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Optical Burst Switch as a New Switching Paradigm for High-Speed Internet

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INTRODUCTION

The concept of burst switching was initially proposed in the context of voice communications by Haselton (1983) and Amstutz (1983, 1989) in the early 1980s. More recently, in the late 1990s, optical burst switching (OBS) has been proposed as a new switching paradigm for the so-called optical Internet, in order to overcome the technical limitations of optical packet switching, namely the lack of optical random access memory (optical RAM) and to the problems with synchronization (Baldine, Rouskas, Perros, & Stevenson, 2002; Chen, Qiao, & Yu, 2004; Qiao & Yoo, 1999; Turner, 1999; Yoo & Qiao, 1997; Xu, Perros, & Rouskas, 2001). OBS is a technical compromise between wavelength routing and optical packet switching, since it does not require optical buffering or packet-level processing as in optical packet switching, and it is more efficient than circuit switching if the traffic volume does not require a full wavelength channel. According to Dolzer, Gauger, Späth, and Bodamer (2001), OBS has the following characteristics:

- **Granularity**—the transmission unit size (burst) of OBS is between the optical circuit switching and optical packet switching;
- **Separation between control and data**—control information (header) and data are transmitted on a different wavelengths (or channels) with some time interval;
- **Allocation of resources**—resources are allocated using mainly one-way reservation schemes. A source node does not need to wait for the acknowledge message from destination node to start transmitting the burst;
- **Variable burst length**—the burst size is variable;
- **No optical buffering**—burst switching does not require optical buffering at the intermediate nodes (without any delay).

In OBS networks, IP packets (datagrams) are assembled into very large size packets called data bursts. These bursts are transmitted after a burst header packet (also called by setup message or control packet), with a delay of some offset time in a given data channel. The burst offset is the interval of time, at the source node, between the processing of the first bit of the setup message and the transmission of the first bit of the data burst. Each control packet contains routing and scheduling information and is processed in core routers at the electronic level, before the arrival of the corresponding data burst (Baldine et al., 2002; Qiao & Yoo, 1999; Verma, Chaskar, & Ravikanth, 2000; White, Zukerman, & Vu, 2002). The transmission of control packets forms a control network that controls the routing of data bursts in the optical network (Xiong, Vandenhoute, & Cankaya, 2000). Details about OBS network architecture are given in the next section.

OBS NETWORK ARCHITECTURE

An OBS network is an all-optical network where core nodes, composed by optical cross connects (OXC), plus signaling engines, transport data from/to edge nodes (IP routers), being the nodes interconnected by bidirectional links, as shown in Figure 1. This figure also shows an example of an OBS connection, where input packets come from the source edge node A to the destination edge node B. The source edge node is referred to as the ingress node, and the destination edge node is referred to as the egress node. The ingress node of the network collects the upper layer traffic, sorts and schedules it into electronic input buffers based on each class of packets and destination address. These packets are aggregated into bursts and are stored in the output buffer, where electronic RAM is cheap and abundant (Chen et al., 2004). After the burst assembly process, the control packet is created and immediately sent towards the destination to set-up a connection for its corresponding burst. After the offset time, bursts are all-optically transmitted over OBS core nodes without any storage at the intermediate nodes within the core, until the egress node. At the egress node, after the reception of a burst, the burst is disassembly into IP packets and provides these IP packets to the upper layer. These IP packets are forwarded electronically to destination users (Kan, Balt, Michel, & Verchere, 2002; Vokkarane, Haridoss, & Jue, 2002; Vokkarane & Jue, 2003).

Recently, a new multilayered architecture for supporting optical burst switching (OBS) in an optical core network was defined by Farahmand, Vokkarane, Jue, Rodrigues, and Freire (in press). This article discusses the layered architecture of IP-over-OBS, describing each layer of the OBS layered architecture, separating them into a data plane and a control plane.

