



Time-Space Label Switching Protocol (TSL-SP)—A New Paradigm of Network Resource Assignment

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Received January 17, 2003; Revised and Accepted April 14, 2003

Abstract. In this paper we propose a new protocol called time-space label switching protocol (TSL-SP) in optical burst switching (OBS), and define the terms time-space label (TSL) and time-space routing (TSR). An important concept of response time is introduced in the time label mechanism. The TSL-SP is a new technology that can quickly and efficiently forward data with a label on the optical networks. A two-dimension label switched path (TD-LSP) can be set up, that is maintained and deleted by the TSL-SP. For clearly illuminating the operation principles of the TSL-SP, we propose a new approach of orthogonal time-space coordinates in which the vertical coordinate is the space label and the horizontal coordinate is the time label. The proposed TD-LSP can dramatically reduce the routing failure probability and greatly improve the link network efficiency compared with other signaling protocols. Moreover, we define the time-space label control plane that can achieve the higher efficiency. When the TSL-SP is applied to networks, switching performance can be improved by two orders compared to the switching performance with the conventional OBS signaling protocols. The fundamental goal of TSL-SP is to band the signaling and routing functions together closely. Also, the TSL-SP can reduce the complexity of the network, support automatic service offering, and provide traffic engineering.

Keywords: time-space label switching protocol (TSL-SP), two-dimension label switching path (TD-LSP), time-space label (TSL), time-space routing (TSR), orthogonal time-space coordinates, optical burst switching (OBS)

1 Introduction

Optical communication networks exhibit an explosive development during the last decade. The wavelength-division multiplexing (WDM) technology has offered huge bandwidth to optical networks. How to utilize this bandwidth in an efficient and scalable way is vital to the development of optical networks. A fast and transparent switching method lends itself to realize the goal. Basically, there are three switching schemes for WDM networks: circuit switching, packet switching, and burst switching. Optical circuit switching (OCS) is widely used in the current deployment of WDM, which takes the form of wavelength routing. Since the Internet traffic is self-similar (burst at all time scales), wavelength routing results in lower bandwidth utilization. A longer-term strategy for the network evolution is to employ optical packet switching (OPS), which provides better

flexibility, resource utilization, functionality, and granularity. One of the biggest challenges is that there is no optical equivalence of the random access memory. Optical burst switching (OBS) has been proposed as a combination of the merits of optical circuit switching and optical packet switching while avoiding their shortcomings. As the traffic nature changes from being voice-dominant to data-dominant, traffic load moves to the self-similar property of being bursty at all time scales. Thus, burst switching is suitable for today's bursty traffic where the duration of each burst is neither long enough to be suited to circuit switching nor short enough to fit in single packet [1–6].

OBS allows switching of data channels entirely in the optical domain by doing resource allocation in the electronic domain, as shown in Fig. 1. In OBS networks, a control packet is ahead of the corresponding data burst. The control packet and the

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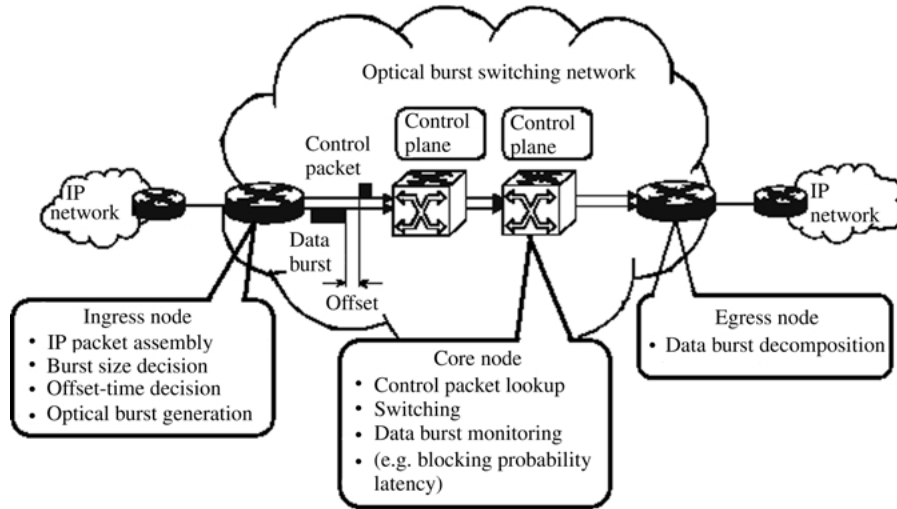


Fig. 1. Burst optical switching paradigm.

corresponding data burst are launched at the source at time instants separated by an offset. The control packet contains information required to route the data burst through the optical transmission core, and it is sent over an out-of-band control channel (wavelength). It is processed electronically at each of the intermediate nodes (optical cross-connects) to make routing decisions (outgoing interface and wavelength), and the optical cross-connects are configured to switch the data burst entirely in the optical domain, thereby removing the electronic bottleneck in the end-to-end data path, mainly due to the growing mismatch between the electronic operating frequencies of processors (currently 1–2 GHz) and the optical line rates currently being at 10 Gbit/s and expected to exceed 40–80–160 Gbit/s per wavelength channel in the near future [1–7].

As the bandwidth-distance product gets increasingly higher in multi-gigabit networks, two issues, namely reducing latency and increasing link utilization, become increasingly important. In order to efficiently utilize the bandwidth, to reduce the latency, and to provide the data transmission transparency, some OBS signaling protocols have been proposed [8–11]. But these protocols are all similar in that the signaling function is separated from the routing function and therefore introduces troubles to the routing, protection, and scheduling of bursts in OBS. Besides, their switching control plane becomes more complex with more overhead.

In optical network, routing and signaling could be considered together instead of separated control components [1].

In this paper, we propose the time-space label switching protocol (TSL-SP) for OBS. We define the time-space label (TSL) and time-space routing (TSR). An important concept of response time is introduced in the time label mechanism. In order to illuminate the operation principles of the two-dimension label switched paths (TD-LSP), we propose a new approach of orthogonal time-space coordinates in which the vertical coordinate is the space label and the horizontal coordinate is the time label. In the orthogonal time-space coordinates, networks resources can be efficiently assigned by the TSL-SP and therefore the routing and signaling functions can be well integrated.

This paper is organized as follows. In Section 2, we present a time-space label control plane for OBS, and the principles of time and space labels are explained. A new control packet format and a new architecture of the node in OBS networks are given. In Section 3, the TSR protocol and TSL-SP are proposed for OBS. Also the merits of the TD-LSP are in particular analyzed. In Section 4, a comparison between the TSL-SP and conventional signaling protocols of OBS is made. The performance of the TSL-SP versus conventional signal protocols is evaluated when they are applied to OBS networks. Finally, we conclude the paper in Section 5.

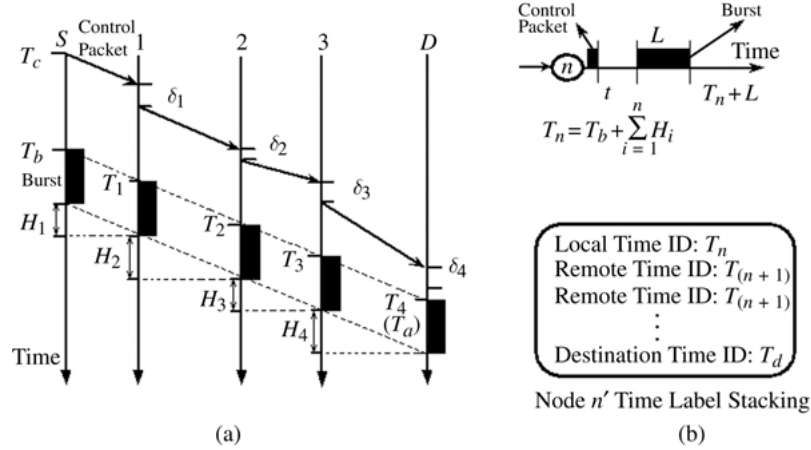


Fig. 2. Time label.

