffering the data burst in each node along the path.

II. ROUTING

A. Routing in Optical Networks

Data routing is the process of selecting the best path for traffic between a source and destination networks based on a specific metric [4]. It is one of the most important parameters in network efficiency. Routing techniques used in optical networks such as wavelength routing is not efficient in network utilization; as it is sort of circuit switching; [5]. Header processing in optical domain still needs more time to mature to deliver the long waiting optical packet switching. The most used routing technique in today's networks is header processing in electronic domain. But, this downgrades the link speed to the electronic processing speed. OBS solves this problem as stated before.

The motivation, in this paper, is to select more than one routing path; if exists; and load balance the traffic between these paths based on each path BLR which leads to best utilization and minimum BLR through the whole network.

B. Routing Protocol

A routing protocol is a protocol that specifies how routers communicate with each other, disseminating information that enables them to select routes between any source and destination on a network cloud. The choice of the route is done by using routing algorithms. Each router has knowledge only of networks attached to it directly. A routing protocol shares this information among neighbors, and then throughout the network. In this way, routers gain knowledge of the topology of the network [4].

C. Routing Metric

Routing protocols depend on a metric technique to determine the best route path. Some routing protocols depend on link bandwidth as the only parameter in calculating its metric such as open shortest path first (OSPF) while others depend on hop count such as routing information protocol (RIP) [4]. So, selecting the best path depends on the metric used such as link bandwidth or number of hops. But, optical networks are special networks having some special parameters such as number of channels. These have a great effect on utilization and BLR. Therefore, a new optical parameters dependent metric based on BLR is introduced. Based on this introduced metric, this paper aims to load balance the traffic load entering the OBS network on more than one path, thus utilizing some or all of the paths and thus decreasing the BLR. In the rest of this paper, we will refer to best route as the route with lowest BLR.

D. Routing Load Balancing

Routing protocols select best path between source and destination networks based on a specific metric [4]. But, if there exists more than one path why don't we use some or all of them to share the traffic load across these paths. Many routing protocols use equal load balance such as OSPF and RIP [4]. The condition for equal load balance to occur is that paths need to have equal metric and the traffic load is shared equally across these paths. But, if the metric for these paths are not equal, one cannot share the traffic load equally. This paper shows a proposed unequal metric proportional load balancing. This will be illustrated in next sections.

III. SIMULATION

A. Simulation Software

Network simulator 2 (NS-2) is used as a simulation software in this parametric study. It is one of the best tools in the network simulation market. NS-2 is an open source code with many references and documentation [6-8]. OBS version 0.9 which is an OBS module under the NS-2 is used. Many papers have used these network simulation tools [9-10].

B. Simulation Topology

Different load generation is experimented on a single segment. The proposed simulation topology is composed of two core nodes (C0 and C1) and one segment in between. Input traffic is generated towards C0 and output traffic comes out of C1.

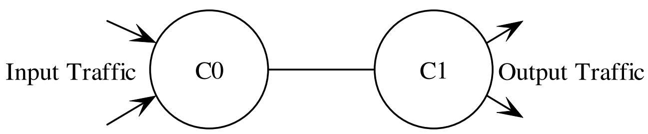

Fig. 2 OBS one segment simulated network topology

Traffic distribution follows Poisson distribution with burst size equals to 120,000 byte [11]. Traffic flows are launched between the source and destination across studied segment. No fiber delay line (FDL) is used. By using this topology one can simulate contention over a single link between two core nodes.

IV. NUMERICAL RESULTS

For the sake of showing the effect of different parameters on BLR in OBS networks, a simulation study is performed for set of traffic load values from 10 to 100 Gbps with different link bandwidth from 10 to 100 Gbps at different number of channels (1-20). This data can be stored on a router chip with larger ranges of load, link bandwidth and number of channels (n). These selected ranges are just for demonstrating the idea. Figures 3 through 6 show the relation between BLR and traffic load at different link bandwidth (BW) and at 1, 5, 10 and 20 channels, respectively.

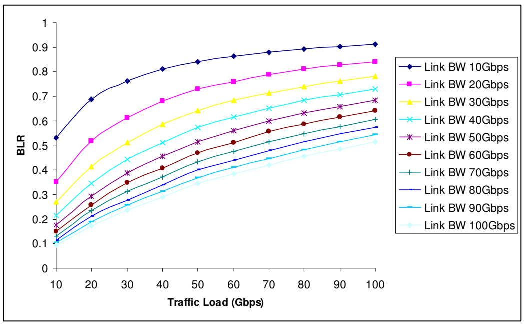

Fig. 3 Relation between BLR and traffic load at different link bandwidths, at n = 1.

