Performance Analysis of Isolated Adaptive Routing Algorithms in OBS networks

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Abstract— **This paper addresses the problem of isolated adaptive routing in connection-oriented optical burst switched networks. We study two adaptive routing strategies, the Multipath and the Bypass. Moreover, as a reference we provide the results obtained for the Shortest Path algorithm. We evaluate these algorithms in several scenarios with two different resources reservation strategies applied in the nodes. The obtained results using the NSFNet topology show that isolated adaptive routing algorithms bring small profit at the medium traffic loads and almost none for the high traffic loads in comparison to the shortest path one. The conclusion is that isolated routing might not cope fine with the congestion in OBS network since it incorporates only the local node state information. Therefore, the routing algorithms for OBS networks may need more knowledge about the state of the network for their routing decision in order to distribute fine the traffic over the network.**

Index Terms—**Adaptive routing, isolated routing, optical burst switching, routing algorithms**

I. Introduction

Optical burst switching (OBS) that has been proposed in the late 1990s is novel photonic network architecture directed towards efficient transport of IP traffic [1]. OBS pretends to be an intermediate solution for optical networks lying between Optical Circuit Switching (OCS) that nowadays in stage of standardization process and Optical Packet Switching considered as a far-term solution for optical networks [1].

OBS uses statistical multiplexing providing fine switching granularity in the optical domain. Since the unit of transmission and switching is a burst which is the aggregation of a flow of data packets, OBS is more efficient than OCS in case the sustained traffic volume does not consume a full wavelength. On the other side, optical bursts are aggregated with the client packets coming from legacy networks (like IP, ATM) on the edge of the network (Figure 1). It results in larger data units than the packets in OPS networks what decreases control complexity. Moreover, the control and data information travel separately on different channels and the control packet is sent first in order to reserve the resources in intermediate nodes for transferring its data burst. The burst follows the control packet with some offset time, and it crosses the nodes remaining in the optical domain. Setting up the offset-times allows using slower switching elements in OBS than in OPS networks.

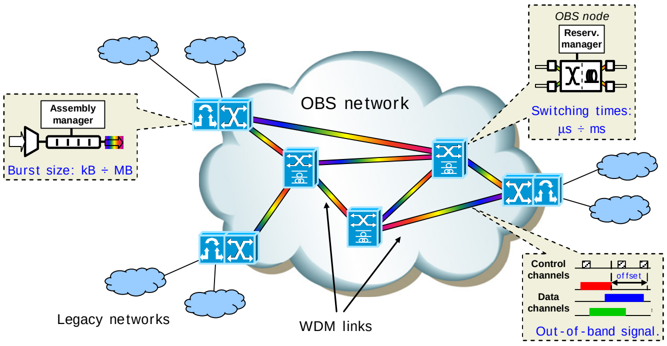

Figure 1. Optical Burst Switched network architecture.

The advantages of OBS paradigm have caused a huge interest in development of the technologies able to provide OBS functionality. The process of network designing is usually divided into two parts, namely the study on switching node elements and then investigation of a network scenario. Several works have been proposed in the literature dealing with node architectures [2], signalization issues [1], burst aggregation [3], resources reservation [4] or QoS provisioning [5] among others. Some of these aspects are discussed in Section III.

The next step in the designing of OBS network is the study of a global optical network scenario. This part concerns such networking issues as topology planning, network dimensioning, congestion avoidance and routing problem.

OBS architectures with limited buffering capabilities are sensitive to traffic overloads. In particular, long burst lengths cause an increase of burst contention probability in the network what produces higher burst losses. Either a proper routing strategy with TE enhancement or adequate network dimensioning can help in reduction of the congestion on specific links resulting in the increase of network throughput. Both approaches treat the congestion problem otherwise. The routing strategy tries to put the traffic where the bandwidth is while the goal of dimensioning is to put the bandwidth where the traffic is. The routing problem introduces higher operational complexity since it often needs advanced routing mechanisms with signalization protocols involved. Nevertheless, the advantage is that it facilely adapts to the changes in the traffic demands. The dimensioning approach fits the node and link capacities according to the matrix of actual traffic load demands and after such optimization it needs only either a simple shortest path algorithm or similar mechanism. However, some parts of such network may encounter congestion problem if the traffic demands change.

In the paper, we focus on the routing problem. In particular, our scope is to analyze different isolated adaptive routing algorithms [6] adapted to the OBS networks.

The rest of the paper is structured as follows. In section II the state of the art as well as a discussion on the routing problem in OBS networks is presented. In section III the considered scenario is presented focusing on both the resources reservation strategies applied in the nodes and the routing algorithms operated in the network. In section IV, we provide performance evaluation in terms of burst loss probability by using a simulation tool. Finally, Section V concludes the paper.

