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A flexible optical switch architecture for efficient transmission of optical bursts

Krishanthmohan Ratnam [a,*], Mohan Gurusamy [b], Kee Chaing Chua [b]

[a] Department of Computer Engineering, University of Peradeniya, Peradeniya, Sri Lanka
[b] Department of Electrical and Computer Engineering, National University of Singapore, Singapore

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ABSTRACT

In this paper, we propose a new optical switch architecture for optical WDM networks. Flexibility and efficiency in terms of controlling and utilizing optical power are key features of the architecture. The architecture uses switching components which have increased flexibility of how optical power received on an input port is managed when switching optical signals. Like the traditional optical switches, optical power can be directed towards one output port only. Further, unlike the traditional switches, on need basis, the power can be split on a desired sub-set of output ports, thus reducing power wastage on unwanted ports. Such split power can be directed fully towards a single output port as and when it is needed. This flexible and efficient power management makes the architecture a potential candidate for optical networks with its usage in several dimensions. The dimensions include (1) switching methods such as circuit level switching and bursty level switching, (2) network types such as core, metro, and access networks, (3) support for technologies such as Light-trails and Light-trees, and (4) support for functionalities such as survivability and multicasting with new features. Importantly, there is potential that the architecture enhances adaptability based on the needs, and it supports co-existence and seamless integration of different environments.

In this paper, our focus is on investigating bursty level switching using the proposed switch architecture. We use the flexibility of the switch and adopt a new switching method for data bursts. This switching method is efficient for switching bursts while introducing new challenges. Unlike the traditional switching method, it switches bursts arriving on an input link with zero (or very small) time gaps to different output links in certain scenarios. Further, it also switches bursts from different input links to the same output link when they arrive with zero (or very small) time interval. Adopting such switching approaches has potential benefits in terms of delay-load performance and blocking performance. While the bursts are switched from the same input link to different output links in this approach, it creates some unwanted signals. We investigate scenarios in which the unwanted signals create any problems and this poses some challenges. To address such challenges, we develop a transmission protocol. We investigate the performance of our solutions using simulation studies and verify the two significant gains: (1) networks' capability to sustain traffic loads up to the maximum level in terms of the delay-load performance, which is similar to the performance seen for hypothetical ideal switches with zero switching time, and (2) improved blocking performance.

1. Introduction

Emerging new applications such as on-demand high definition (HD) TV, HD-video teleconferencing and game services, and cloud based services require high bandwidth demand on the Internet. Optical Wavelength Division Multiplexing (WDM) technology and bursty transmissions are preferred solutions to meet such demands and applications. We use the term burst with the same meaning as it is used in optical burst switching (OBS) networks, which refers to a large-sized optical data. Usually a burst is assembled at an ingress node, containing a number of packets leaving to the same egress node.

1.1. Existing technologies and architectures

Optical burst switching (OBS) is a technology widely considered for burst transmission [1–19]. In OBS, a wavelength channel is reserved only for the duration of a burst by a control message. The control message is sent ahead of the burst. In OBS, bursts are transmitted using statistical time division multiplexing on various wavelengths on a link, which results in better bandwidth

* Corresponding author.
E-mail addresses: rkmohan@gmail.com (K. Ratnam), elegm@nus.edu.sg (M. Gurusamy), eleckc@nus.edu.sg (K.C. Chua).

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utilization. Generally one-way reservation is adopted. Approaches with acknowledged two-way reservation such as wavelength routed OBS (WR-OBS) have also been proposed in the literature [5]. In OBS, switches need to be configured on per-burst basis implying the need for fast switches. Fast switches are needed, otherwise, the switching time gaps between bursts lead to poor performance.

Several switch architectures have been proposed for OBS nodes. Switching fabrics in switches are capable of space switching or capable of switching in space with limited range in wavelength and time switching [6]. The switching fabrics use different space switching technologies which support fast switching as discussed in [7]. Electro-optic switching (lithium niobate $LiNbO_3$ based) is one such technology considered for OBS networks [7,8]. The electro-optic switches with $LiNbO_3$ waveguides are driven by electrical voltage. An electrical voltage applied to the electrodes changes the substrate's index of refraction. This manipulates the light propagating through the appropriate path to the desired output [7]. Broadcast and select based architectures have also been considered for OBS networks, which use semiconductor optical amplifiers (SOA) as switching elements [9–13]. Optical power is split towards the output ports and SOAs used as on–off switches select the desired output port for burst switching. Generally, switches use wavelength converters for wavelength switching in addition to space switching. For switching in time domain, fiber delay lines (FDL) are used. In [14], wavelength-space switching is considered using wavelength converters and wavelength grating routers (WGR). Architectures for time–space switching such as [15,16] have also been considered for burst transmission.