2 Time-space Label Control Plane for OBS

2.1 Time Label

Basically the time label approach is a resource reservation mechanism for optical networks, which corresponds to signaling protocols of OBS. In conventional signaling protocols of OBS, the resource reservation is implemented by the offset time. At the source node, the offset time is not smaller than the sum of the expected control delays in each node of the routing path, namely, $T \geq \sum_{h=1}^n \delta(h)$, where $\delta(h)$ is the expected control delay (e.g., the processing time incurred by the control packet at node h , and n is the total number of traversed nodes) [9]. The typical values of these parameters in current generation of WDM switches are the signaling protocol processing time which are a few μs , and the cross-connect cut-through time with a few ms [8]. There is a specified amount of deviation between the expected and practical control delay time that is about μs . This deviation results in data burst loss and link resource wasting. For keeping away from this problem, we propose a concept of response time. The moment that data bursts arrive just at the intermediate node is called the response time. As shown in Fig. 2(a), the control packet is sent at T_c , and the corresponding data burst is sent at T_b . H_i represents the transmitting time that a data burst will take at the i -th link (or hop), where i is from 1 to n . At the source node, the response time is T_b . At the first intermediate node, the response time is $T_1 = T_b + H_1$. The reserve-fixed-duration (RFD) in this node is from T_1 to $T_1 + L$, where L is the length of the corresponding data burst. The second

intermediate node, the response time is $T_2 = T_b + H_1 + H_2$, and the RFD is from T_2 to $T_2 + L$. At the n -th node, the response time is $T_n = T_b + \sum_{i=1}^n H_i$, and the RFD is from T_n to $T_n + L$, and so on. At the source node, ΔT must not be smaller than the offset time T of conventional OBS signaling protocols, namely $\Delta T \geq T$, here $\Delta T = T_b - T_c$. Because the control packet allocates networks resources for the corresponding data bursts, the control packet must be processed before the corresponding data bursts arrive at each node. Because no optical buffer is introduced into OBS networks, data bursts will be transparently propagated with the light speed without extra delay. Thus, as long as the response time T_b at the source is determined, the corresponding response time of each intermediate node will be exactly determined. Therefore if we take the response time $T_b, T_1, T_2, \dots, T_n$ as the time labels. Each time label is a local time identifier (ID) to its own node, at the same time, and also is a remote time ID to the other nodes located before the own node in the routing path. All the time labels of the routing path consist of an ordinal label stacking, which is shown in Fig. 2(b). Along the routing path, the corresponding time label of each node changes from a remote time ID to a local time ID, which is on the top of the time label stacking. A controller in intermediate nodes reads the local time ID.

Why replace offset time by response time in the signaling? In optical networks, optical propagation time per kilometer is about $5 \mu s$. In current optical networks, the deviation of optical propagating time in each hop (or fiber link) is in the order of $10^{-8} s$, which

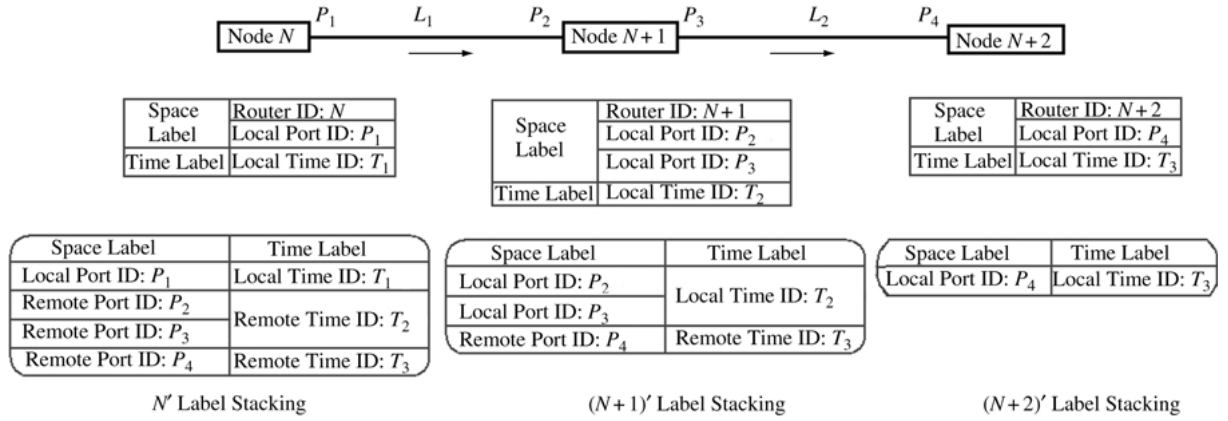


Fig. 3. Space label.

is much smaller than the deviation magnitude caused by the control delay of conventional OBS signaling protocols. Another important advantage of the time label is that the corresponding data burst will be triggered at the explicit time label T_b at the source node, which avoids the prediction mechanism of the start and the end of the data bursts in conventional signaling protocol of OBS [8–9]. Thus, the time label approach will be an exact mechanism to perform and refine reservation of network resources.

