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Challenges, Issues and Research directions in Optical Burst Switching

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Abstract: Optical Burst Switching architecture (OBS) is based on buffer-less WDM network that provides unbelievably huge bandwidth for communication. A brief review on OBS architecture along with its supporting protocols is studied here. This architecture suffers from various issues and these complications along with the future research directions are reviewed here.

Keywords: Optical Burst Switching, Contention resolution, AON, Routing and Wavelength Assignment, OBS research issues.

1. INTRODUCTION TO OBS

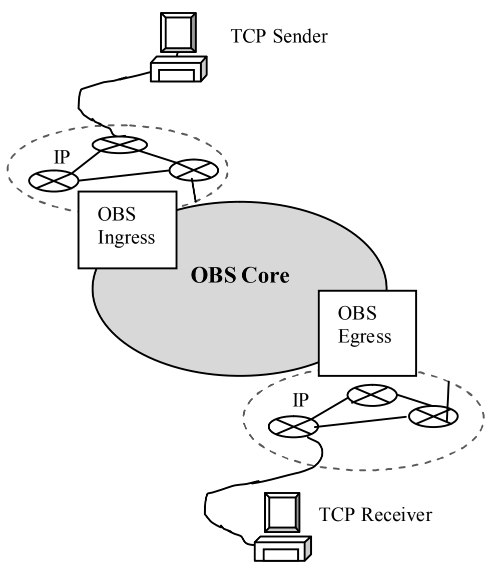

Figure 1. OBS Network Architecture

Optical Switching architecture has become the research focus [1], [2] in recent years due to the heavy demand in huge bandwidth and efficient network resource allocation. Three Optical switching architectures are available and they are Optical Circuit Switching (OCS), Optical Packet Switching (OPS) and Optical Burst Switching (OBS). Among these schemes, OBS [3] combines the merits of mature electronic process capability and the high-capacity optical transport capability. Multiple packets that belong to the same egress node are packed into a single Data Burst (DB) at the ingress nodes. Control information for this DB is sent ahead on separate wavelength and is called Burst Header Packet (BHP). BHPs are processed electronically at each intermediate core nodes to reserve network resources before the arrival of the DBs.

1.1 OBS Assembly

The Burst assembly happens at the input node ingress, where the packets belonging to the same destination are grouped into a single Burst in order to switch all-optically into the core nodes.

- Timer based Burst Assembly Mechanism.
- Burst Length (threshold) based Burst Assembly Mechanism.
- Hybrid/Mixed Burst Assembly Mechanism.
- Composite Burst Assembly Mechanism.
- Optimized/Adaptive Burst Assembly Mechanism.

An assembled burst is sent into the core at periodic/fixed time intervals while the Data Bursts are of variable lengths for Timer based Burst Assembly Mechanism [4]. On the contrary, the burst lengths are fixed and are generated at non-periodic/variable time intervals for Burst; length-threshold based Burst Assembly Mechanism [4]. In some special cases, packets of different classes but belonging to same bursts are combined. Here, these are placed from head of the burst to the tail of the bursts in order of decreasing classes and this is called as composite burst assembly algorithm [4]. In hybrid/mixed burst assembly mechanism, the bursts are assembled and sent either if the timer expires or the burst length is reached [5]. Dynamic adaptive threshold on burst length is set in order to optimize the overall performance in OBS for QoS sensitive traffic [5].

1.2 OBS Routing

Types of routing Strategies include

- Proactive/Static routing
- Dynamic congestion-based routing

The Proactive approach is based on adaptive use of multiple paths between edge nodes. In dynamic congestion based routing 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 and thus routing is done.

There are two subtypes in dynamic congestion-based routing:

- Fixed alternate shortest path dynamic congestion-based routing
- Least congested dynamic route calculation

The other routing strategies are [6]:

- Distributed routing
- Isolated routing approach

Distributed routing algorithm [7] introduces the problem of inaccuracy in network state information. The routing decisions performed by this algorithm are 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 [7] which performs the path selection based only on local node/link state information minimizes problems encountered in isolated routing algorithm. However, its suboptimal nature since it only considers the congestion of the current node and its links may result in worse performance results.

In [8], three different routing algorithms have been implemented, namely:

- Shortest Path (SP).
- Multi-Path (MP) and
- Bypass (BP).

The SP algorithm is used here as a reference for the later two algorithms 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 than 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 cannot be resolved in the frequency and time domains the burst is lost.

In MP algorithms number of paths are 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 cannot 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.

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.