OBS EDGE NODES

The OBS edge node works like an interface between the common IP router and the OBS backbone (Kan et al., 2002; Xu, Perros, & Rouskas, 2003). An OBS edge node needs to perform the following operations:

- Assemblies IP packets into data bursts based on some assembly policy;
- Generates and schedules the control packet for each burst;
- Converts the traffic destined to the OBS network from the electronic domain to the optical domain and multiplexes it into thewavelength domain;
- Demultiplexes the incoming wavelength channels and performes optical-to-electronic conversion of the incoming traffic;
- Disassembles and forwards IP packets to client IP routers.

The architecture of the edge node includes three modules (Vokkarane & Jue, 2003): routing module,

Figure 1. Schematic representation of an IP over OBS network

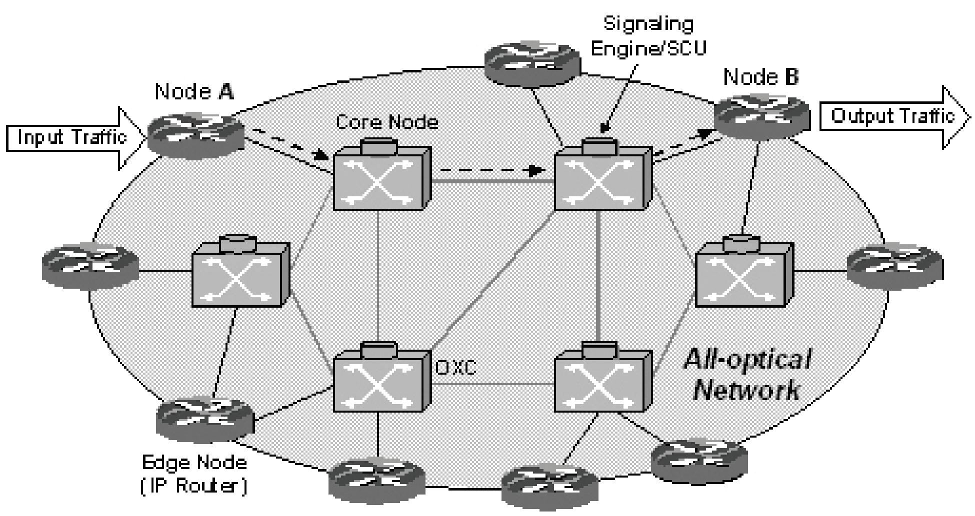
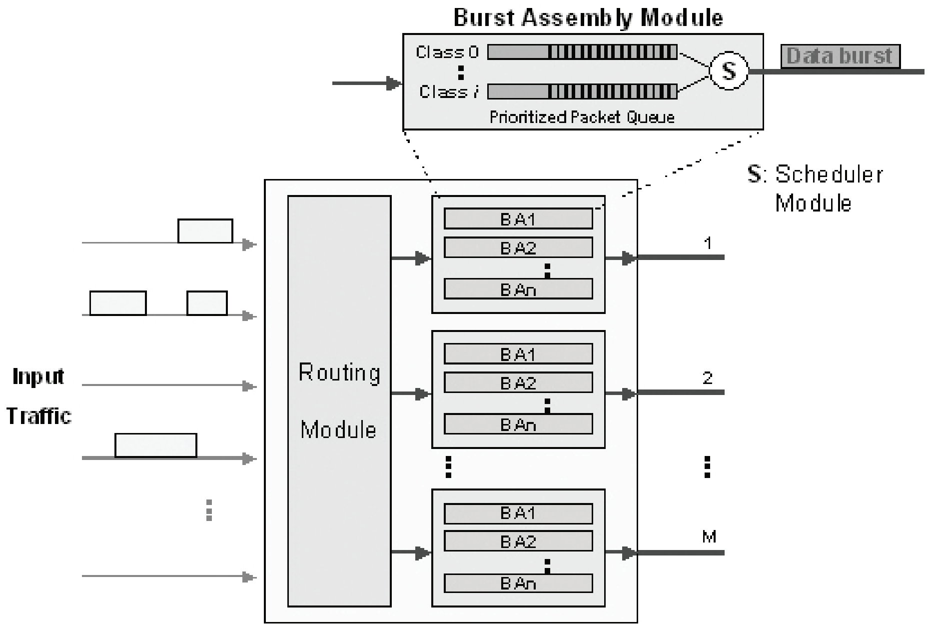


Figure 2. Schematic representation of the architecture of an OBS edge node



burst assembly module, and scheduler module. Figure 2 shows the architecture of an edge node (Chen et al., 2004; Vokkarane et al., 2002; Vokkarane & Jue, 2003). The routing module selects the appropriate output port for each packet and sends it to the correspondent burst assembly module. The burst assembly module assembles bursts containing packets that are addressed for a specific egress node. In this module, there is a different packet queue for each class of traffic. Usually, there are different assembly queues for each class of traffic (or priority). The burst scheduler module creates a burst and their corresponding control packet based on the burst assembly policy and sends it to the output port.

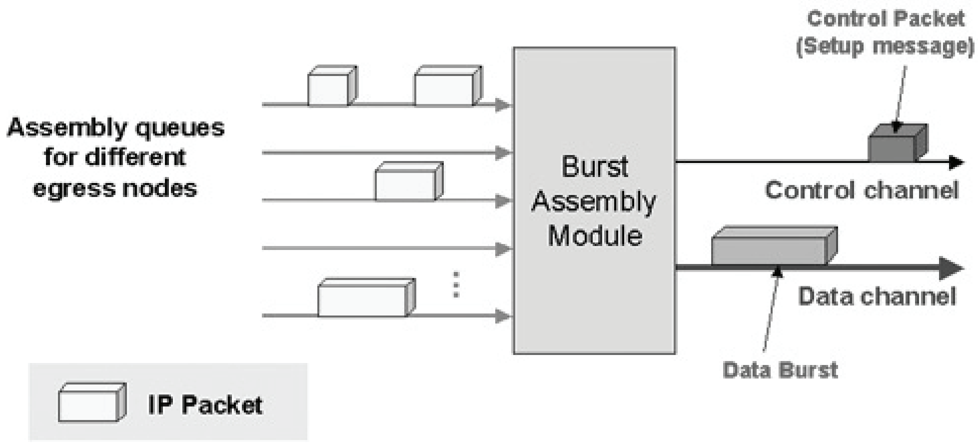
Burst assembly process is the most important task performed by the edge node. Burst assembly (Cao, Li, Xen, & Qiao, 2002; Vokkarane & Jue, 2003; Xiong et al., 2000), in OBS networks, is basically the process of aggregating and assembling packets into bursts at the ingress edge node. In this node, packets that are destined for the same egress node and belong to the same Quality of Service (QoS) class are aggregated and sent in discrete bursts, with times determined by the burst assembly policy. The burst assembly process is made into the burst assembly module, inside the edge node (see Figure 3). Packets that are destined to different egress nodes go through different assembly queues to burst assembly module. In this module, the data burst is assembled and the corresponding burst control packet is generated. At the egress node, the burst is subsequently de-aggregated and forwarded electronically.

In the burst assembly process, there are two parameters that determine how the packets are aggregated: the maximum waiting time (timer value) and the minimum size of the burst (threshold value). Based on these parameters, some burst assembly algorithms have been proposed:

- Timer-based algorithm (Cao et al., 2002)
- Burst length-based algorithm (Vokkarane et al., 2002)
- Hybrid algorithm or mixed timer/threshold-based algorithm (Chen et al., 2004; Xiong et al., 2000).

Recently, it was proposed a mechanism to provide (QoS) support that consider bursts containing a combination of packets with different classes, called composite burst assembly (Vokkarane & Jue, 2003). This mechanism was proposed to make a good use of burst segmentation (which is a technique used for contention resolution in the optical core network), where packets toward the tail of the burst have a larger probability of being dropped than packets at the head of the burst. The authors concluded that approaches with composite

Figure 3. Burst assembly process



bursts perform better than approaches with single-class bursts in terms of burst loss and delay, providing differentiated QoS for different classes of packets.

OBS CORE NODES

An OBS core node consists of two main components (Vokkarane & Jue, 2003; Xiong et al., 2000): an optical cross connect (OXC), and a switch control unit (SCU), also called a signaling engine. The SCU implements the OBS signaling protocol (also referred to us as resource reservation protocols), and creates and maintains the forwarding table and configures the OXC.

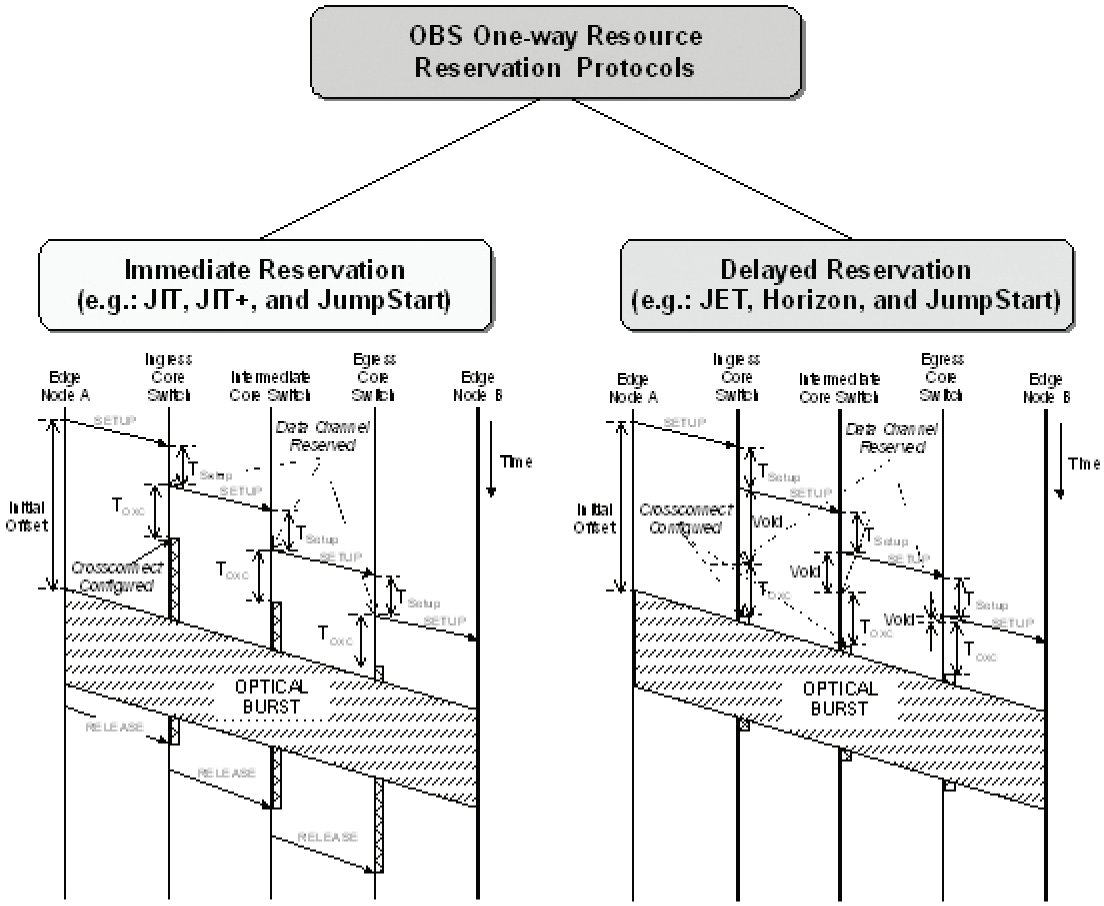
Kan, Balt, Michel, and Verchere (2001) summarize the operations that an OBS core node needs to perform, which are the following:

- Demultiplexes the wavelength data channels;
- Terminates data burst channels and conducts wavelength conversion for passing through the optical switch fabric;
- Terminates control packets channels and converts the control information from the optical to electronic domain;
- Schedules the incoming bursts, sends the instructions to the optical switch matrix, and switches burst channels through the optical switch matrix;
- Regenerates new control packet for outgoing bursts;
- Multiplexes outgoing control packets and bursts together into single or multiple fibers.

Signaling is an important issue in the OBS network architecture, because it specifies the protocol that OBS nodes use to communicate connection requests to the network. The operation of this resource reservation protocol determines whether or not the resources are utilized efficiently. Resource reservation protocols are use in the sense that they perform the signaling and scheduling functions at each intermediate core node. According to the length of the burst offset, resource reservation protocols may be classified into two classes: one-way reservation and two-way reservation.

In one-way reservation, a burst is sent shortly after the setup message, and the source node does not wait for the acknowledgement sent by the destination node. Therefore, the size of the offset is between the transmission time of the setup message and the round-trip delay of the setup message. Different optical burst switching mechanisms may choose different offset values in this range. Tell And Go (TAG) (Widjaja, 1995), JIT (Just-In-Time) (Wei & McFarland, 2000), JIT+ (Teng & Rouskas, 2005), JumpStart (Baldine et al., 2002; Baldine, Rouskas, Perros, & Stevenson, 2003; Zaim, Baldine, Cassada, Rouskas, Perros, & Stevenson, 2003), JET (Just-Enough-Time) (Qiao & Yoo, 1999), and Horizon (Turner, 1999) are examples of one-way resource reservation protocols. In the TAG protocol, a source node sends a control packet and immediately after sends a burst. At each intermediate node, the data burst has to go through with an input delay equal to the setup message (control packet) processing time. If a channel cannot be reserved on a link, along the ingress-egress path, the node preceding the blocked

Figure 4. Classification and message flow of one-way resource reservation protocols for OBS networks



channel discards the burst. To release the connection, a "tear-down" control signal or packet is sent (Widjaja, 1995). TAG is practical only when the switch configuration time and the switch processing time of a setup message are very short (Xu et al., 2003).

The offset in two-way reservation class is the interval of time between the transmission of the setup message and the reception of the acknowledgement from the destination. The major drawback of this class is the long offset time, which causes a long data delay. Examples of resource reservation protocols using this class include the Tell And Wait (TAW) protocol (Widjaja, 1995) and the scheme proposed by Duser and Bayvel (2002). Due to the impairments of TAG protocol and the two-way reservation class, a one-way reservation scheme seems to be more suitable for OBS networks. Therefore, the remaining of this session provides an overview of resource reservation protocols with one-way wavelength reservation schemes. As shown in Figure 4, one-way reservation schemes may be classified, regarding the way in which output wavelengths are reserved for bursts, as immediate and delayed reservation (Rodrigues, Freire, & Lorenz, 2004). JIT and JIT+ are examples of immediate wavelength reservation, while JET and Horizon are examples of delayed reservation schemes. The JumpStart signaling protocol may be implemented using either immediate or delayed reservation.

The JIT resource reservation protocol considers that an output wavelength is reserved for a burst immediately after the arrival of the corresponding setup message. If a wavelength cannot be reserved immediately, then the setup message is rejected and the corresponding burst is dropped. Figure 4 illustrates the operation of JIT protocol. As may be seen in this figure, T_{Setup} represents the amount of time that is needed to process the setup message in an OBS node, and T_{OXC} represents the delay incurred since the instant that the OXC receives a command from the signaling engine to set up a connection from an input port to an output port, until the instant the appropriate path within the optical switch is complete and can be used to switch a burst (Teng & Rouskas, 2004). JIT+ is a modified version of the immediate reservation protocol of JIT. Under JIT+, an output wavelength is reserved for a burst if (i) the arrival time of the burst is later than the time horizon of the wavelength and (ii) the wavelength has at most one other reservation (Teng & Rouskas, 2004). This protocol does not perform any void filling. Comparing JIT+ with JET and Horizon, last ones permit an unlimited number of delayed reservations per wavelength, whereas JIT+ limits the number of such operations to at most one per wavelength. On the other hand, JIT+ maintains all the advantages of JIT in terms of simplicity of hardware implementation.

Delayed reservation schemes, exemplified by the schemes used in JET and Horizon protocols, considers that an output wavelength is reserved for a burst just before the arrival of the first bit of the burst. If, upon arrival of the setup message, no wavelength can be reserved at a suitable time, then the setup message is rejected and the corresponding burst is dropped (Teng & Rouskas, 2004). In this kind of reservation schemes, when a burst is accept by the OBS node, the output wavelength is reserved for an amount of time equal to the length of the burst plus T_{OXC}, in order to account for the OXC configuration time. As one may see in Figure 4, a void is created on the output wavelength, between time $t + T_{Setup}$, when the reservation operation for the upcoming burst is completed, and time $t' = t + T_{offset} - T_{OXC}$, when the output wavelength is actually reserved for the burst. The Horizon protocol is an example of resource reservation protocols with delayed reservation scheme without void filling and it is less complex than the protocols with delayed reservation schemes with void filling, such as JET. When Horizon protocol is used, an output wavelength is reserved for a burst if, and only if, the arrival time of the burst is later than the time horizon of the wavelength. If, upon arrival of the setup message, it is verified that the arrival time of the burst is earlier than the smallest time horizon of any available wavelength, then the setup message is rejected and the corresponding burst is dropped (Teng & Rouskas, 2004).

On the other hand, JET is the most known resource reservation protocol with delayed wavelength reservation scheme with void filling, which uses information to predict the start and the end of the burst. In this protocol, an output wavelength is reserved for a burst if the arrival time of the burst (*i*) is later than the time horizon of the wavelength, or (*ii*) coincides with a void on the wavelength, and the end of the burst (plus the OXC configuration time) occurs before the end of the void. If, upon arrival of the setup message, it is determined that none of these conditions are satisfied for any wavelength, then the setup message is rejected and the corresponding burst is dropped (Teng & Rouskas, 2004).

It was observed by Rodrigues et al. (2004) and Rodrigues, Freire, and Lorenz (2005) that the above five resource reservation protocols lead to a similar network performance, and, therefore, the simplest protocols (i.e., JIT-based protocols) should be considered for implementation in practical systems.

CONCLUSION

OBS has been proposed to overcome the technical limitations of optical packet switching. In this article, an overview of OBS networks was presented. The overview was focused on the following issues: OBS network architecture, edge nodes and burst assembly process, core nodes and resource reservation protocols.

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KEY TERMS

Bursts: In OBS networks, IP packets (datagrams) are assembled into very large size data packets called bursts.

Burst Assembly: Basically the process of aggregating and assembling packets into bursts at the ingress edge node of an OBS network.

Burst Offset: The interval of time, at the source node, between the processing of the first bit of the setup message and the transmission of the first bit of the data burst.

Control Packet (or burst header packet or setup message): a control packet is sent in a separated channel and contains routing and scheduling information to be processed at the electronic level, before the arrival of the corresponding data burst.

Network Architecture: Defines the structure and the behavior of the real subsystem that is visible for other interconnected systems, while they are involved in the processing and transfer of information sets.

One-Way Reservation Schemes: These schemes may be classified, regarding the way in which output wavelengths are reserved for bursts, as immediate and delayed reservation. JIT and JIT+ are examples of immediate wavelength reservation, while JET and Horizon are examples of delayed reservation schemes.

SCU: Switch control unit or signaling engine. The SCU implements the OBS signaling protocol, and creates and maintains the forwarding table and configures the optical cross connect.