2.2 Space Label

The time label can perform provision of services in the time domain, but how to realize provision in the space domain is equally important.

As shown in Fig. 3, there are routing adjacency relationships with three neighboring nodes. In the routing protocol, each node and its ports can be distinguished from one another by some specific identifiers. Those corresponding identifiers are called space labels. In Fig. 3, the $(n+1)$ -th node is represented by Router ID: $N+1$. Each intermediate node of the routing path has an input port and an output port, such as $(n+1)$ -th node with an input port ID P_2 and an output port ID P_3 . The labels P_2 and P_3 are local for the $(n+1)$ -th node, but they are also the remote labels for the n -th node. In Fig. 3, the arrowheads show the traffic direction. In the optical network, a fiber link (or hop) can be uniquely identified by two port IDs, for example, in Fig. 3, a link L_1 is uniquely identified by P_1 and P_2 . Each port ID contains three necessary pieces of information: (1) switching information, (2) Maximum (or reservable) bandwidth, and (3) data encoding information. Also

optional information may be attached in the descriptor; for example, the allowed max burst length could be added. An example of a port ID is as follows: Switching type OBS-1; encoding = Ethernet 802.3; max bandwidth[0] = 1.0 Gbps for priority 0; max burst length = 300 ms.

In WDM, an optical fiber has a number of channels with different wavelengths. By space labels, a node ID is used to identify a node, and a port ID can be used to identify further fine-grain information within each node. All space labels of routing path consist of a label stacking, which is shown in Fig. 3. The space label stacking operates in the same way as time label stacking. In each node, the controller reads the space ID along with time ID and others ID based on space label information, the resource reservation will be made in the nodes. Along the routing path, the local space ID is located at the top of the stacking is read and then stripped off. At the next node, the first remote space ID arrives at the top of the stacking and becomes a local space ID.

Space labeling can implement provision of services in the space domain and is part of the routing information.

2.3 Control Packet Format

The control packets are separated from data bursts in OBS networks. Based on the time and space labels, we define a concrete format and functions for the control packets in the TSL control plane of OBS.

As shown in Fig. 4, signaling, and data bursts information compose a single control packet in TSL control plane, which is different from the conventional control plane where these information

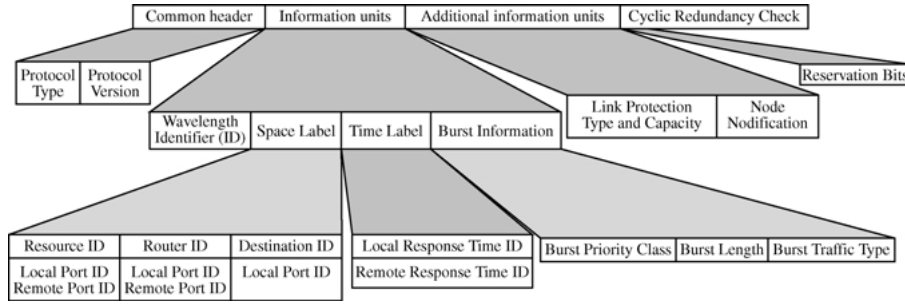


Fig. 4. Control packet format.

components are carried by independent control packets. Thus, packet handling complexity and the amount of overhead can be reduced in the TSL control plane. The control packet format can easily be implemented and is flexible enough to support the future needs of networks. In Fig. 4, the control packet consists of four parts: a common header, information units, additional information units, and a cyclic redundancy check. The common header contains the information about the type and version of the protocol. The information units include routing, signaling, and data burst information that are wavelength ID, space label, time label, and burst information. The time and space labels are used in the signaling and routing functions. The data burst information consists of the traffic type, priority class, and burst length. This information allows traffic engineering (TE). In additional informational units, link protection type and capacity and node notification are included. The information permits realization of quality of service (QoS). The node notification is to inform the nodes about a failure in the path, thus allowing to start recovery. The reserved bits in additional informational units primarily serve the needs for network upgrading. According to the information included in the control packet, the TSL control plane can perform routing, signaling, burst scheduling and link protection management and so on.

2.4 A New Node Architecture in OBS Networks

Fig. 5 shows a new node architecture in OBS networks that consists of two parts: the optical control plane and the OBS plane. The control channel should be separated from the data channel in OBS networks.