1.3 Traffic Distribution in OBS

Traffic distribution in OBS can be done at the Burst Level (BL) by making a path selection for each newly incoming burst at ingress node according to a calculated distribution probability within a time period. It can also be made at the Flow Level (FL) by making a path selection for each newly incoming flow at ingress node according to a calculated distribution probability within a time period and all bursts within a particular flow will follow the same path. Balance the traffic load by shifting incoming bursts along the primary and secondary paths. Probe the sent packets periodically and sent through the least congested path. Always aim to minimize Burst loss and average transfer delay [8].

- Equal Proportion Multipath Routing (EPMR).
- Hop Length Multipath Routing (HLMR).
- Adaptive Alternative Routing Algorithm (AARA).
- Gradient Projection Multipath Routing (GPMR).

GPMR-BL (Burst level) outperforms all. Burst Loss for GPMR-BL is 20% less than AARA-BL for low traffic loads and also improves with medium/ high loads. GPMR-BL converges quickly (with sudden traffic increase). Burst level probability first decreases and then increases as measurement time window increases. For small Window size, GPMR-BL cannot work with inaccurate traffic information. For large Window size, GPMR cannot adapt to changing traffic load in networks [15].

1.4 Scheduling in OBS

- Horizon Scheduling.
- Latest Available Unused Channel with Void Filling (LAUC-VF).
- Minimum Starting Void (MSV).
- Constant Time Burst Resequencing (CTBR)

The latest time at which a channel is currently scheduled to use is called as a "horizon". In the horizon scheduling algorithm, the horizon scheduler selects the channel with latest horizon from the set of channels whose horizons are less than burst arrival times. LAUC-VF keeps track of all voids in a channel and schedule bursts in one of the voids. If more than one void can fit a burst then the one with latest beginning time is assigned.MSV uses a geometric approach (binary search tree) that minimizes the distance between the starting time of the void and starting time of the burst. CTBR is the "Optimum Wavelength Scheduler". Instead to process burst as soon as the BHP arrive, we delay scheduling of the bursts and process in order of expected Burst arrival time. BHP is processed not in its arrival times but at the arrival times of Data bursts. The link utilization of LAUC-VF is higher than horizon scheduling but gets slower with huge number of voids.

Table 1. Time Complexity for Scheduling Algorithms

Complexity	Scheduling Algorithm
O (log h)	Horizon Scheduling
O (log m)	Latest available unused channel - Void filling
O (log m)	Minimum Starting Void
O (1)	Constant Time Burst Resequencing

1.5 Signaling in OBS

The wavelength reservation algorithm for OBS network was adopted from "ATM Block Transfer (ABT)". There are two versions of ABT and they are [7].ABT with immediate reservation and ABT with delayed reservation. In the former, the wavelength is immediately reserved and Data Bursts are sent on receiving Burst Header. If wavelength cannot be reserved then the DB is dropped. In the latter, the header and

Bursts are separated by a period called "Offset Time (OT)".Based on the above two versions of ABT, there are three Burst Reservation schemes in OBS

- Tell And Go (TAG) protocol.
- Just in Time (JIT) protocol.
- Just Enough Time (JET) protocol.
- Horizon.

TAG does immediate reservation with Zero/ minimum offset. DB is delayed by FDL while CP is processed. Negative Acknowledgement (NACK) is sent if DB is dropped.JIT does immediate reservation with Zero/ minimum offset. DBs and CPs are separated by time slot. In-band Terminator (IBT) at the end of each DBs to release wavelength.JET does delayed reservation. CPs and DBs are separated by an "Offset Time (OT)". OT corresponds to the number of hops between source and destination. Delayed reservation is required for OBS networks, because the travelling speed of the DB is usually slower than that of the CP. It is because the DB can cut through the switches without buffering/processing delay unlike the CP which has that. So, this reservation would deny the catching up of the DB with its CP. Horizon [12] based on the knowledge of the latest time at which the channel is currently scheduled to be in use.

1.6 Contention Resolution in OBS

"Contention" occurs in OBS if two or more incoming bursts contend for the same output wavelength at the same link [11]. This contention is to be resolved and is done by

- Optical Buffering.
- Wavelength Conversion.
- Burst Deflection Routing (Alternate Routing).
- Burst Segmentation.
- Burst re-transmission.
- Burst TCP (BTCP) [12].

If a contention occurs at any OBS core node without any of the above contention schemes or if the degree of contention is so high and it is not able to tackle the contentions then the network would opt for a policy called "Dropping Policy (DP)". There is an extension of the DP with retransmission [13], where we may retransmit and drop DBs that have experienced fewer retransmissions. Buffering in OBS is done in time domain by the use of the Fiber Delay Lines that limit the amount of time a burst could reside unlike electronic buffers, where a packet can stay in the buffer for an undefined time. Electronic buffers are present at the electronic edge nodes. Optical technology is immature and buffers are not invented for optical core nodes. It is impossible to delay the burst for infinite period of time using Fiber Delay Lines (FDLs). It is done in "Space domain". Wavelength Conversion is the capability of the optical network to convert an input wavelength to a desired output wavelength. It is done in spectral/Wavelength domain. It is immature, costly and produces linear effects such as noise.

