CONGESTION CONTROL IN OPTICAL SWITCHING NETWORKS: A SURVEY

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***Abstract*—**with the advance in technology the focus has shifted from desktops and laptops to handheld devices like tablets, phablets, mobile phones, PDA etc. giving rise in the number of users connected to internet. About 900 million computers are connected to internet. In an hour 383 thousand TB of data transmission takes place. As the traffic on internet increases giving rise to the problem of congestion. Several congestion techniques have been proposed by many researchers time to time. This paper presents a survey of congestion control approaches in high speed wired network by taking into account directions of router based congestion control. Various survey papers reported in the literature, regarding congestion control approaches, have considered router based approach independently. The research directions is considered for a particular network domain. It is a practicable idea to take a holistic view and study router base congestion control approach. The main motivation of this work is to summarize router base congestion control approach, and identify major issue and challenges in congestion control.

Keywords*—Congestion control; High speed network; Router based approach.*

I. INTRODUCTION

Network congestion in data networking and queueing theory is the reduced quality of service that occurs when a network node or link is carrying more data than it can handle. Typical effects include queueing delay, packet loss or the blocking of new connections. A consequence of congestion is that an incremental increase in offered load leads either only to a small increase or even a decrease in network throughput. Network protocols that use aggressive retransmissions to compensate for packet loss due to congestion can increase congestion, even after the initial load has been reduced to a level that would not normally have induced network congestion. Such networks exhibit two stable states under the same level of load. The stable state with low throughput is known as congestive collapse.

Networks use congestion control and congestion avoidance techniques to try to avoid collapse. These include: exponential back off in protocols such as CSMA/CA in 802.11 and the similar CSMA/CD in the original Ethernet, window reduction in TCP, and fair queueing in devices such as routers and network switches. Other techniques that address congestion include priority schemes which transmit some packets with higher priority ahead of others and the explicit allocation of network resources to specific flows through the use of admission control.

In recent years, the development of science and technology has increased user demand for computer networks, which has accelerated the severity of network congestion problems. The increase in devices having applications that require file downloading and sharing, Internet browsing, voice over Internet phone, and multimedia has also contributed to the severity of network congestion problems. Thus, efficient congestion control is a key factor to ensure IP network stability and robustness. There are two approaches in solving the network congestion problem. The first is the end-to-end approach, where research is focused on the mechanism of terminal congestion control to relieve congestion. The second is the network side approach, where congestion control is achieved through data stream scheduling and line management on the forwarding nodes. The initial research focused on the end-to-end congestion control, such as the widespread use of transmission control protocol (TCP). Because of its good adaptability and extensible capability, TCP has received widespread interest and became the main congestion control algorithm presently. Researchers in this area have conducted significant exploration and investigation and have put forward many improvements. For example, the latest versions of the four kinds of TCP congestion control algorithms, namely, Veno, Westwood, Hybla, and Cubic, have achieved optimization by packet loss judgment, bandwidth prediction, time delay compensation, and homogeneous compensation mechanism, respectively [1–3]. Paper [4] has studied the micro-level behavior characteristics of TCP congestion control algorithm in multichip wireless networks. Paper [5] has proposed an adaptive cross-layer-based TCP congestion control for 4G wireless mobile cloud access. A deadline-aware congestion control mechanism, based on a parametrization of the traditional TCP New Reno congestion control strategy, has been proposed in [6]. The appropriate limit of the biggest transfer rate of each data flow can effectively reduce network congestion and packet loss. However, previous studies reported that when the underlying network and information flow are unknown, TCP must increase or reduce the size of congestion window to adjust to the changes of traffic [7–9]. This finding highlighted that the traditional IP network lacks the direct control of forwarding queue and cannot guarantee link utilization and quality of service. We have considered this aspect in our research to find a solution for the network congestion problem. In the traditional IP network architecture, the control and forwarding planes are highly integrated, and the network is difficult to extend and customize. It has a long technology update cycle and is too dependent on network equipment manufacturers. Simultaneously, the increasingly complex network environment makes it difficult to develop the network and make innovations related to the hardware of physical devices or software of related protocols and performances, especially in the proprietary equipment and closed interfaces. Programmable models and code that allow data transmission from the network to the application are needed. The technology of software-defined everything from applications to infrastructure is one of the top 10 strategic technology trends identified by Gartner [10]. Software-defined networking (SDN) separates the network control and forwarding functions, enabling the network to be directly programmable, dynamic, and manageable. The separation of the control plane and data plane allows the core technology Open Flow to realize the flexible control of the network traffic, making the network more intelligent, and provide a better platform for network application innovation [11–13].

