A Cluster Network Based Distributed Resource Management Scheme For OBS Networks

Beverly Pule
Microsoft S.A
Johannesburg
beverlypule@gmail.com

Bakhe N, Andrew Mutsvangwa
DUT, Electronic Engineering Dept
bakhen@dut.ac.za

***Abstract*— All-optical networks (AON) based on optical burst switching (OBS) are rapidly becoming the ultimate backbone network solution for next (future) generation networks because of their potential ultra high bandwidth capacities both at transmission and switching levels. The OBS switching paradigm was conceptualized and ultimately designed using the good features of both optical circuit switching (OCS) and optical packet switching (OPS) and thus provides improvements over wavelength routing in terms of bandwidth efficiency, at the same time eliminating the need for huge buffers at the network edges as well as optical –to- electronic conversions and vice-versa of the data bursts at the core (switching) nodes. With such networks end to end light channels will transmit users data , transparently i.e. without being aware of its bit rate, modulation format as well as network protocol thus enhancing capacity, flexibility and scalability of the network. A buffer less /limited buffered lead OBS network would mean high contention and blocking, hence to guarantee and end-to-end consistent QoS in would require that the resources are properly managed. Effective management of both control and data planes is a key issue in this regard. Thus in this paper, we propose and analyse a partial distributed resource management scheme for OBS networks. We describe the concept, followed by routing and wavelength selection procedures.**

Keywords*— OBS, resources management,

I INTRODUCTION

Continuing advancements in optical transmission and switching technologies, notably in fibre bandwidth capacity and optical switching, have shifted the bandwidth and operational bottlenecks from the core network to the egress and access networks. Meanwhile there is a steady proliferation of applications the majority of which have very high bandwidth and/or stringent performance requirements, which threaten to constringent core networks in both required bandwidth capacity and flexibility. Simultaneously need arises to address the capacity demands that bandwidth-intensive applications are expected to generate in the access and further in the core networks. To continue the cycle of optical networking advancements, it is important to understand the benefits and limitations of today’s technologies and architectures and determine what advances will be needed to meet the requirements of future-generation core networks in the near future. Moreover these will require significant improvements in capacity, configurability, and resiliency. Aggregate network demand, as measured by summing the traffic at demand endpoints, could easily be in the order of hundreds of Terabits per second, which is a significant order of magnitude relative to current capacities. The ever surging traffic levels has also lead to ever increasing bandwidth demands which should be provisioned at minimal costs. The mismatch between all optical backbone achievable transmission speeds versus switching capacities has also prompted research on a switching paradigm to eradicate the unavoidable bottleneck. Currently OBS appears to be the best feasible solution when compared to other paradigms such as optical circuit switching (OCS) and optical packet switching (OPS) in reducing this bottleneck. OPS is conceptually ideal, but the required optical technologies such as optical buffering and optical logic are too immature for it to happen anytime soon. We will thus focus on OBS which overall is based on the premise that data is aggregated into various-size bursts and transported from an ingress point (figure 1) to an egress point of a given network, by setting up a short-life lightpath in the network in such a way that the burst finds the path configured when it crosses a given intermediate (core) node (figure 2) .

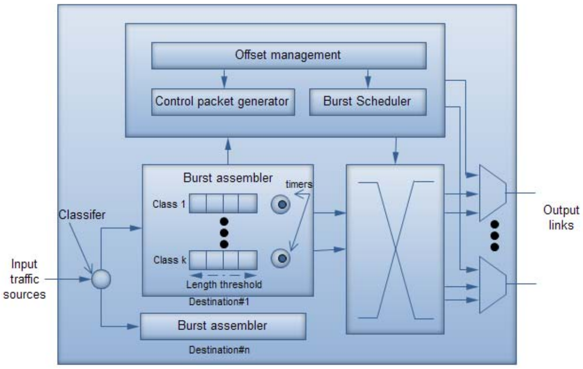


Fig. 1. Ingress edge node.

During burst assembly, both individual data packets and bursts are buffered at the edge nodes where there is provision for electronic RAM. A control packet, is dispatched ahead of the data burst to a core node (figure 2) where it is electronically processed to provide information for pre configuring the optical switch shortly before the actual data burst arrival. This process is called burst reservation. The offset time, which is the difference between the end time of

978-1-5090-2576-3/16/$31.00 ©2016 IEEE.

control burst and staring time of data burst at the ingress node, is sized such that the data burst is switched wholly in optical domain at any intermediate node, thus incurring no switching delays. This separates OBS from OPS, where the header information is an integral part of the transported information unit. Summarily, upon receipt of the control packets sent from the OBS users, the OBS nodes schedule their resources based on the included information. There are four generic types of control packets corresponding to the wavelength reservation approach that has been adopted:- [1,2]