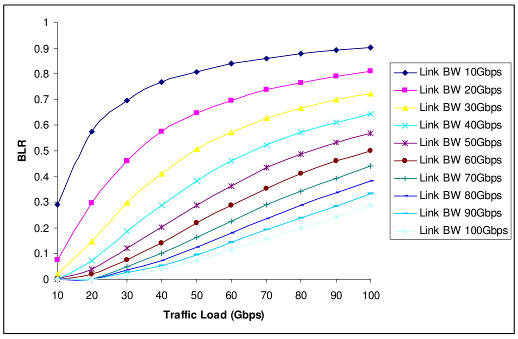

Fig. 4 Relation between BLR and traffic load at different link bandwidths, at n = 5.

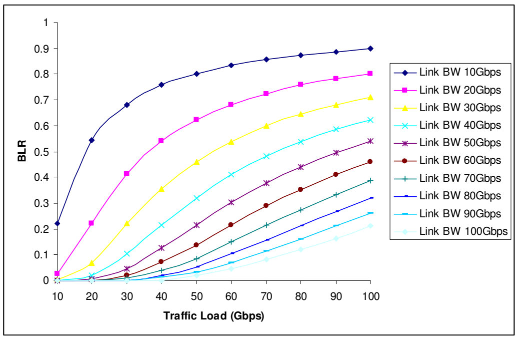

Fig. 5 Relation between BLR and traffic load at different link bandwidths, at n = 10.

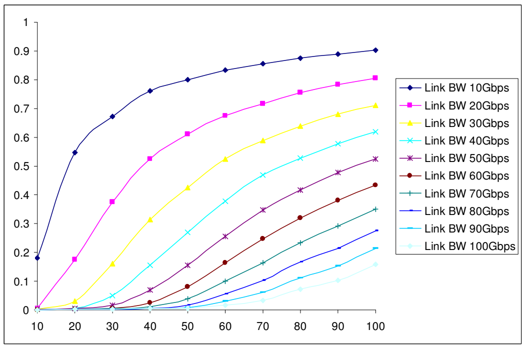

Fig. 6 Relation between BLR and traffic load at different link bandwidths, at n = 20.

The proposed routing metric depends on BLR. But, BLR depends on various parameters. So, weights for these parameters affect the BLR and thus a proposed metric must be illustrated. Previous figures show the weights of link bandwidth, traffic load and number of channels on BLR in OBS networks. Also, these figures will be used heavily to get some data for the proposed routing algorithm in next section.

V. ROUTING ALGORITHM

Our main goal is to decrease contention. Instead of using a reaction to resolve contention, a pre-action method of routing load balance is used as will be seen in next section. Routing techniques involve two stages; route calculation and route selection. Route calculation is done using the BLR metric. In the route selection process, if more than one path exists between source and destination networks, they will be installed in the routing table as route1, route2,….etc and traffic will be load balanced across these paths as will be shown.

Due to long relevant periods of optical cross connect (OXC) in core nodes (milliseconds) in comparison to burst duration, OXC cannot change the output interface for the traffic while the burst is crossing the core node. Thus, routing load balance cannot be done on the core nodes. This paper aims to solve this problem on the edge node.

It is assumed that edge and core nodes running the same link state routing protocol. Thus, the edge node will have all the knowledge of the paths between source and destination networks including the weights (metric) for each path. The traffic burst on the edge node will be split into more than one burst (according to the algorithm shown in next section). These divided bursts will be pushed into the core nodes on different wavelengths and will have different routing paths as will be seen. Before the burst is sent a burst header packet (BHP) containing all needed data for the core node reservation as time of arrival, input wavelength and burst length is sent ahead. A proposed field in the BHP which is route number will be added; thus making the edge node selects the route number that the core node will reserve for this burst. This will force the core node (which have for a specific destination route1, route2,..etc) to reserve different routes leading to routing load balance.

Next section describes a routing algorithm for selecting the paths on which load balance will occur and the relevant predicted traffic loads (bursts size) on these links. This procedure depends on the BLR metric. Also, it takes some numeric input data from previous figures.