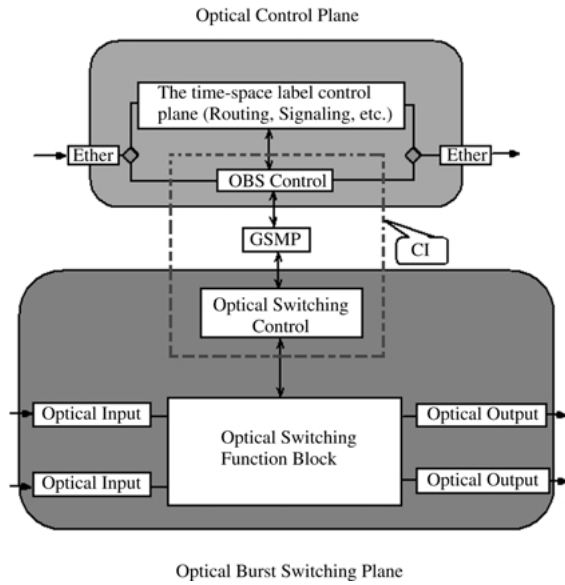


Fig. 5. An architecture paradigm of node in OBS networks using the time-space label control plane.

One of the good reasons for separation is that the control channel should not share the fate with the data channel, and it does not have to be the same physical medium as the data channel. For example, an optical network can use optical channels to transport data, but an Ethernet link to transport control signals.

In Fig. 5, the control packet processor in the TSL control plane takes and processes a control packet, and then gets the necessary control information (CI) for burst routing and signaling. The TSL control plane gives the CI to the OBS Control. Then the OBS control send it to the OSC through the generic switch management protocol (GSMP), which converts the CI

of the OBS control into the CI suitable for optical switching control by changing the signaling format. After that, the optical switching is a set functioned by the CI of the optical switching control.

The TSL control plane is essential for the evolution of open and interoperable optical networks, it simplifies the operation and management, and reduces the cost of operations. The information of routing, signaling, and link management are all included in a single forwarding control packet. Thus, routing, signaling, and link management in OBS can be harmoniously implemented in the TSL control plane.

The time-space control plane takes full advantages of matured electronic processing for the control packet and the high-speed optical transmission of data bursts. In the TSL control plane, the functions of central management and distributed control can be organically integrated. There are three major functions in the TSL control plane: renewing the database of networks status, reserving the network resources, and distributing and maintaining the labels. The necessary CI in Fig. 5 consists of the time and space labels of the TSL-SP. The TSL control plane can allocate and reserve network resources in the time and space domains according to the CI. The next section will continuously explain those three major functions.

3 Time-Space Label Switching Protocol (TSL-SP)

3.1 Time-Space Label (TSL)

The TSL consists of time and space labels, which has two dimensions. The time label avoids the control delay that impacts the provision of services. A node synchronization is needed in the time label scheme, just as the JET procedure [9], and it can be easily implemented when comparing with bit or packet synchronization. The TSL carries the routing and signaling information. Also the topology and status information of globally optical networks should be collected for appropriate utilization of networks resources. Thus, the distributed control and central management can be effectively united by the TSL in the TSL control plane.

As shown in Fig. 3, there are two local space labels in each intermediate node, being the input port ID and output port ID, respectively. For example, input port ID P_2 and output port ID P_3 are the local labels for $(n + 1)$ -th node. Despite that P_2 is in front of P_3 in the

space stacking, they have the same local time ID T_2 in Fig. 3 as the propagating time of data bursts in an intermediate node is neglected, and we consider this true for all intermediate nodes. Most importantly, a TSL is network-wide and globally unique.

3.2 Time-Space Routing (TSR)

The conventional routing protocols can be extended and upgraded to support the TSL, and an extension version for the open shortest path first (OSPF) [12–16] is named the TSR which can be used to discover network topology, distribute traffic engineering information, and TSL-specific features.

We propose the TSR as a constraint-based routing algorithm. These kinds of algorithms can find a path that optimizes a certain scalar metric and at the same time does not violate a set of constraints. Such a path is called a constraint-based path [16]. The objective of the TSR is to find a shortest path tree in which the necessary network resources are not only usable in the space but also available in the time dimension. The TSR consists of three major steps: (1) The TSL control plane collects network status information and a status database of networks is built. Here, the Dijkstra's shortest path first (SPF) [16] algorithm is used to select some routing paths between source and destination nodes. These routing paths constitute a set in which they are ranked from the most preferred to the least preferred. We can also use other SPF algorithms. (2) Some routing paths from the set are picked out, and they constitute a subset that can be reserved in time dimension. In the TSR, only the most preferred in the subset is singled out, which is a SPF tree, and serves as a map for data routing. (3) At the source node, a routing table is built based on the corresponding SPF tree, which consists of space and time labels in the TSR. In the TSR, the selected shortest routing path may not be the shortest routing path in space dimension, but it should be available in time dimension. Here, the meaning of "shortest" is refer to the shortest path among all paths that are allowed in the time dimension.

