ISSN No. 0976-5697

Volume 4, No. 6, May 2013 (Special Issue)

International Journal of Advanced Research in Computer Science

REVIEW ARTICAL

Available Online at www.ijarcs.info

Optical Burst Switching

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Abstract: Optical burst switching is a promising solution for all-optical WDM networks. It combines the benefits of optical packet switching and wavelength routing while taking into account the limitations of the current all-optical technology. In OBS, the user data is collected at the edge of the network, sorted based on a destination address, and grouped into variable sized bursts. Prior to transmitting a burst, a control packet is created and immediately sent toward the destination in order to set up a buffer less optical path for its corresponding burst. After an offset delay time, the data burst itself is transmitted without waiting for positive acknowledgment from the destination node. The OBS framework has been widely studied in the past few years because it achieves high traffic throughput and high resource utilization. However, despite the OBS trademarks such as dynamic connection setup or strong separation between data and control, there are many differences in the published OBS architectures. In this article we summarize in a systematic way the main OBS design parameters and the solutions that have been proposed in the open literature.

I. INTRODUCTION

The benefits of optical communication systems have been known for quite awhile, but it was not until the invention of wavelength-division multiplexing (WDM) that the potential of fiber was fully realized. The evolution of WDM optical networks can be classified. Current WDM networks operate over point-to-point links, where optical-to-electrical-tooptical (OEO) conversion is required at each step. All future WDM designs, however, are focused on all-optical networks (AONs) where the user data travels entirely in the optical domain. The elimination of OEO conversion in AONs allows for unprecedented transmission rates. AONs can further be categorized as wavelength-routed networks (WRNs), optical burst switched networks (OBSNs), or optical packet switched networks (OPSNs). *Also*, each step of the optical evolution begins with a simpler ring design before moving on to the more general mesh topologies. In the following paragraphs we briefly outline the pros and cons of future all-optical architectures. The AON evolution begins with WRNs, whose operation consists of setting up circuit connections, called lightpaths, between the network nodes.

The main constraint of WRNs, typical of all optical communications, is the limited number of wavelengths per fiber. In a larger WRN, for example, this scarce number of wavelengths makes it impossible to create a full mesh of lightpaths between all end users. Consequently, for each WRN topology, network architects have to solve the NP-hard problem of routing and wavelength allocation (RWA) of the lightpaths in order to optimally satisfy the desired user communication. The other challenge of WRNs is their quasi-static nature, which prevents them from efficiently supporting constantly changing user traffic. The proposed signaling protocol for WRNs is generalized multiprotocol label switching (GMPLS). In OPSNs, user traffic is carried in optical packets along with in-band control information. The control info is extracted and processed in the electrical domain at each node. This is a desirable architecture because it is a well known fact that electronic packet switched networks are characterized by high throughput and easy adaptation to congestion or failure. The problem with OPSNs, however, is the lack of practical optical buffer technology. In optical burst switching (OBS), data **is** transported in various-size units, called *bursts* [Z]. Due to the great variability in the duration of bursts, the OBS network can be viewed as lying between OPSNs and WRNs.

That is, when all burst durations are very short, equal to the duration of an optical packet, the OBSN can be seen as resembling an OPSN. On the other hand, when all burst durations are extremely long (they may last several months), the OBSN can be seen as resembling a WRN. In OBS, there **is** a strong separation between the control and data planes, which allows for great network manageability and flexibility. In addition, its dynamic nature leads to high network adaptability and scalability, which makes it quite suitable for transmission of bursty traffic. In general, the OBS network consists of interconnected core nodes that transport data from various edge users. The users consist of an electronic router and an OBS interface, while the core OBS nodes require an optical switching matrix, a switch control unit, and routing and signaling processor. OBS has received considerable attention in the past few years, and various solutions have been proposed and analyzed in an attempt to improve its performance. The following sections describe the various OBS architectures by grouping the material logically per OBS design parameter. First, we explain the functions executed by the edge OBS users and then we describe the operation of the OBS core nodes inside the network. Next, we discuss the addition of quality of service (QoS) and multicast capability to an OBS network.

II. BURST AGGREGATION

One of the main functions of an OBS user is to collect upper layer traffic, sort it based on destination addresses, and aggregate it into variable-size bursts. 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 use bit-padding if there is not enough data to assemble a minimum size burst. Another possible functionality of the burst assembly process is the differentiation of classes of traffic. The burst assembly algorithm can create classes of service (COS) by varying the preset timers and maximum/minimum burst sizes. An interesting benefit of burst aggregation is the fact that it shapes the traffic by reducing the degree of self-similarity, making it less bursty in comparison to the flow of the original higher-layer packets. Traffic is considered bursty if busy periods with a large number of arrivals are followed by long idle periods. The term self-similar traffic refers to an arrival process that exhibits burstiness when viewed at varying timescales:

Milliseconds, seconds, minutes, hours, even days and weeks. Self-similar traffic is characterized by longer queuing delays than random (Poisson) traffic and higher packet losses, and therefore degrades network performance. Therefore, reducing self-similarity is a desirable feature of the burst assembly process. Simulated a burst assembly process and concluded that traffic is less self-similar after the assembly.

III. CONNECTIONS MECHANISM

OBS users are also responsible for setting up the connections for each burst. This procedure consists of three main components: signaling, routing, and wavelength allocation. Signaling is used to set up and tear down the connections for the bursts. Routing is used to decide the path of a burst through the OBS network. Wavelength allocation is used to determine on which particular wavelength to transmit the burst.

Signding for OBS - Signaling is an important aspect of an OBS architecture. It specifies the protocol by which the OBS nodes communicate connection requests to the network, and itsoperation determines whether or not the resources are utilized efficiently. Distributed Signaling With One-way Reservation - Most of the proposed OBS architectures utilize a one-way signaling procedure (Fig. 3a) to set up a burst transmission path through the network. Prior to transmitting a burst, a user transmits a control packet to its ingress OBS node. This control packet contains information about the corresponding burst, and is electronically processed by the ingress OBS node and all the subsequent nodes along the path to the destination user. The control packet is transmitted in an out-of-band control channel, which may be a wavelength dedicated to signaling or a separate electronic control network, such as an IP or asynchronous transfer mode (ATM) network. In either case, the separation of control and data, in both time and physical space, is one of the main advantages of OBS. It facilitates efficient electronic control while allowing for great flexibility in the user data format and rate because the bursts are transmitted entirely over an optical signal and remain transparent throughout the OBS network.

The burst itself is transmitted after a delay, known as the offset, without waiting for a positive acknowledgment (ACK) that the entire path has been successfully established. Intuitively, the one-way reservation scheme is appropriate because OBS will most likely be implemented in long-haul networks, and therefore it will significantly decrease the time needed for connection establishment analyzed the setup latency of a one-way reservation OBS signaling protocol called Just-In-Time (JIT) and compared it to circuit switching.

They concluded that the one-way signaling scheme has a much shorter setup time and better throughput performance. Due to the one-way reservation scheme, burst loss may occur in an OBSN because the control packets may not succeed in reserving resources at some of the intermediate OBS core nodes. In addition, burst loss is possible if the control channel itself suffers from congestion or other failure. Because of these reasons, the burst loss probability is an important performance measure of an OBS architecture. Despite the fact that burst loss is possible in OBS, the proposed architectures do not implement retransmission of lost bursts. One reason is the high data rate, which makes it unmanageable to keep copies of all previously transmitted bursts at the OBS edge nodes. Therefore, retransmission of lost bursts in an OBS network is left as a responsibility of the higher-layer protocols.

It is also possible that an application may tolerate burst loss, in which case there is no need for retransmissions.

Centralized Signaling with End-To-End Reservation - Contrary to the more common one-way OBS signaling protocols, Dueser.

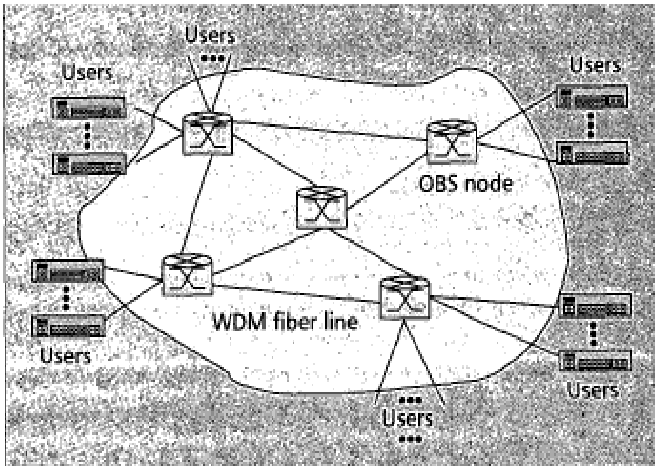

Figure 1. The OBS network architecture.