A. Routing algorithm steps

1. Calculate the summation of link BLR for each available path between the source and destination network.

   $$BLR_S(path) = \sum_{L=1}^{Z} (BLR)_L \qquad (1)$$

   where BLR_S (Path) is the summation of BLR across a path, L is link number in path, Z number of links across the path and $(BLR)_L$ is the BLR for link.
2. Select the best single path having minimum BLR_S (path), as calculated from Eq. 1.
3. Calculate the drop rate on the best path selected from step 2.
   To deduce a relation for the drop rate, one can assume that the transmission probability $\{1-(BLR)_L\}$ for each link is independent from other links. Also, the traffic will go across all the links of the path. Thus, it can be seen that an independent probability relation exist. Then the transmission rate T(path) can be calculated according to

   $$T(path) = L(path) \times \prod_{L=1}^{Z} (1-(BLR)_L) \qquad (2)$$

   The drop rate can be calculated as

   $$D(path) = L(path) - T(path) \qquad (3)$$

   Substituting Eq. 2 in Eq. 3, drop rate is

   $$D(path) = L(path) \times (1 - \prod_{L=1}^{Z} (1-(BLR)_L)) \qquad (4)$$

   where D (path) is the burst drop rate per path, L (path) is the traffic load carried on this path.

   By dividing Eq. 4 by L(path) BLR can be shown as,

   $$BLR(path) = 1 - \prod_{L=1}^{Z} (1-(BLR)_L) \qquad (5)$$

4. Equation 6 calculates the summation of BLR for all the paths (BLR_S (lb)) on which load balance will occur.

$$BLR_S(lb) = \sum_{p=1}^{m} BLR(path)_p \tag{6}$$

where BLR_S (lb) is the summation of path BLR across all selected paths on which load balance occurs, p is the path number, m is the number of selected paths between source and destination networks.

5. A new traffic load across the selected paths for load balance should be calculated. This represents dividing the burst on the edge node to give the required traffic load. We propose splitting the total traffic load inversely proportion to the percentage of the BLR.

$$L_{lb}(path) = L(total) \times \frac{BLR_S(lb) - BLR(path)}{BLR_S(lb)} \tag{7}$$

where L_{lb}(path) is the new traffic load for this path after load balancing, L (total) is the total traffic load and BLR(path) is the burst loss ratio across this path.

6. Due to change in traffic load L_{lb}(path), the link $(BLR)_L$ is changed to $((BLR)_L)_{lb}$ and consequently BLR(Path) are changed.

7. Using the new $((BLR)_L)_{lb}$ calculated from step 6 and substituting in Eq. 4 one can calculate the total burst drop rate after using load balance routing.

$$D(lb) = \sum_{p=1}^{m} D(path)_p \tag{8}$$

where D(lb) is the total burst drop rate between source and destination networks after load balancing, D (path) is the burst drop rate per path and can be calculated from Eq.4

8. Equation 9 is used to calculate the percentage of decrease in drop rate before and after load balancing.

$$D(dec) = \frac{D(path)_{best} - D(lb)}{D(path)_{best}} \times 100 \tag{9}$$

where $D(path)_{best}$ is the drop rate for the best single path route (lowest BLR(path)) calculated from step 3, D(dec) is the percentage of decrease in drop rate after using load balance routing.

The following equations illustrate the BLR for single best path routing, the decrease in BLR after using load balance routing and the decrease in BLR percentage, respectively.

$$BLR(Path)_{best} = \frac{D(path)_{best}}{L(total)} \times 100 \tag{10}$$

$$BLR(lb) = \frac{D(lb)}{L(total)} \times 100 \tag{11}$$

$$BLR(dec) = \frac{D(path)_{best} - D(lb)}{L(total)} \times 100 \tag{12}$$

VI. ROUTING TOPOLOGIES EXAMPLE AND NUMERICAL RESULTS

This section demonstrates the benefit of using unequal load balance routing using an example for an OBS network topology. A comparison is demonstrated between using a single best path routing and load balance routing on this topology. Drop rate and BLR before and after load balance routing will be calculated showing the enhancement in OBS network performance.

Topology 1 is displayed in Fig. 7 showing four routers, router A, B, C and D having four links in between. These links form two paths between source and destination networks; path x and path y. The sample parameters of these links are as follows.