3.3 Time-Space Label Switching Protocol (TSL-SP)

A data burst is carried by a dedicated wavelength in OBS. Thus, a wavelength could be viewed as an implicit label. TSL-SP combines the TSL with the TSR in a dedicated wavelength. The fundamental goal of TSL-SP is to coordinate the signaling and routing

functions organically. The routing function uses the label-based routing protocols to distribute and maintain the information about the topology and resources of the network. The routing protocol is the means by which the non-local resource information is distributed. The topology and resources of the network will be taken into account as parameters for the path algorithm to calculate a label switched path (LSP). The signaling protocol is the procedure through which service provisioning is done. The service provisioning includes LSP establishment, LSP deletion, and LSP modification. Thus, the TSL control plane makes use of the TSL-SP to realize the three major functions mentioned above. In the TSR, after comparing the time label information of the routing table at different intermediate nodes with the time information in the network status database, the routing path is confirmed if there are no contentions between them. And if not it goes to the second preferred path

and so on, until a routing path is finally confirmed. Then, the TSL-SP distributes the TSL along the confirmed routing path, and the network resources are assigned according to the TSL. Thus, a LSP in time and space dimensions, which is called TD-LSP, can be set up by the TSL-SP.

In order to illuminate the operation principles of the TSL-SP, orthogonal time-space coordinates in which the vertical coordinate is the space label and the horizontal coordinate is the time label is shown in Fig. 6.

Note that the TD-LSP role is for resource allocation and usage. In this figure, there are some prerequisites: a mesh network with 10 nodes, four ports per node with two inputs and two outputs, and the nodes in the network being connected to each other by a single fiber. In the orthogonal time-space coordinates, a crossing point between time label and space label is a concrete intermediate node. As shown in Fig. 6, each

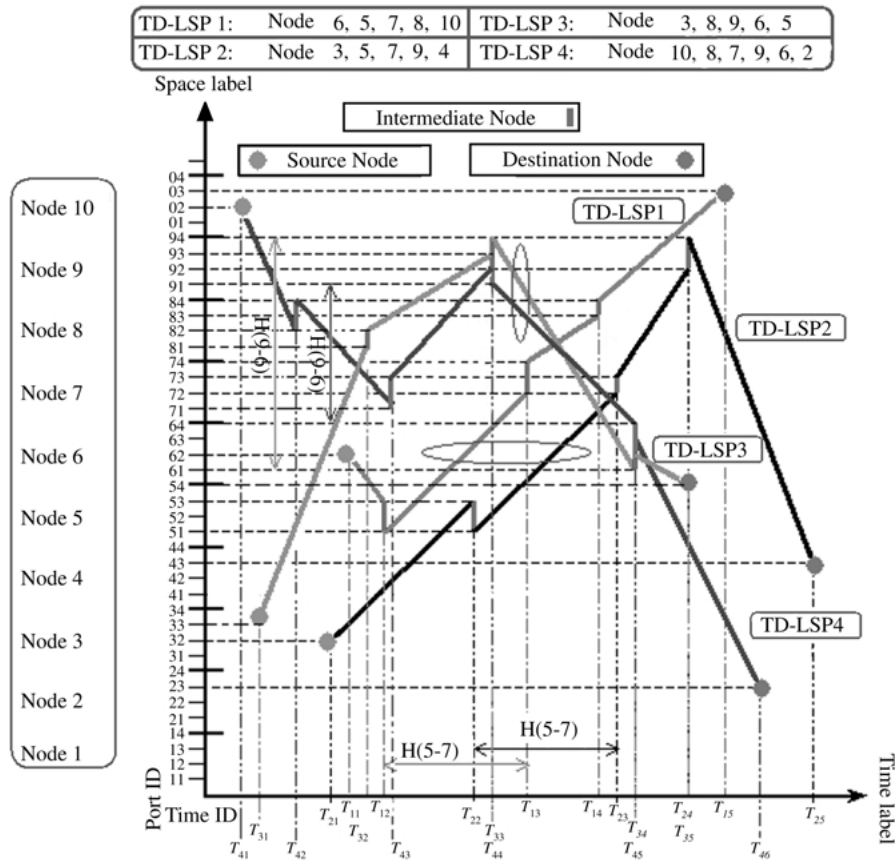


Fig. 6. Orthogonal time-space coordinates.