II. Routing in OBS

A. State of the art

The literature on routing in OBS networks is not too wide yet. The most relevant papers on this topic are [7], [8] and [9].

The authors of [7] present a proactive approach for tackling the problem of a burst contention based on adaptive use of multiple paths between edge nodes. The proposed adaptive framework is based on dynamically finding the optimal path among multiple paths for forwarding bursts and pipelined burst delivery to avoid out-of order packet delivery and use for seamless path shifting.

The authors of [8] propose two dynamic congestion-based techniques to reduce loss of data in the network. The first is a congestion-based dynamic route selection technique using fixed alternate shortest path routes. The second is a least-congested dynamic route calculation technique with different weight functions. In both the techniques, the core nodes in the network gather the load information on their output links and send feedback to all the edge nodes, so as to enable the edge nodes to balance the load. The congestion information gathered at each core node is the offered load on a link.

The authors of [9] present an approximate integer linear optimization problem, as well as a simple integer relaxation heuristic to solve the problem for large networks.

B. General assumptions

Highly dynamic character of OBS networks, due to statistical multiplexing paradigm, produces inaccuracy effect in network state information. This involves network performance degradation (i.e. increase burst loss probability). Moreover, there is a need to deal with a big number of relatively small transmission units (bursts) in OBS networks. It makes the problem more close to the routing in IP network with the additional issue of the lack of optical memories causing that the switch has to use complex contention resolution algorithm in order to provide acceptable burst loss rates when burst contention occurs (a related problem is providing QoS guarantees).

In OBS networks the offset-time between burst control packet and corresponding data burst is calculated in the edge node on the basis of a sum of processing times in all consecutive nodes lying on the path the burst is transmitted on. In order to calculate optimal (minimal) value of the offset-time, the number of nodes the burst is going through should be known. Therefore, to meet this objective an introduction of a connection-oriented environment with constrained LSP paths to OBS network is reasonable.

Distributed routing [6] introduces the problem of inaccuracy in network state information. In fact, routing decisions performed by such algorithm is optimal as long as this information perfectly represents the actual network state, what is impossible to achieve in real network. Moreover, distributed routing involves additional signalization complexity so as to exchange the state information inside the network.

The isolated routing approach [6] which performs the path selection based only on local node/link state information minimize discussed above problems. However, its suboptimal nature since it only considers the congestion of the current node and its links may results in worse performance results. Therefore, the goal of the study is to investigate the capability of pure isolated adaptive routing algorithms to distribute the traffic and reduce data losses in connection-oriented OBS networks. We assume that such connection-oriented networks have a number of pre-established paths between all source-destination pairs of nodes. The selection of the path is performed for each burst individually according to one of routing strategies, which are presented in Section III-B.

III. Scenario

In general the OBS node consists of 4 principal parts: input interface, switching core, output interface and control unit [1] (Figure 2). The main part of the switching core is an optical switching matrix of the size $(N\times W)(N\times W)$ where N is a number of output/input ports and W is the number of wavelengths in case the WDM multiplexing is used. Moreover, the wavelength converters and optical buffers could be found in the switching core.

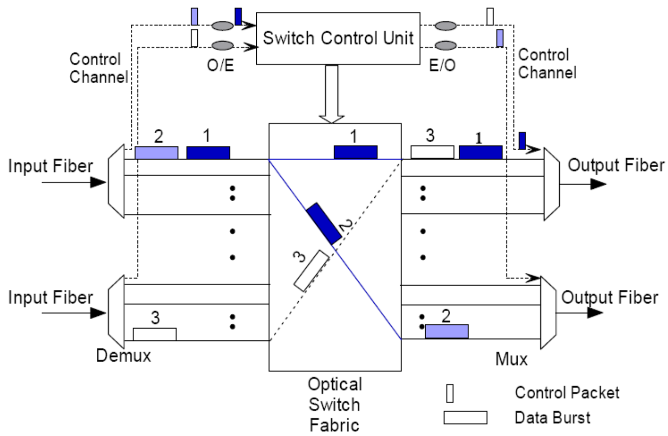

Figure 2. OBS node architecture.

As it was already mentioned, the control information (control packet) and the data (burst) are transmitted on separated wavelengths (Figure 1). Edge nodes are responsible for aggregation of the packets coming from legacy networks into burst units of different lengths. When a burst if ready to be transmitted the node generates a corresponding control packet and sends it towards the destination. After a defined period of time called an *offset-time*, the node transmits the burst. The control packet is responsible for signalization of the intermediate nodes of coming of its corresponding burst. This information is translated to the electrical domain in order to be processed by the control unit. It should be mentioned that the data burst unit still remains in the optical domain.