Link S1: Bandwidth=60 Gbps, n=1
Link S2: Bandwidth=90 Gbps, n=5
Link S3: Bandwidth=40 Gbps, n=10
Link S4: Bandwidth=50 Gbps, n=10

These parameters are random and just for demonstration

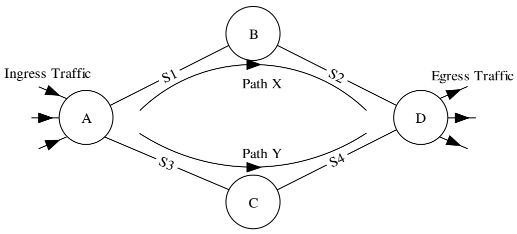

Figure 7 Four core nodes topology.

A load of 30 Gbps is assumed going from node A to node D on all links per path.

A. Drop rate for best path routing
By using Figs 3, 4 and 5, taking into account topology 1 link parameters one can obtain the BLR for each link as
BLR (s1) = 0.34920, BLR (s2) = 0.02454
BLR (s3) = 0.10467, BLR (s4) = 0.04507

Using Eq. 1, BLR (path) is obtained as

BLR (path[x]) = BLR (s1) + BLR (s2) = 0.37374
BLR (path[y]) = BLR (s3) + BLR (s4) = 0.14974

In this example, the best routing path will be (y).

One can calculate the drop rate D (path[y]) from Eq. 4. This is the best result using single best path routing. D (path[y]) = 4.35 Gbps.

B. Drop rate for load balance routing
Using Eq. 6, BLR(lb) is

BLR(lb) = BLR(path[x]) + BLR(path[y]) = 0.52348
To calculate a new traffic load (by the same percentage the burst on edge node is divided) crossing path x and path y after load balancing, Eq. 7 is used. Hence,

$L(path[y])_n$ = 21.4 Gbps.
$L(path[x])_n$ = 8.6 Gbps.

From previous load calculations and Figs. 3, 4 and 5, the new $(BLR)_l$ can be extracted as

BLR $(s3)_n$ = 0.03262 , BLR $(s4)_n$ = 0.01233
BLR $(s1)_n$ = 0.128 , BLR $(s2)_n$ = 0

Using Eq. 1, $BLR(path)_n$ are calculated as

BLR $(path[x])_n$ = BLR $(s1)_n$ + BLR $(s2)_n$ = 0.128
BLR $(path[y])_n$ = BLR $(s3)_n$ + BLR $(s4)_n$ = 0.04495

Using previous data, Eq.8 and Figs. 3, 4 and 5 one can calculate D(lb) as

D(lb) = $D(path[x])_n$ + $D(path[y])_n$ = 1.1 Gbps + 0.9533 Gbps = 2.0533 Gbps

Substituting D(lb) in Eq. 9-12, one gets
$BLR(path)_{best}$ = 14.5 %
D(dec) = 52.8 %
BLR(dec) = 7.66 %
BLR(lb) = 6.84 %

It is clear that more than 50 % of the drop rate is avoided and a decrease in BLR by more than 7 % is achieved after the use of unequal load balance routing against using single best path routing.

A complete analysis for Topology 1 with different traffic loads from 10 Gbps to 100 Gbps is illustrated in the following section. This analysis will prove the importance and efficiency of our unequal load balance routing technique.

Figure 8 shows the relation between total traffic load and its distribution on different paths (path x and path y) after using unequal load balance routing. This distribution follows the rules in our routing algorithm in step 5. It can be shown that the traffic is distributed inversely proportional to the BLR as shown in Fig. 9.

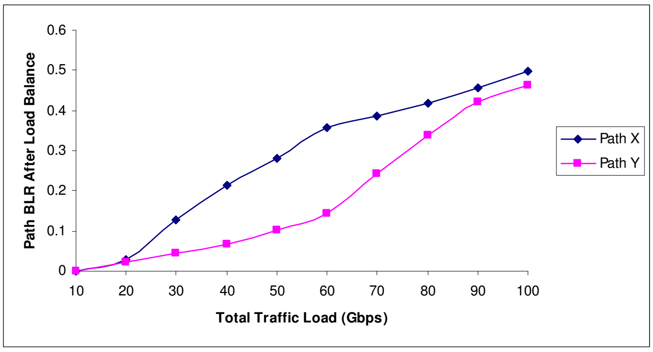

Figure 9 Relation between total traffic load and path BLR after using unequal load balance routing.