Break the assembled data-burst into a number of segments and the process is called "Segmentation" [14]. "Segments" are basic transport units [8] and are electronic transport units invisible in optical domain [15]. There are two segmentation policies and they are: Head dropping policy and tail dropping policy. In the former, the head of the contending burst is dropped. In the latter, the tail of the contending burst is dropped. In [11], 'The modified-tail dropping policy' was proposed, where the tail of the contending burst is dropped only if the number of segments in the tail is less than the total number of segments in the contending burst . On the other case, the entire contending burst is dropped. This reduces the probability of a short burst preempting a longer burst and minimizes the number of packets lost during contention. Deflection Routing is done in a "Space domain". If there is a contention at the preferred link then the burst is forwarded at any available output. This is also called as "Hot Potato Routing" [11]. In [8], two different algorithms for contention resolution are described in frequency and time domains, namely

- *MINLEN* that is a Horizon type and
- *VF-MM* that is a Void-Filling type.

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.

2. OBS CHALLENGES

2.1 Burst Segmentation in Practical System

Challenges when implementing burst segmentation in practical systems were:

- **Switching time:** Since the system does not implement buffering or any other delay mechanism, the switching time is the number of packets lost during reconfiguring the switch due to contention. Hence, a slower switching time results in higher packet loss. While deciding which burst to segment, we consider the remaining length of the original burst, taking the switching time into account. By including switching time in burst length comparisons, we can achieve the optimal output burst lengths for a given switching time.

- **Segment boundary detection:** In the optical network, segment boundaries of the burst are transparent to the intermediate nodes that switch the burst segments all-optically. At the network edge nodes, the burst is received and processed electronically. Since the burst is made up of many segments, the receiving node must be able to detect the start of each segment and identify whether or not the segment is intact. If each segment consists of an Ethernet frame, detection and synchronization can be performed using the preamble field in the Ethernet frame header, while errors and incomplete frames can be detected by using the CRC field in the Ethernet frame.

- **Trailer creation:** The trailer has to be created electronically at the switch where the contention is being resolved. The time to create the trailer can be included in the header processing time, at each node.

2.2 Challenges in Contention Resolution Strategies

- A burst can reside in an optical buffer only for a specified amount of time unlike electronic buffers.
- Wavelength conversion produces linear effects like 'noise' and it is costly.
- In tail dropping segmentation scheme, the header contains the total burst length even if the tail is dropped

[15], and thus downstream nodes are unaware of truncation. This is called "*Shadow Contention*".

- In head dropping segmentation scheme, there will be more out-of-order delivery [15] in contrast to the tail dropping policy where the sequence is maintained.
- Long bursts passing through different switches experience contention at many switches [15].
- Bursts of bigger lengths cannot be stored at the "Fiber Delay Lines" [7].
- Burst deflection routing dynamically deflects the Bursts in an alternate path due to contention in the primary path and is usually longer than the primary path. Thus it increases the propagation delay [5].
- The deflected bursts might also loop multiple times wasting network bandwidth [14].

2.3 TCP over OBS Challenges

It is quite normal to employ OBS as core architecture under TCP as it constitutes almost 90% of the current internet traffic and thus when an optical core network, i.e.., Optical Burst Switching is considered there would be number of challenges namely:

- OBS experiences Bandwidth Delay Product (BDP) , thus suffers from speed mismatch with TCP. Even if the TCP Scaling option is employed to reach congestion window to 4MB from 64KB longer time would be consumed.
- The Delayed ACK must be used in TCP over OBS as in reality all TCP segments cannot be included in a single burst which causes further delay. .
- High Speed TCP (HSTCP) was proposed for high BDP networks that offers bad throughput for Burst losses.

3. OBS ISSUES

In [13], a TCP over OBS network is considered. The throughput of various implementations of TCP namely TCP Tahoe, Reno and New Reno are done. An experimental study represented results of throughput of TCP source variants, Tahoe, Reno and New Reno. The network parameters such as, bandwidth, packet size, congestion window size and queue-limit were considered for this experiment. The vital issue in this paper is TCP variants like TCP Vegas, TCP SACK, and TCP FACK etc.., were not considered. Most cases consider TCP Westwood over OBS networks.

