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CoCONet: A collision-free container-based core optical network

Amin R. Mazloom *, Preetam Ghosh, Kalyan Basu, Sajal K. Das

CReWMaN, The University of Texas at Arlington, Arlington, TX 76019-23015, USA

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ABSTRACT

Electrical-to-optical domain conversions and vice versa (denoted by O/E/O conversions) for each hop in optical core transport networks impose considerable capital and financial overhead on the providers. In this paper, we propose a full-mesh topology driven core network with a central scheduler that handles the task of signaling and coordination among slot transmissions for every hop to eliminate such O/E/O conversions. We introduce the concept of a *container* as a macro data unit that forms a separate layer in the protocol stack above the optical layer. A *FAST* centralized scheduling algorithm is proposed based on a preemptive scheduling technique that can ensure that there are no collisions between the containers. We also analyze the complexity of this algorithm. Next we design the logical architecture for the core and edge switches following the *de facto* policy of moving the complexity to the edge. We also designed a hierarchical architecture for the edge switch and provide the respective block diagrams. To get a more concrete design prototype, we further proposed a generic (vendor independent) physical architecture for a single port of the switch considering SONET/SDH on the access side. Moreover, we develop a concise delay model for the containers to analyze the packet arrival process and derive the optimal container size, based on the link speed. Finally, we present some simulation results to study the performance of the algorithms and models proposed in our work.

1. Introduction

Optical technology is the pioneer in terrestrial data hauling and demands rapid improvement to cater for the immense bandwidth demand in today's networks. The present optical burst switch (OBS) architecture has significant complexities due to the limitations of the fiber delay lines (FDL) and quality of service (QoS) management techniques. The capital expenditure on the FDLs, peripheral equipment, cooling devices and floor space is significant. Also, recent measurements from the Sprint core router network [1] identified that the major delay contribution in the core network is from the transport delay compared to the delay due to packets waiting at the router ($\frac{Routing\_Delay}{Transport\_Delay} \ll 1$). Hence, from the network throughput perspective, QoS management for different services at the core routers is less important, because the QoS management scheme does not affect the transport delay. The reduced O/E/O conversion in the core is hence a more significant challenge and motivates our work.

As the core becomes more data transparent, its function tends to involve pure packet transport. This network can be very similar to the airlines network with the hub and spoke mechanism. The hubs are completely mesh connected with very low cost and high capacity transport vehicles. This leads us to the exploration of Collision-free Container-based Optical Network (CoCONet) technology that can provide a very low cost, high capacity information transport network. The core nodes of this photonic network should utilize in-flight redirection of the bursts, and other physical layer functional requirements, where all other responsibilities are pushed to the edge. CoCONet, which is an OBS-based technology, provides this functionality besides bringing the following benefits:

* Corresponding author. Tel.: +1 469 831 0782.
E-mail addresses: mazloom@uta.edu (A.R. Mazloom), ghosh@uta.edu (P. Ghosh), basu@uta.edu (K. Basu), das@uta.edu (S.K. Das).

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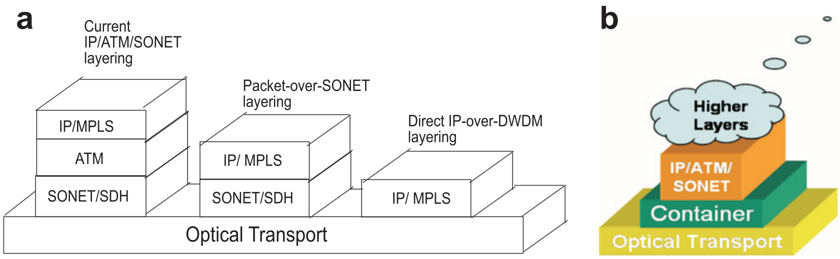

Fig. 1. (a) Traditional protocols stack; (b) CoCONet Container Protocol Stack.

- Reduces the number of electrical to optical conversions.
- Reduces the number of layers in the core network and simplifies the network architecture.
- Integrates different types of transport services, thereby minimizing the capital and operational expenditures.

The CoCONet is a full-mesh topology of N routers that are connected to a central scheduler. Data in such a network will be transported by macro data units called *containers*. Traditional protocol stacks used in today's network are shown Fig. 1a. CoCONet uses an additional layer inserted on top of the optical layer (Fig. 1b) to create an abstraction for diverse upper layers to interface with the underlying photonic network. Containers differ from traditional Multi Protocol Label Switches (MPLS) [2] as follows: (a) there is no concept of physical labelling, routing bits and forwarding class in containers, (b) the container is an end to end data unit, e.g., it will not be inspected along the path except by the destination egress router.

The central scheduler in CoCONet determines the precise transmission slots for each container at each edge switch ensuring that there is no data loss due to collisions in the network. We present the basic concept behind the central scheduling algorithm [10,11] and analyze its complexity. The full-mesh topology is required to reduce the complexity of the centralized scheduling algorithms and is not too restrictive because:

1. It is inherently simple.
2. The transmission cost being substantially low, we can now support a small number of higher capacity nodes at the core following the basic principles of Moore's law (Fig. 2). With decrease in transmission cost, the optimal working points shift to the left resulting in the reduction in the number of nodes required to be deployed. In fact, the toll network of AT&T with microwave transmission had 155 switches in 1984 whereas Sprint deployed just 36 nodes for their all-optical core network in 2005 (http://www.sprintworldwide.com/english/maps/).
3. We assume a logical mesh-physical ring topology to keep the fiber deployment cost down to a minimum.

The edge switch design is referred to as the Centralized Scheduled Time Sliced Optical Burst Switch (CSTOBS) which is a hybrid of two former signalling and data packaging techniques [3,4].

Our CSTOBS design leads to a considerable floor space saving due to the elimination of low speed CMOS-based cross-connect switches. We show that this architecture can solve most of the complexities of existing OBS mechanisms that are caused by the optical delay line, QoS management and one-way reservation [5] techniques. Recent proposals involving JET [6] and JIT [7] schemes in OBS networks have been extensively studied in [8]. These extensions try to improve the QoS of the optical network, but suffer from issues such as blocking, high set-up-delay, packet drop and low throughput due to synchronous traffic. Our goal is to make the core an all-optical, zero-packet-loss[1] network that also guarantees equal QoS to all the users.

We also study the switching functionalities of the CSTOBS, and the related delay model. Our architecture design considers a generic architecture of the edge switch with a typical access network. A template implementation diagram for a single port of the switch considering SONET network on the access side is also provided.

This work is an extended version of our work in [12,15,21] and is organized as follows: Section 2 describes the architecture of the core and edge switches. Section 3 discusses and analyzes the central scheduler. Section 4 provides the delay model for the container, while Section 5 presents numerical results. Conclusions and future works are discussed in Section 6.

2. Architecture of the photonic network and component tasks

CoCONet consists of N optical switching core and edge nodes. Each node is interconnected to all other nodes as well as to the central scheduler by high-speed optical links. Thus each node is a $(N-1) \times (N-1)$ optical switch as shown in Fig. 2a. The US core optical network currently interconnects the major NFL city hubs by optical transport using 400 Gbps optical links. Hence we assume that in the proposed core network the optical links operate at 400 Gbps on single fiber without any wavelength division multiplexing. However the λ overlay of the network is dynamic and does not guarantee that each single link shown in Fig. 2b is available all the time in the multi-hop network. On the other hand, it is also possible to have multiple light paths between two physical node-peers over a single link.

[1] Throughout this paper, the term 'packet' will refer to all upper layer data units, unless otherwise mentioned.