There are different proposals for the signalization protocol in OBS networks. In the paper we study one based on *Just-Enough-Time* (JET) approach [1]. In JET protocol the control packet carries among other things information about both offset-time and length of the corresponding burst. This information allows for resources reservation that starts from the burst arrival time to its departure. When the burst has been transmitted the resources are released.

A. Resources reservation

The process of resources reservation involves 3 distinct domains, namely the frequency, time and space domain. In case there is a contention of burst reservations in a node, the control unit tries to resolve it by using the mechanisms applied in each of domains:

- Wavelength conversion in frequency domain;
- Optical queuing with *Fibre Delay Lines* (FDLs) in time domain;
- Alternative/deflection routing in space domain. In this case the contending burst is switched to different output port than the default one but which still allows achieving desired destination in the network. The implementation issues of the algorithms for alternative routing are discussed in subsection III.B.

In case, none of these mechanism can resolve the contention the burst is dropped.

In the study, we implement 2 different algorithms for contention resolution in frequency and time domains, namely: 1) *MINLEN* that is a Horizon type and 2) *VF-MM* that is a Void-Filling type [4]. The Horizon algorithms base on the knowledge of the latest time at which the channel (wavelength) is currently scheduled to be in use. The MINLEN allocation algorithm looks for a free channel with a minimum queue, i.e. with the earliest possible allocation. The Void Filling scheduling algorithm can make a reservation of free resources even if they are located between two reservations already done. Basing on this approach the VF-MM algorithm tries to place a new reservation in a space of a minimum gap.

B. Isolated adaptive routing algorithms

In this work, three different routing algorithms have been implemented, namely: 1) Shortest Path (SP), 2) Multi-Path (MP) and 3) Bypass (BP). The SP algorithm is used here as a reference for the later two algorithms that according to the [6] could be classified as isolated adaptive routing algorithms.

SP assigns a route of the shortest distance between source and destination nodes for each burst. If more then one such path exists, the first computed is selected. In this case, only one route is available for a burst. Therefore, if there is a contention between burst reservations that can not be resolved in the frequency and time domains the burst is lost.

In MP algorithms there is a number of paths (e.g. *k* shortest paths) pre-established between each pair of source and destination nodes. The algorithm makes a routing decision for each individual burst selecting the shortest path available, i.e. the path that has free output channel available for resources reservation procedure. Therefore, the first route that is analyzed is the SP and in case the burst can not be transmitted on it the next one of a length equal or higher is checked. After path selection in source node the burst follows this path towards the destination node. If the congestion occurs inside the network the routing algorithm can reroute the burst to the other path under condition that this path is originated and terminated in the same pair of nodes as the burst source and destination nodes. In the evaluation study we consider that there are 4 paths available between each pair of source-destination nodes.

BP algorithm assumes that a burst can by-pass congested link by transmitting it through another node. In particular, if there are no resources available for burst transmission on specific output port, the burst is allowed to make one additional hop through other node with the objective to return to its default path in the next hop.

Regarding the isolated adaptive routing, the isolated term means that the routing decision is made on base of local node state information. Likewise, the adaptive routing term expresses capability to dynamic changes in route selection in order to perform the best decision. Both considered isolated adaptive routing takes into account availability of transmission resources for a given burst on its default output port. In case, there are not free resources the algorithm tries to reroute a burst on other path (if it is available) with other output port according to the routing strategy, by selecting either one of multiple paths in MP or bypassing congested link in BP.

IV. EVALUATION

The performance of routing algorithms is evaluated by event-driven simulator.

A. Simulation scenario

In the study we consider the NSFNet (Figure 3) network topology with 15 nodes and 23 links. We assume that the links are bi-directional and each link multiplexes 16 wavelengths at 10 Gbit/s. The nodes are enhanced in FDL buffers of size depending on the simulation scenario. For each contention resolution algorithm, the granularity of the FDL is equal to the value that provides the lower burst losses.

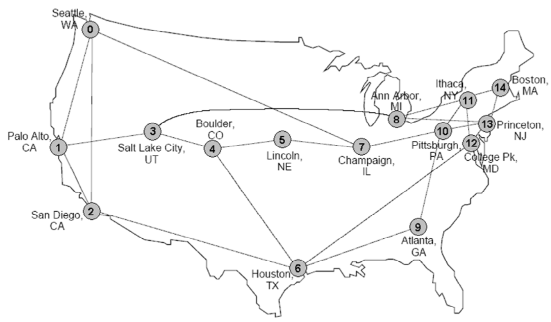

Figure 3. NSFNet network topology.