In the next section, we discuss waveband switching (WBS), followed by a description of photonic slot routing (PSR). Then, optical flow switching (OFS) is explained. The next two sections deal with optical burst switching (OBS) and optical packet switching (OPS), respectively. We then briefly interpret some recent switching techniques as derivatives of the presented switching trends, and the final section concludes the article.

II. BACKGROUND

A. *Waveband Switching*

Compared to ordinary optical cross connects (OXCs), so called multi-granularity OXCs (MG-OXCs) hold great promise to reduce significantly the complexity, size, and cost of OXCs by switching fibers and wavebands together without demultiplexing the arriving WDM comb signal into its individual wavelengths, giving rise to WBS. As a result, the size of ordinary cross connects that traditionally switch at the wavelength granularity can be reduced, including the associated control complexity and cost, by using a single input/output port instead of multiple input/output ports, one for each individual wavelength. A typical multi-granularity photonic cross connect, consisting of an MG-OXC at the fiber (FXC), waveband (BXC), and wavelength (WXC) layers, as well as a digital cross connect (DXC) [16]. The MG-OXC allows to switch, as well as to add and drop traffic at multiple granularities by deploying a bank of transmitters and receivers. Traffic can be shifted from one granularity level to another by using appropriate multiplexers (MUX) and demultiplexers (DEMUX). For sub-wavelength switching the MG-OXC is equipped with an additional DXC that performs optical-electronic-optical (OEO) conversion. By using MG-OXCs, fibers and wavebands that carry in-transit traffic are not required to undergo demultiplexing and multiplexing.

B. *Waveband Grouping*

To determine which wavelengths to group together into a single waveband, several waveband grouping strategies exist, which can be categorized into end-to-end or intermediate approaches. In [17], an end-to-end waveband grouping strategy that groups wavelengths with the same source-destination pair into a waveband was compared with an intermediate waveband grouping strategy that groups wavelengths with the same destination at an intermediate node. The obtained results indicate that intermediate waveband grouping strategies outperform end-to-end grouping strategies in terms of required ports at MG-OXCs.

C. *Routing and Wavelength Assignment*

The routing and wavelength assignment (RWA) problem in WBS networks that use MG-OXCs is, in general, more involved than that in conventional wavelength-switching networks due to additional constraints, apart from wavelength continuity. Several new RWA-related problems in WBS networks were identified and solved. The so-called routing and wavelength/tunnel assignment (RWTA) problem deals with the bundling and switching of wavebands and fibers and routing lightpaths through them [18]. The so-called RWA+ problem is formulated as a combinatorial optimization problem with the objective to minimize the bottleneck link utilization of mesh WBS networks [19]; whereas the so-called routing, wavelength, and waveband assignment (RWWBA) problem aims at maximizing cost savings in terms of required MGOXC ports and minimizing blocking probability in mesh WBS networks [20]. The benefits of various types of wavelength conversion on solving the RWA problem in WBS networks were examined in [21].

D. *TDM Switching and Grooming*

The additional DXC is used to perform TDM switching and grooming in the electrical domain by means of OEO conversion of wavelengths and wavebands. Grooming allows for grouping multiple low-volume traffic flows into a wavelength or waveband and thereby improve their bandwidth utilization. In [22], a design study of networks based on a hybrid WBS-OEO grooming switch architecture was performed taking physical transmission impairments into account to study the maximum distance and number of nodes the optical signal can traverse without undergoing OEO conversion.