Bayvel [6] propose a centralized connection signaling method, termed wavelength-routed optical burst switching (WR-OBS), which utilizes an end-to-end resource reservation procedure. In this design there is a centralized request server, responsible for resource scheduling of the entire OBS network.When an OBS ingress node receives a setup request from a user, it sends a control packet to the centralized scheduler, where it is queued up based on the destination address. This centralized server has global knowledge of the state of the OBS switches and wavelength availability along all the fiber links. The responsibility of this central server includes processing incoming control packets, determination of routes to the required destinations, and assignment of available wavelengths along each link. The central server processes the control packet and sends a positive ACK to the OBS user, upon receipt of which the node transmits the burst.

IV. ROUTING

The routing of a burst through an OBS network can be done on a hop-by-hop basis, as in an IP network, using a fast table lookup algorithm to determine the next hop. Another approach is to use multiprotocol label switching (MPLS). The MPLS idea is to assign control packets to forward equivalent classes (FECs) at the OBS users in order to reduce the intermediate routing time to the time it takes to swap the labels. A third approach is to use explicitly precalculated setup conqections, which can be established via Constraint-Based Route Label Distribution Protocol (CR-LDP) or Resource Reservation Protocol with Traffic Engineering (RSVP-TE). Explicit routing is very useful in a constraint-based routed OBS network, where the traffic routes have to meet certain QoS metrics such as delay, hop count, bit error rate (BER), or bandwidth. In addition, in order to deal with node or link failures, OBS routing should also be augmented with fast protection and restoration schemes. Unfortunately, this is a weak point for explicit routing schemes because sometimes the routing tables can become outdated due to the long propagation time until a failure message reaches all of the OBS nodes. OBS protection and restoration schemes require further study.

V. RELATED WORK

There are several OBS protocols such as IBT,TAG [8,9], and RFD-based protocol JET [10] available in the literature. These protocols could handle data bursts as short as a few kilobytes to several megabytes efficiently. Specifically, IBT and TAG are suitable for distributed control based on ‘‘open-ended’’ resource reservation. Open-ended resource reservation refers to reservation without the knowledge of the end time of reservation. The resources are reserved until the _release_ control signal is received. The major drawback of the open-ended protocol is that if the release control signal is lost, the wavelength reserved on a link will not be released even after the entire data burst has been transmitted. This results in bandwidth wastage. On the other hand, JET with its ‘‘closedended’’ bandwidth reservation, as described in [10], is an attractive one because of its efficiency in utilizing bandwidth and FDLs with the use of two features, namely offset time and delayed reservation (DR). With the feature of closed-ended reservation (end of reservation is known), resources are open for reservation by other requests after the end time of current reservation and it also provides ensured end-to-end delay, which is the building block for providing QoS. Besides that, JET as a one way reservation protocol (need not wait for acknowledgment and knowing the end time for reservation) has the control packet sent to set up the connection including reservation of bandwidth and configuration of the switches along the chosen route before the burst is sent out. With offset time introduced between the control packet and data burst, the data burst is allowed to be sent without having a dedicated wavelength path a priori, and the tight coupling between the two in terms of space (separate control channel and data channel) and time (non zero offset time) is resolved [10].

It will also alleviate the problems of needing a large buffer space to optically buffer the data burst at intermediate routers when the path is not available for transmission or when switching fixed-length packets synchronously is needed as in optical packet switching. At present, optical buffering is achieved by using FDLs which is a scarce resource in optical networks. Optical burst switching which allows statistical multiplexing of data bursts where wavelengths are assigned only while bursts are being sent, provides better utilization of bandwidth and also FDLs. The offset time plays a key role in OBS and is determined before the burst is sent. For a pair of source and destination nodes H hops apart, a base offset time of D _ H is used, where D refers to the processing time for each node, which is the time to process the control packet, reserve the appropriate bandwidth and set up the switch. The value of the time gap or offset decreases as the control packet moves towards the destination node and it remains positive until it reaches the destination node. This ensures that the processing of a control packet has been completed at a node by the time its data burst arrives at the node. Service differentiation can also be ensured between different classes of traffic by using different initial offset time values. In a multiclass environment, a higher offset time is assigned to the traffic belonging to a high priority class when compared to those belonging to a low priority class. With the increased offset time, a control packet makes wavelength reservation well in advance for its data burst and the burst dropping probability for the high priority burst is therefore reduced.