In [17], a performance evaluation of an OBS router was done. It was said that OBS with LPI can reduce energy consumption up to 60% at low loads. A desired scheduler buffer size to minimize the overall packet blocking probability of OBS was considered in [18]. A novel label Switched path design for Generalized MPLS over OBS was modeled in [19].

The Control plane in IP and optical domains are usually separated. But in [20], a "unified control plane" is made for end-end service provision. Another contention resolution technique by proposing new CRT based on control packet buffering was done in [21]. Mathematical model also been proved to analyze the performance of OBS network core node with JIT, buffering is done on electronic node. The Control Packet that fails reserving required amount of resource were not dropped immediately, rather electronically buffered for some threshold time, the time is decided at ingress node depend on each burst duration. Offset time must be increased so that to avoid the burst to reach the core node are still not ready. New quality theory impatience concept was mathematically driven .JIT is used; slight modification is done at MAC layer performance enhancing technique.

LPI was proposed by IEEE 802.3az task Force to reduce energy consumption in network devices. In [22] a Wake Transition Decision algorithm was proposed to maximize sleep time thus improving performance. A hybrid Wavelength Division Multiplexing and Optical Code Division Multiplexing (WDM/OCDM) scheme is used to mitigate the blocking probability of OBS networks in [23]. Fiber Delay Lines are Optical buffers that can tap/delay an optical data for a finite amount of time and they are costly. An aim to minimize this issue, OBS Tune and Select (TAS) node architecture was proposed in [24], where a dedicated input/output port of the switch is assigned to an FDL shared between the output ports in a feedback configuration (TAS-shFDL).

In [25], several alternative TCP protocols were reviewed and their performance in terms of throughput and fairness were compared to select the most suitable TCP protocol for end-to-end Grid data transmission all the proposed methodologies are demonstrated and evaluated on an actual OBS/WSON testbed with both control and data planes, allowing the verification of their feasibility and effectiveness, and obtaining valuable insights for deploying the proposed solutions into real consumer Grid networks. However, even though state-of-the-art techniques are being considered, there are three major limitations namely Limitation of network infrastructures, limitation of resource discovery and management Schemes an limitation of end-to-end transmission control protocols (TCP) that prevent the wide deployment of the consumer Grid. In order to address these above 3 issues, an integrated OBS/wavelength switched optical network (WSON) was proposed with the assistance of a self-organized resource discovery and management scheme to support consumer Grid applications. These proposed solutions are experimentally demonstrated and evaluated on an actual OBS/WSON testbed. An experimental demonstration and evaluation of dynamic provisioning of consumer Grid services by using the integrated OBS/WSON as a network infrastructure, SRDM for resource discovery and management, and High-speed TCP were done.

4. OBS RESEARCH DIRECTIONS

OBS has attracted lot of researchers due to its ability to achieve dynamic and on-demand bandwidth allocation that offers improved network economics and enables control and management integration. Optical Burst Switching is currently one of the biggest research topics under study and the research issues in it can be broadly classified into two namely: Security issues in OBS and QoS issues in OBS. The QoS issues were discussed in (SECTION 3) and can be sub-categorized based on two kinds of blocking either QoS issues due to contention or QoS issues due to Bit Error Rates.

At the industrial level, commercial products were very rarely made based on OBS and the only company that offers this product is "Matisse networks" as the technology is still immature [10]. To model or design an OBS node, there is a requirement of test beds or simulators. Few of the OBS simulations were implemented on test beds. These OBS network test-beds would not be imported to most Asian countries like India, Sri Lanka, and Pakistan etc. So, these researchers are forced to a single option namely, implementing on a simulator. On the other hand, simulators that are available for Optical Burst Switching do not cater the entire requirements that are needed to simulate the entirety of a particular OBS protocol. The survey of various simulators was done in [26], [27], and [28]. It was inferred that simulators like NCTUns could satisfy all the specs for simulation but are not freely available. Some others like JAVOBS, DESMO-J, OBSIM etc use Java as its building programming language, thus much time is consumed for the temporary compilation of user code to byte code. This code does not become executable code until the program is actually run.

5. CONCLUSION

Optical Burst Switching is an efficient architecture to utilize the enormous bandwidth provided by the optical fiber and cater communication at the network cores with minimal Burst losses. OBS suffers from a phenomenon called as contention as it cuts-through switches unlike other architectures where the data is stored and forwarded. Various contention resolution mechanisms available were thus discussed highlighting their merits. Challenges thus faced when these resolution policies are used are also discussed and hence concluded that every contention policy carries one issue or another. Finally, it was discussed that research directions on OBS can be reviewed either based on QoS constraints or security constraints.

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