E. *Photonic Slot Routing*

To improve the utilization of lightpaths under burst traffic without requiring electronic traffic grooming at the source node, a cost-efficient design approach for WDM networks called PSR was proposed in [23]. In PSR networks, time is divided into fixed-size slots, whereby each slot spans all wavelengths, and slot boundaries are aligned across all wavelengths. The resultant multi-wavelength slot is called a photonic slot. Each wavelength in the photonic slot may contain a single fixed-size packet. Furthermore, all packets in a given photonic slot must be destined for the same node, but each photonic slot may be destined for a different node. As a consequence, the photonic slot can be routed as a single entity, thereby avoiding the need for demultiplexing the individual wavelengths and routing them individually. Thus, PSR networks require no wavelength-sensitive components, resulting in lower network costs by using wavelength-insensitive components and reduced complexity of switching nodes.

PSR Functions PSR nodes perform the following three functions on a per photonic slot basis [24]:

- Photonic slot routing: photonic slots arriving on any input port are switched to any output port, possibly invoking contention resolution (see below).
- Photonic slot copying: a photonic slot arriving on an input port is duplicated and switched to two or more output ports, giving rise to multicasting.
- Photonic slot merging: photonic slots concurrently arriving on multiple input ports are switched to the same output port. Synchronization

To achieve the aforementioned functions, PSR requires mechanisms to achieve and maintain network wide slot synchronization such that photonic slots arrive synchronized at PSR nodes. One possible solution is the use of fiber delay lines (FDLs) at the input ports of PSR nodes to delay and synchronize arriving photonic slots [24]. Another way to achieve network wide synchronization for a two-layer PSR networks was described in [25]. Contention Resolution a PSR node that deploys switched delay lines (SDLs) to resolve contention [26]. The PSR node consists of a wavelength-insensitive optical packet switch, SDLs to temporarily store photonic slots, and electronic buffers to hold locally generated packets. Each SDL comprises FDLs interconnected by photonic cross-bar switches that are set to delay photonic slots until contentions at the output ports are resolved. Evolution toward OPS By breaking up the photonic slot and switching each wavelength independently, PSR can be transformed into individual wavelength switching (IWS). It was shown in [24] that the network capacity can be increased significantly by carefully replacing a relatively small percentage of conventional PSR switches with IWS switches. IWS enables smooth migration paths from PSR networks to (synchronous) OPS networks, which are discussed in greater detail in the next section.

F. *Optical Flow Switching*

One of the main bottlenecks in the current optical Internet is electronic routing at the IP layer. To alleviate this electro optical bottleneck, routers can be offloaded by switching large transactions and/or long-duration flows at the optical layer, leading to so-called OFS [27]. In OFS, a dedicated lightpath is set up for the transfer of large data files or upon detection of long-duration flows, whereby flows with similar characteristics (e.g., same destination IP router) may be aggregated and switched together by means of grooming to improve the utilization of the established lightpath. Because in OFS the setup of a lightpath takes at least one round-trip time between source and destination IP routers, clearly, the size of a transaction/flow should be in the order of the product of roundtrip propagation delay and line rate of the lightpath. The set-up lightpath enables the optical bypassing of intermediate IP routers and thereby eliminates the need for (electronic) packet processing, for example, buffering, routing, and so on. It is important to note that OFS can be end-user initiated or IP-router initiated [28]. OFS offers the highest-grade quality of service (QoS) because the established lightpath provides a dedicated connection. However, OFS must determine carefully when to set up a lightpath because wavelengths are typically a scarce network resource. The dynamic lightpath set-up in OFS requires flow routing, wavelength assignment, and connection set-up through signaling. In [29], the following two integrated OFS approaches were proposed for dynamic lightpath set-up in OFS networks:

- **Tell-and-go (TG) reservation:** TG is a distributed algorithm based on periodic or event-driven link state updates that allow each node to acquire and maintain global network state. TG uses a combined K-shortest path routing and first-fit wavelength assignment approach. Connection set-up is achieved by one-way reservation, where the control packet precedes the trailing optical flow along the chosen route.
- **Reverse reservation (RR)**: In RR, the initiator of an optical flow sends link state information gathering packets to the destination node on the K shortest paths. Upon arrival at the destination, route selection and first-fit wavelength assignment are performed by the destination node, and a reservation control packet is sent along the chosen path in reverse to establish the connection.