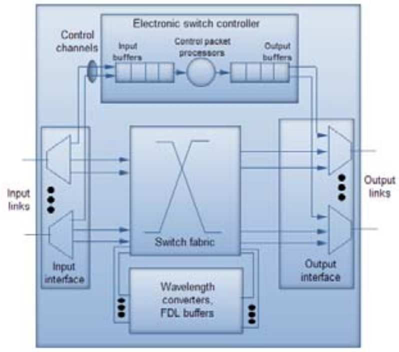


Fig. 2. Intermediate (core) node

i) Explicit setup and explicit release control packet. This type contains the offset of the burst, but not the duration of it. The reservation of resources starts immediately after the switch receives the setup message, and ends when the release message is received.

ii) Explicit setup and an estimated release control packet. This contains both the offset and the duration of the burst. Each wavelength has an associated deadline indicating the resource will become free. The reservation starts after the switch receives the setup message and ends when the burst is switched and transmitted, a time that is calculated using the duration field.

iii) Estimated setup and an explicit release. The setup control message contains only the offset of the burst. The reservation starts at the beginning of the burst. This time is calculated using the previous offset information. The release of resources is executed once the release message arrives.

iv) Estimated setup and an estimated release. The setup message of this scheme has the offset and the duration of the burst. Reservation and releasing of resources are calculated using previous data.

Any of these reservation approaches does overcomes the current technological limitations of not being able to realize large scale optical buffering as control packets pre-configure the core nodes ahead of bursts arrivals.

The exact algorithm for creating the bursts can greatly impact the overall network operation because it allows the network designers to control the burst characteristics and therefore shape the burst arrival traffic. The burst assembly algorithm has to consider the following parameters: a preset timer, and maximum and minimum burst lengths. The timer is used by the user in order to determine when exactly to assemble a new burst. The maximum and minimum burst parameters shape the size of the bursts. This is necessary since long bursts may hold resources for long times and cause higher burst losses**,** while short bursts may give rise to too many control packets. The burst aggregation algorithm may resort to bit-padding if there is not enough data to assemble a minimum size burst. The most common burst-assembly approaches are timer based and threshold based. In a timer-based burst-assembly approach, a burst is created and sent into the optical network when the timeout event is triggered. In a threshold-based approach, a limit is placed on the number of packets contained in each burst. A more efficient assembly scheme may be achieved by combining both timer based and threshold-based approaches. So far overall, traffic management decisions are performed at the edge nodes, thus keeping the core nodes as simple as possible. Thus when an edge node transmits a burst into the network, its control packet (CP) already includes information on the path for the burst. The information in OBS nodes is of local significance, even though ideally the entire network should be updated about the state of resources on each of the individual core nodes. However, it is noted that various models e.g. such as centralized and distributed management architectures which are geared towards optimizing the utilization of the network resources information have been extensively explored in literatures Both have their merits and demerits. With centralized control and reservation architecture a centralized scheduler performs major tasks such as offset calculation, routing and wavelength assignment, network resource scheduling, light path establishment (LPE) failure recovery etc. The approach however lacks scalability i.e., increase in the number of core nodes in the network, brings about the risk of the single central scheduler (CS) being over congested and hence unacceptable delays in processing incoming control packets. To bring about scalability, a distributed architecture was also proposed in which the entire multiple network switches are clustered and each cluster is headed by a cluster head (CH) [2]. A sub-cluster head (SCH) is also elected within each cluster for resilience enhancement i.e. it is connected both to its CH as well as a CH of another cluster. Both CH and SCH are key to resources management both within each cluster as well as among clusters in a distributed fashion e.g. this includes control packet processing, resources reservation and switching fabric configuration functionalities. However issues like accurate offset calculation, better resource scheduling and fault management may not be accomplished perfectly under this approach that being primarily due to unavailability of global knowledge of network resources at a single point in the network.

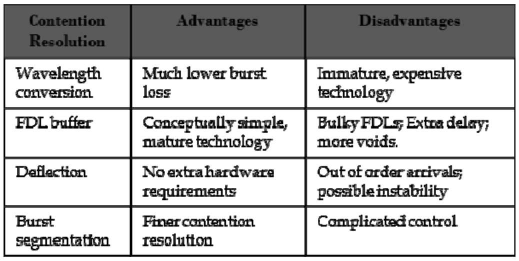
We start by briefly describing the various techniques used for contention resolution in an optical burst switching network in section II as this is key in overall effective resource management in OBS networks. This is followed by QOS differentiation mechanisms. An overview description of the proposed hybrid resource control architecture follows next and lastly Simulation results followed by conclusions are finally presented.