VI. SCHEDULING OF RESOURCES: RESERVATION AND RELEAS

Upon receipt of the control packets sent from the OBS users, the OBS nodes schedule their resources based on the included information. The proposed OBS architectures differ in their resource (wavelength) reservation and release schemes. classified these schemes based on the amount of time a burst occupies a path inside the switching fabric of an OBS node. In explicit setup, a wavelength is reserved, and the optical cross connect is configured immediately upon processing of the control packet. In estimated setup, the OBS node delays reservation and configuration until the actual burst arrives. The allocated resources can be released after the burst has come through using either explicit release or estimated release. In explicit release, the source sends an explicit trailing control packet to signify the end of a burst transmission.

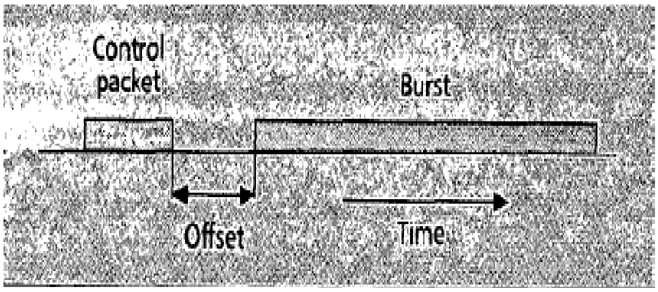

Figure 2. An OBS time diagram.

Estimated release, an OBS node knows exactly the end of the burst transmission from the burst length, and therefore can calculate when to release the occupied resources. Based on this classification, the following four possibilities exist: explicit setup/explicit release, explicit setup/estimated release, estimated setup/explicit release, and estimated setup/estimated release. Each of these schemes has advantages and disadvantages.

For example, when estimated release is implemented the OBS node knows the exact length of the burst, and thus can release the resources immediately upon burst departure. This results in shorter occupation periods and thus higher network throughput than explicit release. The difficulty, however, is that the estimated schemes are quite complicated, and their performance greatly depends on whether the offset estimates are correct. On the contrary, the explicit setup/explicit release scheme is easier to implement but occupies the-switching fabrics for longer periods than the actual burst transmission, and therefore may result in high burst loss probability.

The burst assembly strategy, implemented at the OBS users, also dictates how resources are reserved and released in the OBS network. For example, if the length of the burst is known prior to sending its control packet, the estimated release scheme could be implemented. However, if the control packet is sent before the burst is completely assembled, the OBS nodes have to utilize explicit release. In the Jumpstart project, which defines the OBS signaling protocol for the JIT architecture, considered only the explicit setup/explicit release and explicit setup/estimated release schemes. The other two schemes were disregarded because of their necessity for a scheduler at each node. The Jumpstart signaling protocol, however, is designed to be implemented mostly in hardware and does not use a scheduler. In the JET architecture, utilize the estimated setup/estimated release scheme, where the occupation of the resources is exactly from the burst arrival until the transmission of its last bit. They term this scheme delayed reservation. In their analytical and simulation studies, they confirm the beneficial effects of delayed reservation on the burst loss probability in an OBS network. Intuitively, these results are expected because of JET'S efficient resource occupation scheme. Another OBS resource scheduling scheme.

This scheme can be classified as explicit setup/estimated release. In Horizon, the control packets contain both the offset time and burst length; therefore, the scheduler can maintain a deadline (horizon*)* when each resource will be freed and available for future scheduling. This scheme is categorized as explicit setup because as soon as the control packet arrives at an OBS core node, a wavelength is immediately scheduled for the future burst arrival. In other words, upon processing the control packet, this algorithm schedules the resource with the closest horizon to the time when the corresponding burst would arrive. The Horizon scheme is practical and simple, and its resource management minimizes the wasteful gap between reservation time and the actual burst arrival. *An* extension of the Horizon scheme, latest available unused channel with void filling (LAUC-VF)**.**unscheduled resources, which are available just before the arrival time of an oncoming burst. In other words, even if are source is scheduled it is still considered available because it may be possible to fit a short burst into a time gap before the arrival of a future scheduled burst. Recently also proposed several algorithms, based on techniques from computational geometry, for scheduling bursts in the JET architecture. In fact, the simulation of one of their algorithms called Min-Sv showed that it can schedule bursts as fast as Horizon but achieves burst loss as low as LAUC-VF.

VII. FUTURE WORK

In this paper we survey the OBS technology; a rapidly growing solution for all-optical WDM networks. We describe the various OBS design characteristics such as connection establishment mechanisms, offset time, scheduling of resources, aggregation and loss of bursts, implementation of classes of traffic, and addition of multicast capability. In addition, we presented the ideas of deflection routing, partial burst dropping, and fiber delay lines because of their potential to lower the burst loss probability in an OBS network. With respect to the current state of the technology, OBS combines the best features of both circuit switching and packet switching.

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