G. *Optical Burst Switching*

OBS aims at combining the transparency of optical circuit switching with the statistical multiplexing gain of optical packet switching [30]. In OBS, only preceding control packets carried on one or more control wavelength channels undergo OEO conversion at each intermediate node, whereas data is transmitted and all-optically switched at the burst level on a separate set of data wavelength channels. OBS is best explained by first discussing the functions executed by users at the edge of an OBS network, followed by a description of the functions performed by OBS nodes inside an OBS network [31].

H. *OBS Network Edge*

Each edge-OBS user executes the following four functions: Burst assembly: OBS users collect traffic originating from upper layers, for example, IP, sort it based on destination addresses, and aggregate it into variable-size data bursts by using appropriate burst assembly algorithms. Most burst assembly algorithms use either burst-assembly time or burst length or both as the criteria to aggregate bursts. Typically, the parameters used are a time threshold T and a burst-length threshold B, which can be fixed or dynamically adjusted. Various time and/or burst length-based assembly algorithms can be designed based on these thresholds [32]. Under a light load, a burst length-based assembly algorithm does not provide any constraints on the queuing delay of packets that wait to be aggregated into a burst of size B. A time-based assembly algorithm could solve this problem because it sends out the burst after time T at point P2. Under heavy traffic, however, a burst-length algorithm leads to smaller average queuing delays because it already sends out the burst at point P1. Clearly, it is desirable to use mixed time/burst length-based assembly algorithms. Signaling: in OBS, there are two types of signaling.

•Distributed signaling with one-way reservation

•Centralized signaling with end-to-end reservation

In the more common one-way reservation scheme, a source OBS user sends a control packet on a separate out of-band control channel prior to transmitting the corresponding burst. The control packet contains information about the burst, for example, size and offset (defined shortly), and is OEO converted and electronically processed at each intermediate OBS node. Examples of one-way reservation are so-called just-in-time (JIT) and just-enough-time (JET) signaling. In the less frequently used centralized signaling approach, OBS users send their connection set-up requests to a central server that sends ACKs to the requesting edge-OBS users upon connection establishment. Routing and wavelength assignment: Routing in OBS networks can be done either on a hop-by-hop basis by deploying GMPLS routing protocols to compute explicit or constraint-based routes. Along the selected path, each link must be assigned a wavelength on which bursts are carried. Offset: After sending the control packet, an OBS user waits for a fixed or variable delay, called offset, until it starts transmitting the corresponding burst. The offset is used to enable the control packet to be processed, reserve the required resources, and configure the optical switching fabric at intermediate OBS nodes, such that the arriving burst can cut through each intermediate OBS node without requiring any buffering or processing. Note that by using different offsets, traffic classes can be isolated and service differentiation can be achieved [33].

I. *OBS Network Core*

OBS nodes located in the core of OBS networks perform the following two functions: Scheduling: Based on the information carried in the control packet, resources inside the optical switching fabric of a core OBS node are reserved and released for either explicitly signaled or estimated start and end times. Available burst scheduling algorithms can be categorized into non-void-filling and void-filling algorithms [34]. Contention resolution: Contention occurs if two or more simultaneously arriving bursts contend for the same local resources of a given core OBS node. Several techniques for contention resolution in OBS networks have been investigated, for example, optical buffering (FDL, SDL), deflection routing, wavelength conversion, and burst segmentation, or any combination thereof.

J. *OBS MAC Layer*

To implement the aforementioned functions, a medium access control (MAC) layer is required between the IP layer and the optical layer [35].Note that the functional blocks correspond to the previously described functions executed by edge-OBS users and core-OBS nodes.