II. CONTENTION RESOLUTION IN OBS

Avoidance of both control packets and data bursts loses is crucial in the overall performance of OBS networks. Under the assumption that control packet losses are negligible and control packet processing delays are within the expected values, that is, the control channel is contention-free or has very small losses and the electronic processing speed of the node's control unit is large enough [2,3], burst losses only occur due to unresolved contention for the data channels. In particular, resource contention arises whenever two or more bursts, overlapping in time, reach a common core node from different input fibres, but using the same wavelength, and are directed to the same output fibre. Various schemes such as wavelength conversion [4], optical buffering [5], burst segmentation (BS) [6,9], and deflection routing [11] are proposed for contention resolution in the literature. Also see [15-20].

In an OBS network with no wavelength converters, the entire path from source to destination is constrained to use a single wavelength. The other possibility is an OBS network with a wavelength conversion capability at each OBS node. In this case, if two bursts contend for the same wavelength on the same output port, the OBS node may optically convert one of the signals from an incoming wavelength to a different outgoing wavelength. In addition, the conversion capability at an OBS node can be classified further as full or sparse. In the former case, there is one converter per each wavelength, whereas in the latter case the number of converters is less than the total number of wavelengths.

Table I. comparison of contention resolution schemes



Contention Resolution	Advantages	Disadvantages
Wavelength conversion	Much lower burst loss	Immature, expensive technology
FDL buffer	Conceptually simple, mature technology	Bulky FDLs; Extra delay; more voids.
Deflection	No extra hardware requirements	Out of order arrivals; possible instability
Burst segmentation	Finer contention resolution	Complicated control

The second option applies to optical buffering [e.g. by means of fibre Delay lines (FDLs)], delaying a contending burst until the required resource becomes available. Burst segmentation is a method which attempts to reduce data loss by dividing a burst into segments and only dropping those segments of a burst that overlap with another burst when contention occurs. Finally, the last option deals with deflection routing (DR), where a contending burst is forwarded to a different output port than the preferred one, via the shortest path towards the destination. Another option would be to introduce a multiple fibres per input/output link WDM switch in the core network. For each link there are N input/output fibres each with M wavelengths The various wavelengths channels from input fibres are demultiplexed and switched to the desired output fibres. In the event that contention occurs, the contended bursts are routed via the shared wavelength converters (tunable) and assigned to different available wavelengths thus resolving the contention. In our approach selected core nodes are equipped with wavelength converters thus keeping network operational costs low (figure 3). As seen in the figure such a switch architecture requires a large number of input output ports. Sub switches which can switch only optical channels customised to a particular wavelength are used and have to equal the overall number of wavelengths.[xxx] The number of ports against one sub switch equals to the sum of input/output fibers and shared wavelength converters. The switch controller manages the connections in the fabric as well as processing control packets electronically. To briefly evaluate analyse the performance of the switch we note that at switch level, there are three primary factors that can lead to bursts loss. These include insufficiency in the numbers of shared wavelength converters; more that k bursts, $k \succ M$ are destined for the same output port, as well as loss of control packets due to congestion.

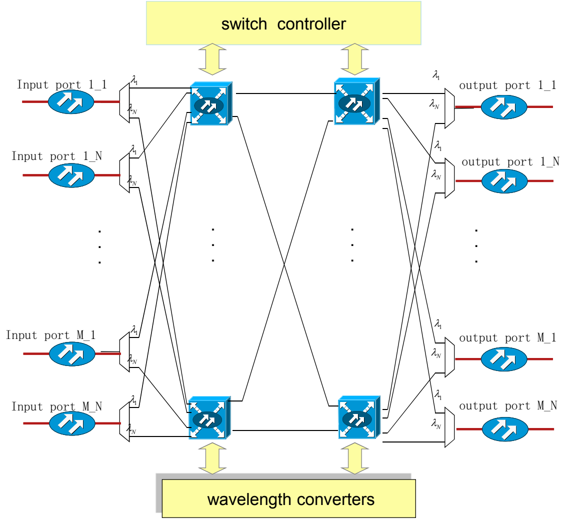


Fig. 3. Switch architecture with shared WCs

As previously cited, contention resolution is accomplished by translating one or more bursts contending for the same output wavelength channel from their original wavelength to different ones allocated on the same output fiber interface. This operation is performed by wavelength converters (WCs). The resulting effect is to increase throughput and output channel utilization and, consequently, reduce output channel blocking. Here we assume a shared-per-node (SPN) architecture. The SPN represents a perfect sharing scheme in the sense that each arriving burst to the switch can exploit any of the r_n available WCs in the system, i.e., maximum degree of sharing. We assume a data burst arriving on wavelength λ_k and destined for an output fibre n, $n \le N$. In the event that all the wavelength channels on that link are occupied, the burst will be blocked. The loss probability for a burst directed to link n,

$$P^{SPN}_{loss} = x^{(n)}_{M} + \sum_{l=1}^{M-1} x^{(n)}_{l} \frac{1}{M} p^{SPN}_{conv}, \qquad 1 \le n \le N \tag{1}$$

$$P^{SPN}_{loss} = \frac{\sum_{n=1}^{N} \eta^{(n)} P^{SPN(n)}_{loss}}{\eta} \tag{2}$$

The traffic intensity destined for link n, but requiring conversion is given by:

$$v^{SPN(n)} = \sum_{l=1}^{M-1} \eta^{(n)} \chi^{(n)}_{l} \frac{1}{M} \tag{3}$$

The intensity of overall bursts destined to the single wavelength converter bank is:

$$v^{SPN} = \sum_{n=1}^{N} v^{SPN(n)} \tag{4}$$

If the bursts inter arrival times are poison distributed, then from the Erlang –B formula we have:

$$P^{SPN}_{conv} = B\left(r_n, v^{SPN}\right) \tag{5}$$

Generally the scheme will perform well for both balanced and unbalanced traffic scenarios, and as a consequence, it provides a promising converter sharing solution in next-generation OBS switching systems

III. SERVICE DIFFERENTIATION

QoS is a major issue in heterogeneous networks. QoS provisioning refers to a collection of mechanisms are enforced in order to meet the QoS requirements of the various traffic types. As is well known, client packets belong to different traffic classes with different QoS requirements in terms of performance parameters such as loss, delay, delay jitter etc.

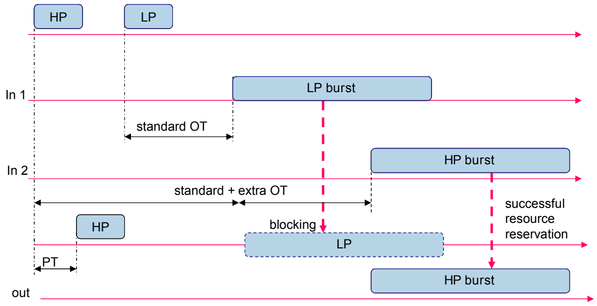


Fig. 4. offset time-based Differentiation

QoS issues including methods have been discussed extensively e.g. the relative and absolute methods for ensuring QoS. [6-9]. Some are appropriate for the edge and others for the core network. Offset time-based (OTD) and burst length-based differentiation (LBD) are two such mechanisms that have been proposed for edge-based QoS differentiation. The OTD concept is illustrated in figure 4. As seen from the diagram an extra offset time is assigned to HP bursts, resulting in an earlier reservation for HP bursts in order to favor them while the resource reservation is performed. Its principal advantage is that of simplicity; coupled with a relative reduction of loss probability for HP bursts by means of their postponed transmission from the edge node. In this case no further differentiation will be needed in the core nodes. With this approach however, the HP traffic class to tends to be sensitive to burst length characteristics and thus an extra requirement for an extended pre-transmission delay that may not be tolerated by some delay-sensitive traffics. Moreover, the end-to-end delay for HP traffic increases as a result of increased offset times which, in turn, decreases the throughput. [10]. The *Burst length-based differentiation (BLD is a*nother edge based mechanism that has been explored quite extensively. Its soley based on the idea that short time bursts are more likely to fit in gaps generated by already scheduled bursts. Consequently, in BLD method, HP class is assigned shorter burst lengths than the LP class for enhancing the performance of the HP class relative to the LP class in terms of loss probabilities. In particular, HP packets are burstified using lower timer [10] and lower burst length thresholds [8,10] compared with the corresponding values for LP packets (see Fig. 5).

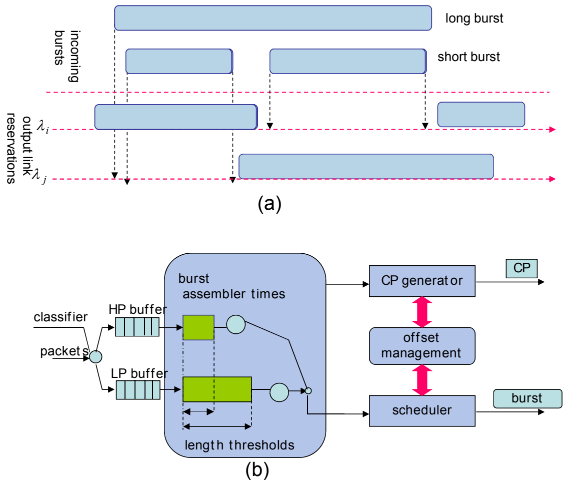


Fig. 5. Edge based Burst length differentiation

Further more; use of a shorter burstification timer for the HP class correspondingly is to reduces the overall end-to-end delay. BLD can also be used as a complementary method in conjunction with another differentiation mechanism, such as OTD, for improved isolation between traffic classes [10]. However its draw backs include the increase in complexity of the burst assembly unit coupled with an increase of signaling overhead. Moreover, in order for this method to be effective, sophisticated void filling algorithms need to be already in place at the OBS core nodes as opposed to simple-toimplement horizon-based scheduling mechanisms that do not take advantage of voids [11].

QoS differentiation in core nodes takes place during contention resolution and is accomplished most typically via a burst dropping policy.

IV. PROPOSED RESOURCES MANAGEMENT SCHEME

Herein we propose a resource allocation method that is partially based on distributed routing, wavelength conversion for contention resolution, as well as wavelength methods that operates at reduced resource information exchanges among the key core and edge network nodes. The key features of this proposal are as follows:

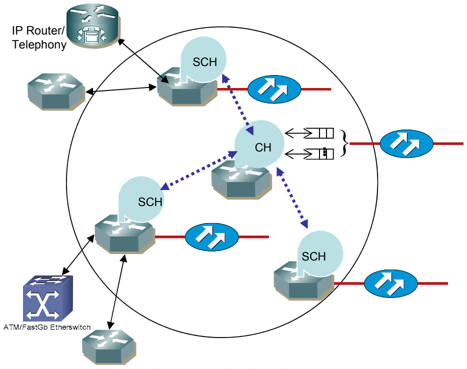
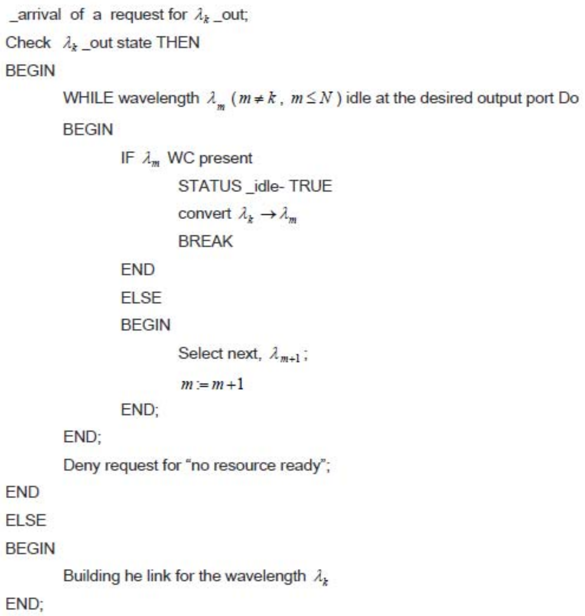


Fig. 6.a. Single cluster

The network (s) are reorganised into multiple clustered networks each with a Cluster header (CH) as well as a sub-cluster Header [2]. Each CH node manages key network resources information, such as e.g., static nodes and link information, candidate routes for all destinations, resources state (available wavelengths) for each outgoing/output link(s), and exchanged link resource information from other nodes.

The CH nodes are equipped with shared per node (SPN) wavelength converters [5,15]. The processing loads of intermediate nodes should be as small as possible. Therefore, one way signalling is adopted. When new optical path is requested, the source node selects a route for transmission from pre calculated candidate routes. After route selection, the source node checks wavelengths at the output link and assign one wavelength for the optical path. After wavelength assignment, the source node sends wavelength reservation message to the destination node along the selected route on the assigned wavelength. If all fibres of the assigned wavelengths are not available at an intermediate node, the optical path setup is blocked.

However, when the contended node has available wavelength contenders, the wavelength of the optical path is converted to another available wavelength and the wavelength reservation is continued. When the wavelength reservation is successful, the destination node replies acknowledgement (ACK) message to the source node.



```
_arrival of a request for $\lambda_k$ _out;
Check $\lambda_k$ _out state THEN
BEGIN
    WHILE wavelength $\lambda_m$ ($m \neq k$, $m \leq N$) idle at the desired output port Do
    BEGIN
        IF $\lambda_m$ WC present
            STATUS _idle- TRUE
            convert $\lambda_k \rightarrow \lambda_m$
            BREAK
        END
        ELSE
        BEGIN
            Select next, $\lambda_{m+1}$;
            $m := m+1$
        END;
    END;
    Deny request for "no resource ready";
END
ELSE
BEGIN
    Building he link for the wavelength $\lambda_k$
END;
```

Fig 6 b. wavelength conversion

The source node can transmit optical data after receiving this ACK message. In the case that contention occurs and there are no wavelength converters, the intermediate node replies negative ACK (NACK). message to the source node. After receiving the NACK message, the source node decides whether wavelength reservation is operated or not for the optical path request. In wavelength re-reservation, routing and wavelength assignment is operated as almost the same RWA of the first wavelength reservation. The different point is that the contended wavelength is excluded. Under low blocking probability, wavelength re-reservation is effective and most requests can be accommodated [15]. If the repeated wavelength re-reservation is not effective, there may be some troubles in the WDM network. In this case, it is necessary to restore the troubles or improve the network capacity.

V. ROUTE SELECTION

For route selection we adopt dynamic generalized routing [21]. We seek to accommodate, unicast , anycast as well as. multicast connections resource allocations, In each case the request can be for one or more channels, where each channel can be routed independently of others using a different route and wavelength. Multicast requests would generally accommodate delivery of data bursts to multiple destinations but from a single original source. For example broadcasting multiple video streams to several locations at the same time, or near to live IP traffic data updating// backups to several locations would require an optical multicast. Furthermore, requests may be bidirectional, where the same route and wavelength is used in both directions, or unidirectional The proposed routing method calculates candidate routes in advance and selects an appropriate route. In this paper, all minimum hop routes are the candidate routes to the destination node. The process of route selection proceeds as follows. Initially We first pick one connection request and attempt to establish a lightpath for it using the shortest free path at the current wavelength failure upon which the algorithm moves to the next wavelength and repeats the same procedure. This is repeated until all the requests have been set up. Generally if the length of the shortest path from source (s) to destination (d) is denoted by $l(s,d)$ and at the current sate, the length is $l^{'}(s,d)$ then the algorithm seeks to minimize:

$$c(s,d) = \min\left[l^{'}(s,d) - l(s,,d) - \Im\right] \tag{6}$$

Where $\Im$- is a normalized path length, $0 \le \Im < 1$. Shortest paths are determined separately for one way and two way connection requests respectively;

$$h_1(i,j) = \begin{cases} 1, \rightarrow p_{ij} > 0 \\ \infty, otherwise \end{cases} \tag{7}$$

$$h_2(i,j) = \begin{cases} 1, \rightarrow p_{ij} > 0, p_{ji} > 0 \\ \infty, otherwise \end{cases} \tag{8}$$

For anycast connection requests $a = \{s, D\}$ one must evaluate each possible destination and the path selection criterion must be adjusted slightly to take into account the alternative destinations

$$c(a,s,d) = l^{'}(s,d) - \Im = \min_{i \in D(a)} l(s,i). \tag{9}$$

The algorithm is summarized next.

```
find all pairs shortest paths, $H_1(\mathbf{P}), H_2(\mathbf{P}) \Rightarrow$ distances $\{\mathbf{D_1}, \mathbf{D_2}\}$;
$W \leftarrow 1$
$\mathbf{P}^{'} \leftarrow \mathbf{P}$
while $A \neq 0$ do
    find all-pairs shortest paths $H_1(\mathbf{P}^{'}), H_2(\mathbf{P}^{'}) \Rightarrow$ distances $\{\mathbf{D}^{'}_1, \mathbf{D}^{'}_2\}$
    $\mathbf{C}_i \leftarrow (1 - \frac{1}{N}) \cdot \mathbf{D}_i^{'} - \mathbf{D}_i, i = 1,2$
    set $c(a) = (C_{b(a)})_{s(a),d(a)} \forall a \in A\{path\_selection\_criteria\}$
    $A^{'} \leftarrow \{a \in A : c(a) < \Delta_l - 1\}$
    if $A^{'} = 0$ then
        $W = W + 1$
        $\mathbf{P}^{'} \leftarrow \mathbf{P}$
    else
        $a \leftarrow \underset{a \in A^{'}}{\arg\_\min\_} c(a)$
        setup request $a$
        reduce the number of free fibers in path $p$
        decrement $m(a)$
        if $m(a) = 0$, then
            remove request from $A$
        end if
    end if
end while
```

VI. SIMULATION

In this section we investigate the performance of the proposed method. We adopt a 14 node network. First of all we extend the performance of the shared per node (SPN) switch with multifiber links.

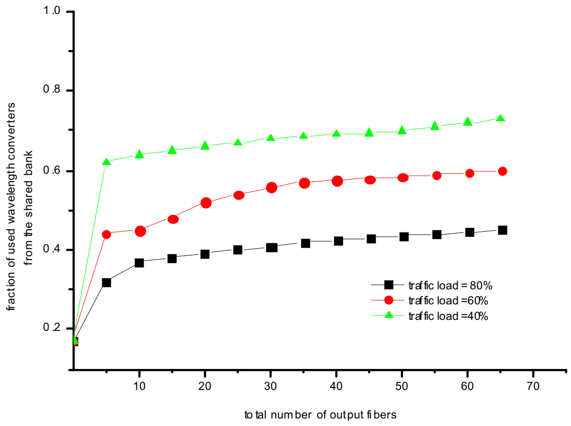


Fig. 7. Fractional usage of WCs versus output fibres

Following the approach defined in [22] we evaluate the performance of the switch in section II, figure 3 with respect to the number of output fibers, for varying traffic loads, keeping the number of shared WCs fixed. The CH node has the same number of wavelengths in both the input and output links. Bursts would come from any input wavelength and require any output link in equal chances.

The bursts arrive at the switching node as a Poisson flow, i.e., with exponentially distributed arrival intervals. And the burst lengths are also exponentially distributed. Such service settings are suitable in a backbone core node, and are usually adopted in other related literatures. We fixed the permissible drop probability to P_{drop}^{SPN} . We then go on to increase the traffic traversing the switch. Contentions arise as traffic increases. We however focus on the number of WCs required to sustain a performance no worse P_{drop}^{SPN}. As can be noted in figure 7, as the number of output fibers is increased for three different traffic loads, more WCs will have to be added in order to sustain the predefined P_{drop}^{SPN}. Low traffic loads coupled with lesser number of fibers in output links will require less WCs.

Next we fix the number of fibers between nodes , and so is the number of wavelength per given fiber. Further we assume that the inter arrival time distributions for all generated control packets (as well as their associated bursts) are exponentially distributed. Only two types of connections namely unicast and multicast are generated.

Initially the update interval among the CHs is assigned a constant value and is maintained for all the shortest path versus the proposed routing algorithms. The number of WCs is kept constant. The results are shown in figures 8 and 9.

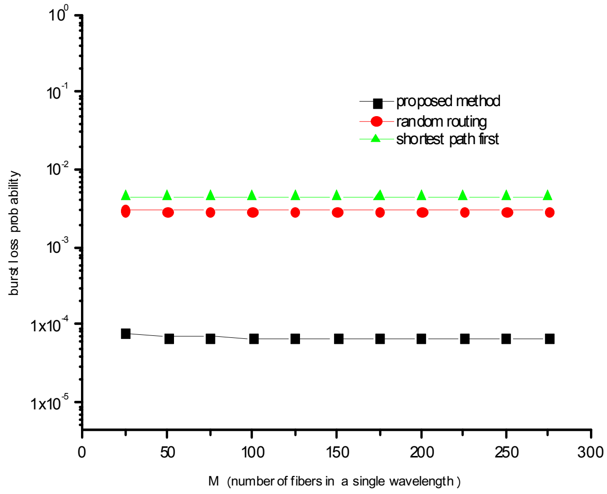


Fig. 8. Overall loss probability versus number of wavelengths.

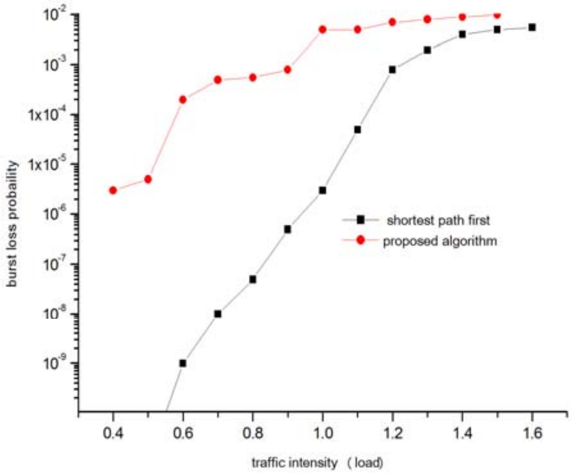


Fig. 9. burst lost probability versus traffic load

VII. CONLUSION

It is noted that to a certain extent the proposed routing algorithm provides an improvement in performance in comparison to the shortest path first (SPF) method. We further compare the two algorithms and in addition the random routing algorithms with regards to network updating interval. The result is that the proposed algorithm still outperforms the other two.

.

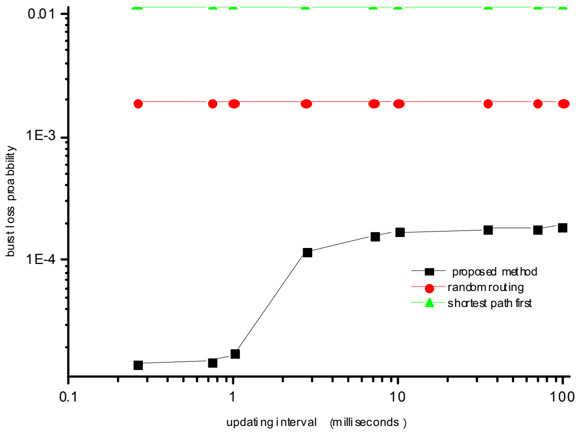


Fig. 10. loss probability versus network updating interval

REFERENCES

[1]. Y. Chen, C. Qiao, X. Yu, "Optical Burst Switching: A New Area in Optical Networking Research", IEEE Network (2004) May/June, pp. 16-23.