Though, many switch architectures have been proposed, deploying fast and cost-effective switches is a major problem to commercialize OBS technology. This is because the switching technologies required for fast switching are expensive. Further, wavelength conversion remains expensive. In addition to this, switching in time domain, for which architectures typically use a combination of space switching fabrics and FDLs, is generally considered most difficult [6]. These are bottleneck-issues for OBS technology to make it practical.

A problem for deploying OBS with the existing optical switches commonly used such as MEMS switches is that they are not fast enough (switching speed in ms). For efficiency reasons, such switches can be considered for the transmission of very large sized bursts only (bursts size of 10's and 100's of ms). However considering such large sized bursts may not be practical since assembling such large bursts at ingress nodes may take very long time and cause long delay. Some research and test-bed studies which consider such large bursts with MEMS switches are also in the literature [17–19]. (A survey of optical switching test-bed activities can be found in [20]). A reason for considering MEMS switches is for reducing the cost as MEMS switches are cost-effective when compared to fast switches. In [17], a connection-oriented OBS network test-bed with planer lightwave circuit (PLC) and MEMS switches has been demonstrated. In this work, burst size of 100's of ms has been considered. The recent research and test-bed studies in [18,19] use MEMS switches jointly with fast SOA switches to achieve cost-effective implementation of a multi-granular OBS network. In this work, MEMS switches are used for large bursts (200 ms and 30 ms).

Light-trail (LT) is another technology [21–25] for burst transmission. A LT requires an optical circuit which is similar to the lightpath. Intermediate nodes on the LT can receive and transmit data in a time multiplexed manner. This technology has shown improved performance especially for linear or ring network topologies. However, mesh networks can have nodes with higher nodal degree and highly dynamic transmissions require switching to (or from) different ports. This approach, therefore, requires frequent dimensioning (expanding/shrinking) of LTs. Hence, it faces the same problems due to slow switches as illustrated above. Another drawback is that no two connections can coexist on a LT at the same time.

1.2. Motivation and our proposal

In the context of these technologies facing different problems to support burst transmissions, in this paper, we investigate a different switching approach. We develop our switching approach by observing the basic limitations generally seen in traditional optical switches (TOS). Consider that optical signals are switched from an input port to an output port by the widely used TOS such as MEMS optical switches. While the signals are switched, simultaneous or concurrent configuration to connect (1) the same input port to a different output port, or (2) a different input port to the same output port is not done. This is because, the simultaneous or concurrent configuration interrupts the ongoing switching. The configuration is, therefore, done only after the existing transmission is over. This constraint is not desirable especially for burst transmission as it requires fast switch configuration between data bursts. It necessitates efforts to find fast switches using various switching technologies (as illustrated above) for burst transmissions. (Even with such fast switches, time gaps, called guard-times which include the time for switch configuration, are left between consecutive bursts in OBS networks [16,15]) Such fast switches are likely to be expensive. Therefore, we focus on identifying possible scenarios for concurrent configuration so as to remove or reduce the switching gaps leading to increased performance.

We propose a new optical switch architecture. The architecture uses switching components which have increased flexibility of how optical power received on an input port is managed when switching optical signals. Like the traditional optical switches, optical power can be directed towards one output port only. Further, unlike the traditional switches, the power can be split on a desired sub-set of output ports on need basis. While power is split on the sub-set of output ports, power wastage on unwanted ports are reduced. Such split power can be directed fully towards a single output port as and when it is needed.

We use this flexibility of controlled power directing and splitting to overcome the constraint illustrated above and adopt a new switching method for burst transmissions. When a burst arrives, it is switched with its power directed only on the desired output port. This is similar to the switching in TOSs. When two bursts (B_1 and B_2) arrive back-to-back on the same port with zero (or very small) time gap, we adopt the following approach when the bursts are switched to different output ports (o_1 and o_2 respectively). By the term zero (or very small) time gaps between bursts, we mean that significant and major portion of time required in the guard-bands for switch configuration is avoided. Initially, B_1 is switched with its power directed on its output port o_1 only. Towards the end of B_1 and the start of B_2, for a short period of time only, the power is split on the two output ports o_1 and o_2. Towards the end of B_1, burst B_1 is switched with split power (the lost power is later compensated). When $B2$ reaches the node even with zero time gap, it can be switched on o_2 with the split power (the lost power is later compensated). After the short period at the start of B_2, power is directed only on o_2. Note that, towards the end of switching B_1, switch configuration is simultaneously done by the power splitting approach for switching the next burst B_2. Switch configurations are done such that a maximum of 3 dB variation of power level only occurs while power splitting. We use power compensators to compensate the power lost in splitting and in switch components. Such power compensation avoids repeated or cascading of power variations and power loss as a result of power splitting when bursts traverse many intermediate nodes. Adopting this switching approach has potential benefits as they