K. *Optical Packet Switching*

One might argue that economics will ultimately demand that optical network resources are used more efficiently and the switching granularity is decreased to optical packets, resulting in OPS [36]. Unlike OBS, OPS does not require edge routers to perform any burst (dis)assembly algorithms at the network periphery. Moreover, in OPS, the header is generally not sent on a separate control wavelength channel, thus avoiding the issue of properly setting the offset time. OPS can be viewed as an attempt to mimic electronic packet switching, most notably asynchronous transport mode (ATM) and IP, in the optical domain while taking the shortcomings and limitations of the current optics and photonics technology into account, for example, the lack of optical random access memory (RAM) and the limitation of optical logical operations. An interesting approach to realize practical OPS networks in the near term is the so-called optical label switching (OLS) [37]. In OLS, only the packet header, referred to as a label, is processed electronically for routing purposes, whereas the payload is switched in the optical domain.

L. *Optical Packet Switches*

OPS networks can be either slotted or unspotted networks that deploy synchronous or asynchronous switches, respectively. OPS node architecture where its building blocks perform different functions [38]:

• Input interface: The input interface performs packet delineation. In the case of synchronous switches, synchronization is done for the performing phase alignment of arriving packets. Next, the packet header is extracted, OE converted, decoded, and forwarded to the control unit. The control unit processes the routing information, configures the switch accordingly, updates the header information, and forwards the header to the output interface.

If necessary, the external wavelength of an arriving optical packet is converted to an internal wavelength for use in the switching matrix.

• Switching matrix: The switching matrix carries out the switching operations of the payload in the optical domain. Additionally, it also resolves contention (see below).

• Output interface: The output interface performs amplification, reshaping, and retiming (3R) regenerative functions. Furthermore, it attaches the updated header to the corresponding optical packet and performs packet delineation. In synchronous switches, the output interface also performs packet resynchronization. When required, it converts internal wavelengths back to external wavelengths.

Based on the switching fabric, OPS nodes can be classified into the following three categories:

- Space switch
- Broadcast-and-select
- Wavelength-routing OPS node architectures

Contention Resolution Similar to OBS, contention in OPS networks can be resolved by using buffering, wavelength conversion, and deflection routing, or any combination thereof. Deflection routing simplifies the OPS node architecture in that no buffers are required. On the downside, however, deflection-routed packets generally consume more network resources, incur higher delays, and may require packet reordering mechanisms at the destination nodes to achieve in-order packet delivery.

Typically, optical buffers are implemented by using an array of FDLs of different lengths or SDLs. According to the position of the optical buffer, OPS nodes can be classified into four major configurations:

- Output buffering
- Shared buffering
- Recirculation buffering
- Input buffering

All these optical buffering schemes can be implemented in either single-stage or multiple-stage OPS nodes in a feed-forward or feed-back configuration... It is important to note that optical buffers realized by FDLs or SDLs offer only fixed and finite amounts of delay, as opposed to electrical RAM. Service Differentiation Service differentiation in OPS networks is closely related to the techniques chosen to resolve contention. Apart from using one or more of the aforementioned dimensions of space, time, and wavelength, service differentiation also can be achieved by means of preemption and packet dropping. With preemption, a high-priority packet is allowed to preempt an OPS node resource currently occupied by a low priority packet, which is then discarded. With packet dropping, an OPS node drops low-priority packets with a certain probability before attempting to utilize any resources, resulting in a decreased packet loss of high-priority packets.

III. CONCLUSION

We have presented the current trends in switching techniques for next-generation optical networks and explained their underlying concepts and mechanisms. Each of these trends has its own specific strengths and limitations and may be deployed depending on various criteria, such as costs, capacity requirements, and traffic characteristics. Our comprehensive overview of the current trends of optical switching provides a framework for anticipating new switching techniques, such as hybrid techniques that exploit the different switching granularities offered by the presented switching techniques. The discussed optical switching techniques significantly improve the flexibility of the data plane by providing a wide range of different temporal and spatial switching granularities. For commercial viability, however, further research is required to reduce the complexity introduced to the control and management planes by each of these optical switching techniques.

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