[2]. M raza, W Mahmood and A Ali. A New Control Architecture for Optical Burst Switching Networks, proceedings of WSEAS ICC, 10-12 July, 2006..Athens, Greece pp 453-459.

[3] . Vokkarane M. Vinod, Haridoss Karthik, and Jue P. Jason, "Threshold-Based Burst Assembly Policies for QoS Support in Optical Burst-Switched Networks," Centre for Advanced Telecommunications Systems and Services, University of Texas at Dallas.

[4]. Ge An, Callegati Franco, and Tamil S. Lakshman, "On Optical Burst Switching and Self-Similar Traffic," IEEE Communications Letter, Vol.4, No.1 (2000) March pp. 98-100.

[5]. N. Akar, C Raffael, M Savi and E. Karasan. Shared-per-wavelength asynchronous optical packet switching: A comparative analysis. Computer Networks, Volume 54, Issue 13, 15 September 2010, Pages 2166–2181.

[6]. J. Wan, Y. Zhou, X. Sun, M. Zhang, Guaranteeing quality of service in optical burst switching networks based on dynamic wavelength routing, Optics Communications 220 (1-3) (2003) 85-95.

[7]. M. Yoo, C. Qiao, S. Dixit, Optical burst switching for service differentiation in the next-generation optical internet, IEEE Communications Magazine 39 (2) (2001) 98_104.

[8]. N. Akar, E. Karsan, K Vlachos, E Varvarigos, D Careglio, M Klinkowski and J. Pareta. A survey of quality of service differentiation mechanisms for optical burst switching networks. Optical Switching and Networking, Elsevier, Number 7, 2010 -111

[9]. V.M. Vokkarane,Q. Zhang, J. P. Jue, B. Chen,, "Generalized Burst Assembly and Scheduling Techniques for QoS Support in Optical Burst-Switched Networks," Proceedings IEEE ICC (2002) April.

[10] .K. Dolzer, C.M. Gauger, On burst assembly in optical burst switching networks — a performance evaluation of just-enough-time, in: Proceeding of ITC 17, Salvador (Brazil), December 2001)

[11]. Y. Xiong, M. Vandenhoute, H.C. Cankaya, "Control Architecture in Optical Burst-Switched WDM Networks", IEEE Journal on Selected Areas in Communications, Vol.18, No.10, (2000) October pp.1838-1851.

[12]. J. Xu, C. Qiao, J. Li, G. Xu, "Efficient channel scheduling algorithms in optical burst switched networks", Proceedings, INFOCOM 2003, Volume 3, pp.2268-2278 (2003) **.**

[13]. M. Yoo, C. Qiao, S. Dixit, "QoS Performance of Optical Burst Switching in IP-Over-WDM Networks," IEEE Journal on Selected Areas in Communications, Vol.18, No.10, pp.2062-2071 (2000) October

[14]. J. Triay and C Pastor. An Optical Burst Switching Control Plane Architecture and Its Implementation.. Dep. Enginyeria Telematica, Universitet Politechnica de Catalnya. Internet downloaded.

[15]. K. Dozer, C. Gauger, J. Spath, S. Bodamer, "Evaluation of reservation mechanisms for optical burst switching", AEU International Journal of Electronics and communications, Vol. 55, No. 1 (2001) January.

[16]. Optimal Burst Scheduling in Optical Burst Switched Networks, Yuhua Chen Turner, J.S. Pu-Fan Mo, journal of Lightwave technology, vol. 25, no. 8, august 2007.

[17]. Y. Xiong, M. Vandenhoute, and H. C. Cankaya, "Control architecture in optical burst-witched WDM networks," IEEE J. Sel. Areas Communications, vol. 18, no. 10, pp. 1838–1851, Oct. 2000.

[18] .V. Eramo, M. Listanti, P. Pacifici, A comparison study on the wavelength converters number needed in synchronous and asynchronous all-optical switching architectures, Journal of Lightwave Technology 21 (2) (2003) 340–355.

[19] .Y. Mingwu, L. Zengji, W. Aijun, Accurate and approximate evaluations of asynchronous tunable wavelength-converter sharing schemes in optical burst switched networks, Journal of Lightwave Technology 23 (10) (2005) 2807–2815.

[20]. T.K.C. Chan, E.W.M. Wong, Y.W. Leung, Shared-by wavelength switches: a node architecture using small optical switches and converters, IEEE Photonics Technology Letters 18.

[21]. Esa Hyyti ¨ A Resource Allocation And Performance Analysis Problems In Optical Networks. Report 5/2004.

[22]. Hailong Li, Ian Li-Jin Thng. Performance analysis of limited number of wavelength converters by share per node in optical switching network. Computer Networks, Elsevier, 51 (2007) 671–682.