intermediate node has an input port and an output port at a TD-LSP. Because the propagating time of a burst through the intermediate node is neglected, at a TD-LSP, the input port ID and output port ID in an intermediate node correspond to the same time ID in Fig. 6. In the intermediate node, the switching cut-through is accomplished just before the corresponding data burst arrives. The corresponding data bursts are forwarded and transmitted along the TD-LSP. In Fig. 6, a TD-LSP is determined by the corresponding time and space labels.

There is a clear advantage for adopting the TD-LSP: dramatically reducing routing and forwarded failure probability. Resource provisioning of conventional signaling protocols is carried out at a single dimension, i.e., either time or space dimension. However, resource provisioning at either of dimensions could lead to the contention of resource provisioning at another dimension. In particular, routing failure and burst loss has larger probability at heavy traffic if only one dimension resource provisioning is adopted. In Fig. 6, H (5–7) represents a hop between node 5 and 7, and H (9–6) represents a hop between node 9 and 6. The H (5–7) hop in TD-LSP 1 and that in TD-LSP 2 are located in a same wavelength channel and in the same fiber link. Although the Port IDs are the same, the Time IDs are different at nodes 5 and 7. This is true to the H (9–6) hop, although the Time IDs are the same at the nodes 9 and 6, the Port IDs are different at nodes 9 and 6. Thus, it shows that, in a mesh network, the network resources can be statistically utilized in time and space dimensions. Moreover, comparing with conventional OBS routing paths, the TD-LSP can provide a connection mode for connectionless networks. The connection nature of the TD-LSP is more advantageous when routing paths go through the more number of hops.

The TSL-SP can realize the link protecting and failure recovery. Also the traffic engineering (TE) and QoS requirement can be easily satisfied by the TSL-SP, and we will discuss them in other papers.

4 Comparison between the TSL-SP and Conventional OBS Signaling Protocols

In Fig. 7, we can see the TSL-SP features: the one-way reservation, switching cut-through, variable length, out-of-band control and medium granularity.

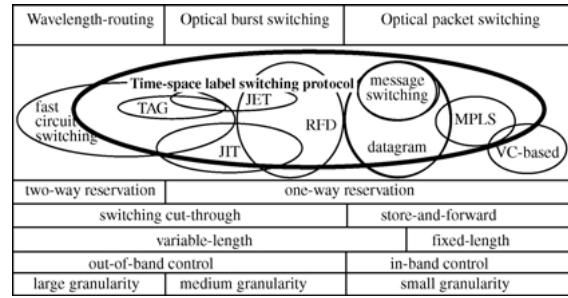


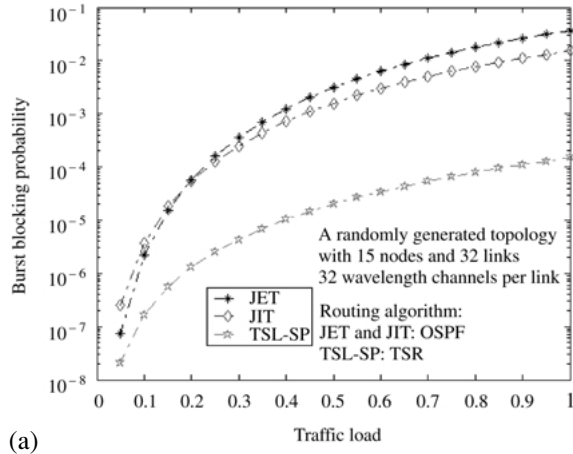
Fig. 7. Comparison among switching protocols of three optical switching. TAG, tell and go; JET, just enough time; JIT, just in time; RFD, reserve-fixed duration; MPLS, multi-protocol label switching; VC, virtual channel.

The one-way reservation obviously reduces control and procession overhead. The switching cut-through avoids the processing of optical payload. The packet synchronization can be kept away and bandwidth utilization can be improved because of medium granularity of bursts. Out-of-band control channel can avoid optical buffer that is important because of its technology being still immature now. Finally, the variable length of burst can provide the flexibility.