Regarding the traffic modeling, each node is an edge node capable to generating burst destined to any other nodes (uniform distribution); the interarrival time of the data bursts is exponential distributed with a mean that depends on the network load; the burst length is exponential distributed with average length of 40000 bytes. The number of simulated bursts is chosen big enough to reach steady-state results.

B. Results

In the following figures, we evaluate overall network Burst Loss Probability (BLP) as a function of both the network load (normalized to the network capacity) and buffer length. The simulation scenarios use different resources reservation and routing algorithms that were discussed in Section III.

Figure 4 presents BLP as a function of traffic load in the network. Each node has implemented an optical buffer of size $B = 4$ FDLs. From the figure we can see that for each of routing scenarios the void-filling resources reservation algorithm performs better then the horizon one, however at high traffic loads the gain is very low. Such behavior could result from high congestions that might appear in some parts of the network and which impact the overall network performance. In such case, doesn't matter which resources reservation algorithm is used since there is an excessive amount of bursts trying to access to specific link and due to the lack of transmission capacity they are lost. This gives a conclusion that neither the MP nor BP isolated routing protocols help in resolving the congestion. Moreover, we can observe that the performance results of both strategies are only slightly better that ones obtained for SP algorithm.

Figure 5 presents BLP as a function of FDL buffer size. The traffic load normalized to network capacity is equal to 0.8. We can observe that by introducing FDL buffers we help in contention problem. However, increasing the buffer capacity does not improve the performance significantly. The results obtained for both MP and BP are still slightly better then for SP algorithm.

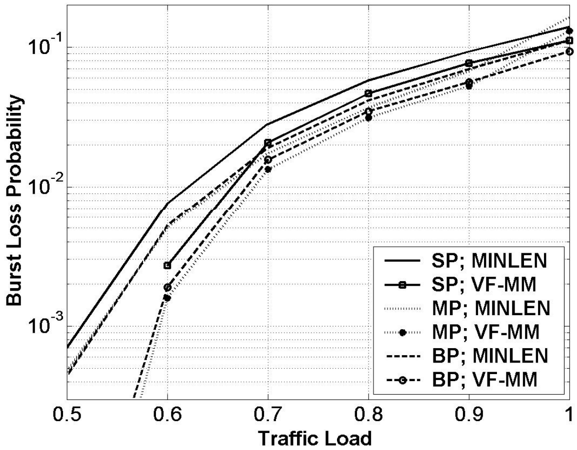

Figure 4. BLP as a function of traffic load

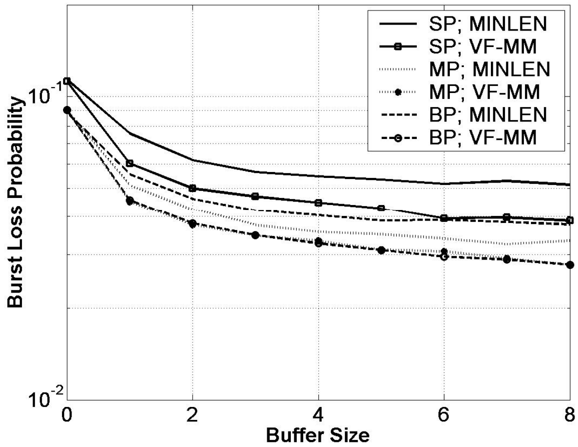

Figure 5. BLP as a function of FDL buffer size

V. CONCLUSION

In this paper we studied two isolated adaptive routing algorithms in connection-oriented OBS networks, the Multipath and the Bypass. These algorithms have been evaluated in the scenarios with different resources reservation strategies applied in nodes and based on the Horizon and the Void-Filling scheduling algorithms. The performance results show that isolated adaptive routing algorithms bring small gain at the medium traffic loads and almost none for the high traffic loads in comparison to the shortest path algorithm.

The main conclusion from the study is that isolated routing might not cope fine with the congestion in OBS network since it incorporates only the local node state information. Therefore, the routing algorithms for OBS networks may need more knowledge about the state of the network for their routing decision in order to distribute fine the traffic over the network.

The future work will concern routing protocols with some signalization function implemented in order to exchange node/link state information inside the network.

ACKNOWLEDGMENTS

The participation in summer school is funded by the NoE e-Photon ONe project (IST FP6-001933) and the MCYT (Spanish Ministry of Science and Technology) under contract FEDER-TIC2002-04334-C02-02.

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