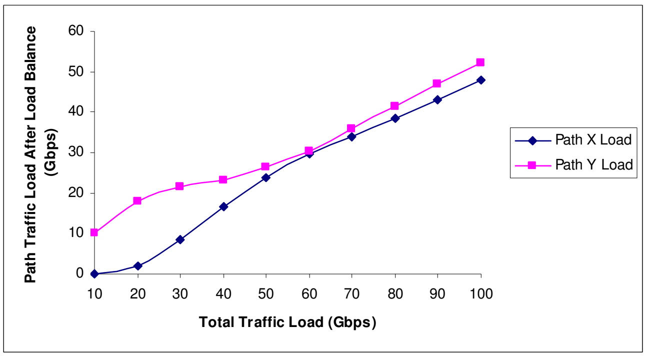

Figure 8 Relation between total traffic load and its distribution on different paths after using unequal load balance routing.

This traffic distribution makes the path with lower BLR carries higher traffic volumes and vise versa. This achieves lower total BLR for the OBS network after we use this load balance technique.

Figure 10 shows the drop rate of the best (single) route as selected in chapter 5 based on the lowest BLR, another large decrease in BLR is achieved by load balancing the traffic load across different paths (in this example path(x) and path(y)). The drop rate for the different paths (path(x) and path(y)) is shown giving lower values per path. This leads to a dramatic decrease in the overall drop rate after using unequal load balance routing.

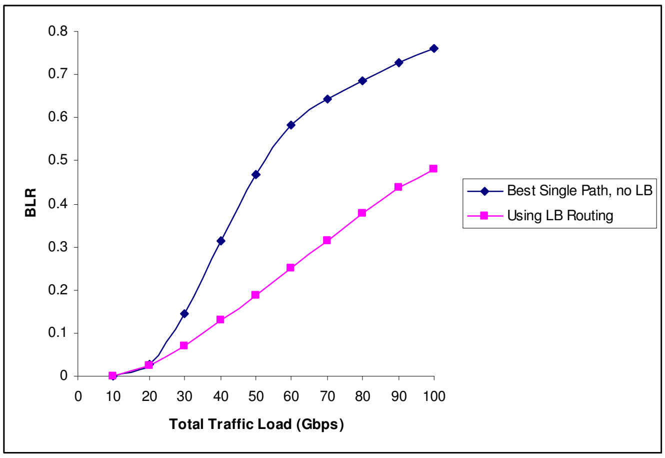

Figure 11 Relation between total traffic load and BLR before and after using load balance routing.

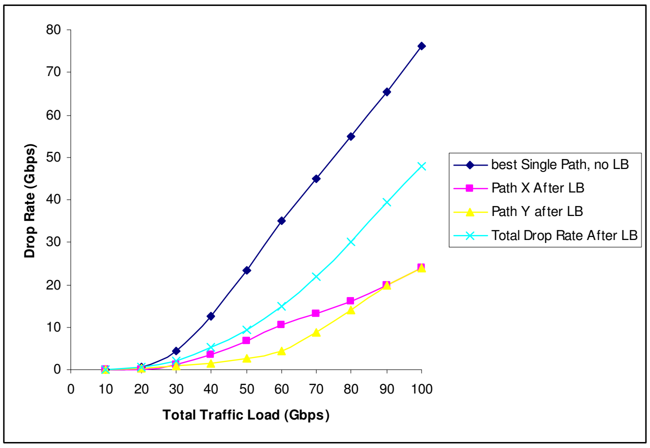

Figure 10 Relation between total traffic load and drop rate before and after using load balance routing.

An overall decrease in the BLR is shown in Fig. 11 after using the unequal load balance routing with comparison to the best (single) path routing shown in chapter 5. It is shown that the BLR difference increase as the traffic load increases because of the saturation of the single path. This makes our existing OBS networks capable of transporting higher traffic loads. This can be done without upgrading the physical network parameters such as link bandwidth and number of channels. This can give a clew of the importance of unequal load balance routing. Also, the previous routing techniques can be used in OBS network design and upgrade to achieve desired BLR or traffic loads. Without changing any of the physical parameters of the running network or with minimum upgrade better OBS network performance can be achieved.

VII. CONCLUSION

It has been shown that single best path routing in OBS networks is not the optimum routing solution. If the OBS network has more than one path between source and destination networks load balance routing shows great effect on decreasing the BLR. This paper proposes a new unequal load balance routing based on a metric taking into account optical parameters.

A new routing algorithm is shown to calculate the traffic loads distributed across the load balance routing and the decrease in BLR. Results show that load balance routing is a promising routing technique leading to better routing decisions, and avoiding a large percentage of the drop rate; in some examples more than 50%. Consequently, this lowers the overall BLR of the network and increases the utilization for OBS networks.

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