Optical Fiber Technology 46 (2018) 125–136

Contents lists available at ScienceDirect

Optical Fiber Technology

journal homepage: www.elsevier.com/locate/yofte

Hybrid wavelength conversion with dynamic pump-wavelength selection for synchronous optical packet switching

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ABSTRACT

In this paper, we propose and study the performance of two conversion schemes for optical packet switch (OPS) with the objective of reducing packet contention, and hence, improving the overall packet loss ratio (PLR). In both schemes, conversion is performed in two layers. The first layer contains a dedicated wavelength converter (WC) for each input wavelength, while the second conversion layer consists of a dynamic pump-wavelength selection (DPS) of parametric wavelength converters (PWCs) shared in a Feed-Back fashion. The first scheme uses non-circular WCs (NCWCs) with DPS of chained PWCs (called LDPSC, for short). In the LDPSC scheme, an incoming packet is accepted only if it could be assigned to its required output using only the NCWCs in the first layer or more than one PWCs in a chained fashion in the second layer; otherwise it will be dropped. The second scheme uses circular wavelength conversion (CWCs) with DPS of PWCs without chaining (named CDPS, for short). In the CDPS scheme, an incoming packet is accepted only if it can be assigned to its required output using only CWCs in the first layer or only one of the PWCs in the second layer; otherwise it will be dropped. For each of the two schemes, a matching algorithm along with a Dynamic pump conversion (DPC) algorithm is presented. The performances of the proposed schemes are compared to two conventional schemes; namely, the DPSC scheme that uses a shared pool of DPS of chained PWCs, and the LDPS scheme that uses a dedicated NCWC for each input wavelength and a shared pool of DPS of PWCs without chaining. Simulation results show that, the new CDPS scheme achieves the same performance (in terms of PLR) of the LDPS scheme, while reducing the required number of PWCs by more than 44% and 57% for conversion distances (that is the maximum number of wavelengths adjacent to any input wavelength on any one of its sides), $d = 1$ and 2; respectively. Moreover, using conversion distance $d = 1$, the new LDPSC scheme reduces the PLR compared to the LDPS scheme by up to 85% and 22% for traffic loads, 0.5 and 1; respectively. In addition, for $d = 1$, the new LDPSC scheme reduces the PLR compared to the DPSC scheme by up to 99.8% and30% for traffic loads, 0.5 and 1; respectively.

1. Introduction

Optical Circuit Switching (OCS) networks passes by three phases: circuit establishment, data transmission and circuit disconnect [1]. In circuit establishment phase, a dedicated link (circuit) is established between the source node and the destination node for each session resulting in having a reliable network. In data transmission, data/packets are explicitly transferred from the source node to the destination node passing by several intermediate nodes. In circuit disconnect, the dedicated links/circuits are tore down. Whenever the circuit establishment is confirmed, the OCS guarantees the full bandwidth of the channel for a certain service. As the circuit remains connected for the full period of the communication, low bandwidth utilization is appeared and delay that equals to the round-trip time is gained. Examples for OCS networks: public telephone network (PTN) which supports services such as plain old telephone systems (POTS) and long-distance calls; integrated services digital network (ISDN).

In Optical Burst Switching (OBS) networks, the incoming packets that arrive at the ingress node are collected considering their destination to be sent as a burst [2,3]. After that when the burst arrives the egress node, it will be disassembled to route each packet to its destination which in turn reduces the latency that results from sending each single packet separately. Thus, OBS burst latency is much lower than optical circuit setup latency. Priority based policy is used to lower the drop probability of a certain burst. Priority based policy may gives a certain burst a higher priority for bandwidth. For the seek of having different levels of priority in bufferless optical networks, authors in [4] extended the features of the just enough time (JET) protocol such as the use of the delayed reservation (DR) and the offset time. Hybrid OCS and OBS network appears to improve the network performance and to reduce costs [5].

In Optical Packet Switching (OPS) networks, incoming packet can be converted and directed to the required output wavelength as they arrive the ingress node without being collected as in the OBS network. So, no need for extra offset time between the start of the transmission of the header and its packet. Hybrid OCS and OPS network was first introduced in [6]. In OBS/OPS network, the trend to have a common circuit between several services results in having packet delay that

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https://doi.org/10.1016/j.yofte.2018.09.019
Received 11 November 2017; Received in revised form 1 September 2018; Accepted 23 September 2018

equals to the time spent in trying to retransmit the packet again and may be having packet drop. This is the reason of lower quality of the OBS/OPS networks compared to the OCS networks. On contrary with the OCS networks, OBS/OPS networks use the one-way unacknowledged reservation protocols that allow bandwidth to be adjusted easily based on the network traffic variations [7]. On contrary with the OPS networks, OBS networks require the control signal/packet to be sent singly in a reserved optical channel and in ahead of the data/burst [8].

Wavelength Division Multiplexing (WDM) is a technology that used to bundle a number of different wavelengths in a single optical fiber resulting in increasing the network capacity [9]. OPS is a WDM core optical network and considered as a promising technology for the future optical Internet [10]. OPS networks can be classified according to the process of packet switching into synchronous networks and asynchronous networks. In synchronous networks, time is divided into slots and all packets have the same size. Synchronous networks need synchronization appliance to align the arriving packets with switching time slots. In asynchronous networks, packets may have different sizes and no need for synchronization appliance as the process of packet switching may occur at any point in time.