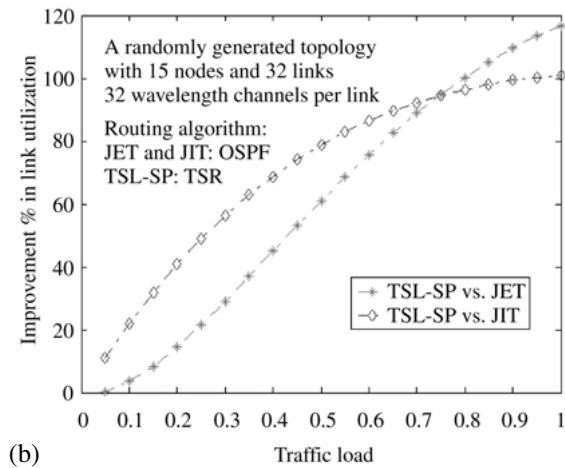
In current OBS technology, there are two important signaling protocols: JET and JIT [8,9,11]. The TSL-SP takes full advantage of both JET and JIT. The TSL-SP is of good efficiency and low pre-transmission latency just as JET, and Qos guaranteed just as JIT. Despite that the TSL-SP has been proposed specially for OBS, its modified version can be applied to wavelength routing and packet switching. In Fig. 7, the bold ellipse shows its applicable fields in optical switching, and the features of all current protocols for optical switching are given in this figure, too.

We evaluate the performance of the proposed TSL-SP on the network. The network has a randomly generated topology, with 15 nodes and 32 fiber links [5]. There are 32 wavelength channels per fiber link. Self-similar traffic is taken as a resource in which the distributions of the burst inter-arrival time and the burst length are Pareto distribution and exponential distribution, respectively [7]. The OSPF and the TSR are adopted respectively in the simulation. We only compare TSL-SP with conventional OBS signaling protocols. Fig. 8 gives the results of the simulations for TSL-SP, JET and JIT.

From Fig. 8(a), we can see that the switching performance of JIT is better than that of JET. The reason is that JIT has connection acknowledge and the release mechanism that can guarantee QoS [8], but JET is best-effort service [9]. When comparing TSL-SP with JET and JIT, we can find that the switching performance for TSL-SP is dramatically improved. In particular, the burst blocking probability can be reduced by two orders of magnitude compared with JET or JIT in heavy traffic periods. This is resulted from the networks resource being statistically utilized in the network during a concrete time domain.



(a)



(b)

Fig. 8. Simulation results. (a) Comparing among burst blocking probabilities in different switching protocols. (b) Bandwidth utilization improvement of TSL-SP versus conventional OBS signaling protocols.

Fig. 8(b) shows the improvements of link utilization with TSL-SP versus JIT and JET when they are applied to the network described above. With increasing traffic load, the improvements of link utilization can continuously increase. This is because that TSL-SP can provide connection service for connectionless networks. In TSL-SP, the network resources can be effectively assigned because of TD-LSP. During heavy traffic, the link utilization improvement of TSL-SP versus JET is more than that of TSL-SP versus JIT. This is caused by the data burst blocking and retransmission probabilities for JET during heavy traffic being increased because of its best-effort service feature.

Thus, the TSL-SP reduces routing failure, data bursts loss, and retransmission probabilities, and it improves bandwidth utilization. In the orthogonal time-space coordinates, networks resources can be more efficient assigned by the TD-LSP of the TSL-SP.

5 Conclusion

In this paper, after introducing an important concept of response time based upon that the optical bursts are transparently transmitted without extra delay in OBS network, we defined the time label and space label, proposed both the TSL and the TSR, and developed the TSL-SP. The fundamental goal of TSL-SP is to band the signaling and routing functions closely together. The TSL-SP is a new technology that can quickly and efficiently forward data with labels in the optical networks. The simulation shows, when the TSL-SP is applied to these networks, the switching performance can be improved by two orders compared with conventional OBS signaling protocols in heavy traffic period. Therefore the complexity and cost of networks will be obviously reduced by employing the TSL-SP. Furthermore, we introduced a new approach of orthogonal time-space coordinates for analyzing networks resources assignment. Because of the statistical nature of the TD-LSP, the network resources can achieve more efficient and reasonable allocation and utilization by the TSL-SP. It can support TE and provide QoS. Therefore, the TSL-SP is one of the most promising protocols for OBS.

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