Contention is considered as the main problem in OPS networks, which arises when several incoming packets with the same wavelength attempt to access the same recourse (output wavelength channel/output fiber) at the same time [11]. Contention can be resolved either through time domain by using fiber delay lines (FDLs), or through wavelength domain by using wavelength converters (WCs), or through space by using deflection routing [12]. FDLs are of fixed length and capable to delay the packet by a amount of time determined by the length of the line which in turn is restricted by the available physical space. WC is based on wavelength tuning and capable to convert the wavelength of an incoming packet to another one in the network. In Deflection routing method, contented packet can be sent to other output port than the required one in which packets may be delayed and arrive out of order.

OPS networks can be classified according to its switching units into single stage and multistage. In a single stage OPS networks, a switch size of $NW \times NW$ is used where N is the number of input/output fibers and each fiber consists of W wavelengths [13]. Single stage designing has bad scalability in large-scale WDM networks [14]. Multistage designing is introduced as a scalable one in which inputs is connected to outputs using several stages of fixed size switching units.

There are three types of casting packets through the network, unicast, multicast and broadcast. In unicast method, an incoming packet can be directed to only one output fiber (OF). In multicast method, an incoming packet can be directed to more than one OF [15]. In broadcast method, an incoming packet can be directed to all output fibers (OFs) in the network [16].

WC can be classified according to its conversion range into: full and limited. In the former, any wavelength can be converted to any other wavelength in the network, whereas in the latter, a wavelength can be converted to a limited set of wavelengths.

Limited WC (LWC) can be classified according to the ability to wrap around boundaries as circular and non-circular WC. In non-circular WC (NCWC) no wrap around boundaries so, conversion degrees (defined as the total number of accessible wavelengths above and below a certain input wavelength in addition to the input wavelength itself) for wavelengths in upper and lower boundaries are lower than the one for intermediate wavelengths resulting in having higher packet loss rate (PLR) [17]. Circular WC (CWC) able to wrap around boundaries such that all the wavelengths have the same conversion degree.

In [18], authors showed that limited wavelength conversion in synchronous networks has a performance close to the performance gained by using full wavelength conversion. Also, in [19] authors showed that the circular wavelength conversion in asynchronous networks with the distance of conversion, d (the maximum number of adjacent outgoing wavelengths on both of its upper and lower sides), equals to 1 or 2 has a performance close to the performance gained by using full wavelength conversion.

Any WC is capable to convert only one incoming wavelength to another at a time, whereas, any parametric wavelength converter (PWC) is capable to allow several wavelengths conversion at a time. In PWC, a pump is set in the middle of the original and the converted wavelength where those two wavelengths are called a conversion pair. Based on the assigned pump, each PWC can be used by a number of conversion pairs.

As the conversion range and/or the number of used converters increases, the complexity and the cost of the converters increases [20–22] so, the trend is to design OPS architectures with small conversion range and small number of used converters. Accordingly, in this paper, we propose two hybrid cost effective schemes with reduced PLR without increasing the conversion distance d and with lower number of the used PWCs. The two proposed schemes have a dedicated WC for each input wavelength and a shared pool of PWCs are used. Two layers algorithms are provided in which each layer is attached by a certain type of converters.

The rest of the paper is organized as follows: Section 2 gives a brief review for conventional OPS architectures and provides basic concepts of WCs and PWCs. In Section 3, the proposed matching algorithms of the proposed schemes are introduced. In Section 4, the simulation results and analysis are provided. Finally, conclusions are given in Section 5.

2. Background and basic concepts

In this section, we give a review of conventional OPS architectures and provide a brief overview of NCWCs, CWCs and PWCs.

2.1. Contention resolution techniques in OPS

Proposed schemes in OPS can be classified (according to the selected pump-wavelength for the PWC) into four schemes, the static pump-wavelength assignment (SPA) [23], static pump-wavelength assignment with chained parametric wavelength conversion (SPAC) [24], the dynamic pump-wavelength selection (DPS) [25] and the dynamic pump-wavelength selection with chained parametric wavelength conversion (DPSC) [26]. Where word static means that the pump-wavelength is statically pre-assigned for each PWC for every time slot. The word dynamic means that the pump-wavelength is dynamically changed (based on the incoming requests) for each PWC for each time slot. The word chain means that more than one PWC is allowed to do the conversion.

The SPA scheme can be adopted using two polices, the number rich (NR) policy and the variety rich (VR) policy whereas the SPAC scheme can be adopted using only the VR policy. Using the NR policy, all PWCs are assigned the same pump-wavelength which equals $\frac{W+1}{2}$ where W equals the number of wavelengths. Using the VR policy, each PWC has a different pump-wavelength which is placed in an interval called the pump-wavelength interval and takes values from $\lceil\frac{M-1}{2}\rceil$ to $W-1$ where M equals the number of PWCs. The pump-wavelength interval has a lowest wavelength λ_l and a highest wavelength λ_h so, the interval size equals $h-l$ and the values of l and h are placed as follows:

$$l = \frac{(W+1-(h-l))}{2} \tag{1}$$

$$h = \frac{(W+1+(h-l))}{2} \tag{2}$$

Taking into consideration that the pump-wavelength of PWC_1 will take the value of λ_l and the pump-wavelength of PWC_M will take the value of λ_h and the pump-wavelength λ_{p_m} for any other PWC can be placed as follows: