Cooperative Clustered Architecture and Resource Reservation for OBS Networks

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***Abstract*-- Resource contention is a major concern in Optical Burst Switching networks that leads to relatively high burst loss probability. This article presents a clustered architecture for OBS networks, called Cooperative Clustered Optical Burst Switching (C2OBS) network architecture. In this architecture, the network is divided in overlapping zones/clusters with a zone/cluster head having the knowledge of available resources within the zone called Zonal Information Base (ZIB) and maintains a short resource usage history called Short History Base (SHB). Furthermore, a resource reservation strategy for the proposed Cooperative Clustered OBS network architecture (C2OBS-RR) is also presented which is centralized within the zone and distributed in the overall network, for combining the benefits of both the centralized and the distributed resource reservation schemes. This novel approach uses the zonal state of the resource availability, ZIB, so that the bursts originating at the ingress nodes in the same part of network having been assigned the same wavelength, can be assigned different time offsets. This will proactively reduce the probability of contention at the intermediate nodes within a zone and is expected to significantly reduce the overall network burst loss probability. For illustration purpose, the proposed C2OBS architecture has been applied to the European Optical Network.**

Keywords- Optical Burst Switching; Resource Reservation; Resource Contention Avoidance.

I. INTRODUCTION

Optical Burst Switching (OBS) is a promising technology for supporting the next generation Internet over Dense Wavelength Division Multiplexing (DWDM) network. An OBS network consists of Edge and Core nodes. Edge nodes may be ingress or egress nodes. The edge nodes are the electronic transit points between the burst-switched backbone and the legacy networks. In the existing OBS architecture, the ingress node performs burst assembly, routing, wavelength assignment, signaling and edge scheduling. The main tasks performed by core nodes are signaling, core scheduling, routing/forwarding, and contention resolution. The core nodes are mainly composed of an optical switching matrix and a switch control unit which is responsible to forward optical data bursts [1][2][3][8].

The ingress node receives packets from the client network, assembles a burst and sends a corresponding Burst Header Packet (BHP) on the control channel. The BHP is received at the input module of core node containing source and destination addresses, burst offset time, burst length and the Class of Service (CoS) of the corresponding data burst. The purpose of the BHP is to reserve the necessary resources at each core node along the path for transmitting the burst. Three reservation schemes have been proposed, namely the Centralized Resource Reservation [4], the Distributed Resource Reservation [5], and the Intermediate Node Initiated (INI) Resource Reservation scheme [6][7].

The Centralized two-way Resource Reservation mechanism proposed in Wavelength Routed OBS networks [4], exploits the knowledge of network wide resources availability to optimize resource reservation, but is more complex to implement and increases the transmission latency due to its two way resource reservation process. The advantages and limitations of this reservation scheme are mentioned in [8].

In the Distributed Resource Reservation mechanism, resources can either be reserved using two-way resource reservation, labeled as Tell-And-Wait (TAW), or one-way resource reservation, designated as Tell-And-Go [8][9] (TAG). TAW relies on establishing a virtual circuit prior to starting burst transmission. More precisely, a BHP is sent from the ingress node towards the egress node to reserve transmission capacity at all the intermediate nodes along a given routing path. When the reservation is successful in the entire path, an acknowledgment message is sent back to the ingress node, which then starts transmitting the data burst. Otherwise, the node detecting resource shortage sends a negative acknowledgment message back to the ingress node to release the reserved resources. Importantly, the delay imposed to data bursts by the resource reservation mechanism, which for TAW is defined as the time elapsed between assembling a data burst and initiating its transmission at the ingress node after receiving the acknowledgment, is equal to or larger than the Round Trip Time (RTT) between the ingress and egress nodes. This is the major limitation of TAW, which may adversely affect the quality of real time delay sensitive traffic.

One-way resource reservation, or TAG, shortens the delay imposed on data bursts by starting the burst transmission shortly after sending the BHP to the core nodes along the routing path without waiting for an acknowledgment of a successful reservation. In this reservation scheme, the reservation may be immediate like in JIT [10], JIT+ [5] and E-JIT [12][13] or delayed as in JET[5] and Horizon [5]. However, in TAG, the burst loss probability is relatively high but end-to-end delay is less than TAW. Therefore, neither TAG nor TAW reservation schemes can have both low latency and low burst loss at the same time.

In the INI Resource Reservation scheme, the reservation request is initiated at an intermediate node, called the initiating node. In the first part of the path, from ingress node to the initiating node, the INI Resource Reservation works with an acknowledgement for the BHP, similar to TAW, and from the initiating node to egress node, it follows the JET reservation scheme. The burst loss probability with INI is less than with JET, and the end-to-end delay in less than with TAW. However, the selection of the initiating node in INI resource reservation scheme is a critical issue, and may be considered as a bottleneck of the proposed solution [8]. Moreover, the intermediate node does not have knowledge of network wide resource availability and cannot optimize the resources reservation and utilization.

This article proposes a novel clustered architecture (C2OBS) and resource reservation strategy for clustered OBS network (C2OBS-RR). The C2OBS-RR strategy will decrease resource contention, reduce the burst drop probability as compared to TAG, and the reservation waiting time as compared to the centralized reservation scheme and TAW as explained in Section III. In C2OBS, the whole network is divided into overlapping zones with a Zone Head (ZH) and Backup Zone Head (BZH). A centralized reservation scheme is utilized only within the zone exploiting the zonal knowledge of resources available at the ZH, while the distributed reservation is employed across the zones. The purpose of the combined strategy is to overcome the shortcomings of the centralized and the distributed resource reservation techniques, while retaining the best of both approaches where appropriate. Across zones a distributed reservation is employed to reduce overall latency while keeping a centralized approach within the zone for reducing the burst loss probability.

A further improvement included in the C2OBS architecture consists of the utilization of a single shared module of Wavelength Convertors (WCs) and Fiber Delay Lines (FDLs) bank placed either at a central location or at the ZH within each zone for resolving contention within the zone. This solution is also attractive from network planning perspective because this module can be easily enhanced or replaced keeping in view the future estimated traffic load.

The article is organized as follows. In Section II, an enhanced architecture called Cooperative Clustered Optical Burst Switching Network architecture is presented. In this section, the same concept has been applied to the European Optical Network (EON) for illustration. Section III presents the proposed resource reservation strategy for reducing the overall network burst loss probability. This section also provides an application of C2OBS-RR to EON topology for illustration. Section IV discusses the expected benefits of the proposed C2OBS architecture and of the C2OBS-RR strategy by comparing it with the existing resource reservation paradigms. Finally, Section V provides conclusion and highlights future work directions.

II. PROPOSED COOPERATIVE ARCHITECTURE

In the C2OBS architecture, the network is partitioned into overlapping zones/clusters as shown in Figures 1 and 2. The zone is defined in terms of number of hops and not physical distance, because we can limit the dissemination of control information based on the number of hops, by using the Time to Live (TTL) value as in IPv4 header, or the HopLimit value as in the IPv6 header [14]. The zone size should be small to reduce dissemination of control information. Furthermore, the gateway (explained later) does not allow the broadcast “Hello messages” from the Zone Head (ZH) to pass through, as such information is not required in adjacent zones. As the zones are overlapping, there will be one or more nodes that will be part of more than one zone and acts as gateway and backup gateway. For example, in Figure 2, Copenhagen (COP) serves as a gateway among Z-3, Z-4 and Z-5 because it is common to the three zones. Similarly, Prague (PRA) is common between zone two and four and functions as a gateway between these zones. Each zone has a Zone Head (ZH) and Backup Zone Head (BZH). For example, the node at Paris (PAR) is a ZH for Z-1. The ZH keeps the information of all of the nodes within the zone. The BZH duplicates the tasks performed by the ZH, either in case of failure of the ZH or if the ZH is overburdened with other processing tasks like performing the job of a gateway and stops broadcasting its “Hello messages”. The role of the ZH is further elaborated in section III. The other members of the zone are referred to as Zone Members (ZMs).

The ZH is dynamically elected with a criterion as the node with the highest degree in the zone. This condition has been imposed because in most cases the ZMs will be directly connected to the ZH and it will be possible for ZMs to communicate with the ZH with the least propagation delay for resource reservation. Furthermore, the ZH needs not to be fixed, because if a node is busier in processing other jobs and cannot efficiently process the ZM’s requests, it will leave its role as ZH and BZH will take over its responsibility. As the BZH will become the ZH, other ZMs will take part in election to become BZH and the node with highest degree will win and will become the BZH. Even in case of failure of ZH, the similar procedure will take place.

Each zone will have common shared wavelength convertors (WCs)/ Fiber Delay Lines (FDLs) bank for contention resolution. This shared bank of WCs/FDLs in a zone is our novel idea and has never been proposed in literature as per our knowledge. This shared bank can be installed at a central location as in Figure 1 or may be placed along with of optical switch having highest degree as shown in Figure 2.

Optimal wavelength converter placement in optical networks has been shown to be NP-hard, and many heuristics have been proposed [15], but still this is an open research area. In optical networks, where do we optimally place the WCs/FDLs is a vital question.

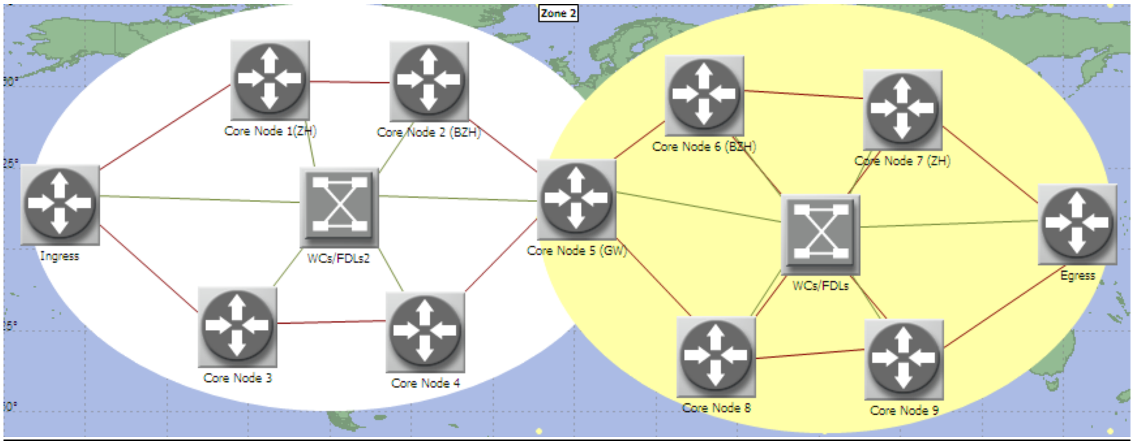

Figure 1. OBS Network Architecture showing ZH, BZH and shared WCs/FDLs

One of the possible solutions is to place the WCs at each output port of the optical switch. This solution is not cost effective as WCs may not be required all the time and it is the wastage of expensive resource. As wavelength convertors are still expensive, providing dedicated wavelength convertors is not a cost effective solution [3][15], the proposed shared WCs/FDLs bank architecture provides a reasonable solution for placement of WCs in OBS network. The WCs/FDLs bank can be accessed by any incoming burst that needs wavelength conversion/buffering. This will also make the network planning simpler and economical because this module can be upgrade as per requirement keeping in view the future increase in traffic without upgrading/replacing the optical switches. This shared architecture will also improve the utilization of this resource (WCs/FDLs) because all the nodes within the zone will use the same resource for wavelength conversion and optical buffering. This will make the OBS networks economically more feasible as augmenting each node with WCs/FDLs is an expensive solution [15]. Although, the use of WCs/FDLs will be minimized as much as possible by using effective resource reservation scheme explained in the next section and this will act as a last resort to save the burst from blocking. In this way, the requirement for number of WCs/FDLs will be reduced, which is technically and economically more attractive.

The proposed architecture has been named Cooperative Clustered Optical Burst Switching architecture because the Gateway nodes in the network cooperate for successful resource reservation in the adjacent zone and tries to reduce the burst blocking probability.

As an illustration, the clustered network architecture model has been applied to European Optical Network (EON) topology [16][17] as shown in Figure 2. The EON topology consists of 20 nodes and 38 links. The network has been divided into five zones (Z-1 to Z-5) and detail about the role of each node in the zone is depicted in Table 1. The table shows the status of each node in its respective zone, i.e. whether the node is Zone Head (ZH), Zone Member (ZM) and Gateway (GW). It also indicates the degree of the node in the network, which is a key selection criterion for the role of ZH. In Figure 2, the WCs/FDLs bank has been shown along with the ZH and the circle, oval and cloud shapes has been used to represent different zones in EON and has been labeled as Z-1 to Z-5.

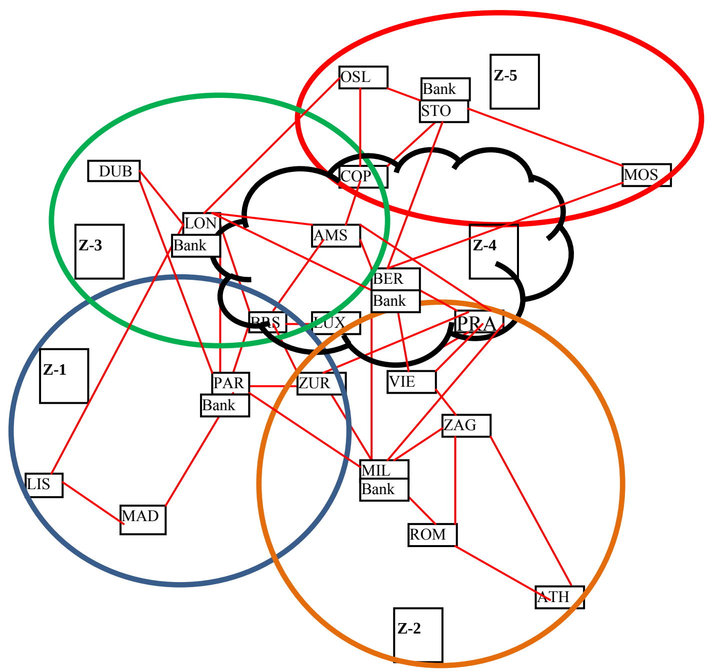

Figure 2. Cooperative Clustered OBS Network Architecture for EON

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Table.1. Node Description of EON

S.No	Location of Node	Zone Member	Member Status	Degree of Node
1.	Libson (LIS)	Z-1	ZM	2
2.	Madrid (MAD)	Z-1	ZM	2
3.	Paris (PAR)	Z-1	ZH	**6**
4.	Brussels (BRS)	Z-1, Z-3 & Z-4	ZM & GW	5
5.	Zurich (ZUR)	Z-1 & Z-2	ZM & GW	4
6.	Athens (ATH)	Z-2	ZM	2
7.	Rome(ROM)	Z-2	ZM	3
8.	Zagreb (ZAG)	Z-2	ZM	4
9.	Vienna (VIE)	Z-2	ZM	3
10.	Milan (MIL)	Z-2	ZH	**6**
11.	Prague (PRA)	Z-2 & Z-4	ZM & GW	5
12.	London (LON)	Z-3	ZH	**7**
13.	Dublin (DUB)	Z-3	ZM	2
14.	Amsterdam (AMS)	Z-3 & Z-4	ZM & GW	5
15.	Berlin (BER)	Z-4	ZH	**7**
16.	Luxemburg (LUX)	Z-4	ZM	1
17.	Copenhagen (COP)	Z-5 & Z-3	ZM & GW	3
18.	Moscow (MOS)	Z-5	ZM	2
19.	Stockholm (STO)	Z-5	ZH	**4**
20.	Oslo (OSO)	Z-5	ZM	3

III. PROPOSED RESOURCE RESERVATION STRATEGY

The C2OBS-RR scheme utilizes centralized reservation for intra-zonal traffic. Centralized reservation is also used for inter-zonal traffic between the ingress node and the zone gateway. Then the gateway prompts the next ZH which becomes responsible for reserving the necessary resources for the upcoming burst. The process is repeated until the burst reaches the zone where the egress node is located.

Although resource reservation is centralized within each zone, it may also be considered as distributed for inter-zonal traffic because a degree of cooperation is required among multiple ZHs and gateways.

In the C2OBS-RR scheme, the ZH acknowledges the BHP by consulting its Zone Information Base (ZIB) and Short History Base (SHB) thereby reducing delay compared to wavelength routed OBS (WROBS) which requires end-to-end acknowledgement [4].

Moreover, while also employing distributed reservation for inter-zonal traffic, the proposed strategy does not require end-to-end acknowledgement like Tell & Wait (TAW) thus reducing delay, and uses zonal knowledge for resource reservation, thereby reducing the burst loss probability compared to Tell & Go (TAG).

For intra-zonal traffic, the ingress node requests resources from the ZH by transmitting a BHP using a control channel. The ZH consults both its Zone-Base, for assigning route and free wavelength, and its Short History Base (SHB) to assign a suitable offset time for avoiding contention at the intermediate core nodes. The SHB is dynamically updated with offset times assigned to bursts as the transmissions from different ingress nodes proceed within the zone. The ZH acknowledges the BHP by transmitting amended BHP containing information about offset time, routing and wavelength assignment for the incoming burst transmission, which is estimated/predicted based on knowledge inferred from the data stored in the ZH. The same amended BHP is forwarded to the intermediate nodes and the egress node for the necessary switching configuration. The routing and wavelength assignment problem has been dealt with in a separate article in detail while the suitable offset time issue is discussed below.

The minimum offset time can be given by [5][7]

$$T_{offset}^{\min} = kT_{BHP} + T_{SW} \quad (1)$$

where k is the number of hops along the path from the ingress node to the egress node, T_{BHP} is the header processing time, and T_{SW} is the switch configuration time. However, the ingress node may also use a larger value for service differentiation [5][18], if necessary.

In the C2OBS-RR strategy the ZH calculate T_{offset}^{total} by looking at the ZIB for the number of hops in the burst route. Then, for avoiding contention it calculates an extra offset time δT by looking for all previously scheduled channels in the SHB. The extra offset is meant to isolate traffic form different ingress nodes that are using overlapping paths. The total offset time for the burst can be finally given by

$$T_{offset}^{total} = kT_{BHP} + T_{SW} + \delta T \quad (2)$$

The ZH forwards the amended BHP to the ingress node and multicasts the same to the intermediate nodes in the zone for resource reservation. Upon receiving the amended BHP multi-casted by the ZH, the intermediate nodes check the value of δT and their location in the routing path and assign that value to k. The parameter k has a different meaning for both the ingress nodes and intermediate nodes. For the ingress node and intra-zonal traffic, k represents the number of hops along the path from the ingress node to the egress node while for inter-zonal traffic, it represents the number of hops from the ingress node to the zone gateway. For intermediate nodes, the node checks its position within the routing path and assigns that value to k. The intermediate nodes perform delayed reservation by using equation (2) and knowledge of both T_{BHP} and T_{SW} to calculate the burst arrival time.

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Early release is also used as the amended BHP informs about the burst length.

For the inter-zonal traffic, the ingress node also starts off by requesting resources from its own ZH. The ZH assigns a free wavelength, a suitable offset time and a route only up to the zone gateway, and amends the BHP with this information. The amended BHP is also forwarded by the ZH to all intermediate nodes till the zone gateway. Then, it is the gateway's responsibility to cooperate with the ingress node for reserving resources in the next zone, by forwarding the amended BHP to the next ZH (NZH). Subsequently, the NZH assigns the necessary resources for the upcoming burst, and the zone by zone reservation procedure is repeated until the burst reaches the zone where the egress node is located.

A. An Application of the C2OBS-RR to the EON Topology

In the following, the C2OBS-RR scheme is applied to the EON topology as depicted in Figure 2 for illustration. The assignment of nodes to each zone has been described in section II.

In case of intra-zonal traffic say within zone-one (Z-1) from Lisbon to Zurich, the ingress node at Lisbon sends a BHP including burst length, Class of Service (CoS) and source and destination addresses to the ZH (Paris). The ZH inspects the BHP and examines both its Zonal Information Base (ZIB), for routing and wavelength assignment, and its SHB for assigning a suitable offset time. The ZH returns the amended BHP to the ingress node and multicasts the same to intermediate nodes. The amended BHP adds information to the BHP about route, i.e., LIS-MAD-PAR-ZUR, a free wavelength along the route, say $\lambda_{1,}$ and suitable offset time for the ingress node. The intermediate nodes and destination calculate the offset time as explained above and reserve the resources using delayed reservation. The ingress node transmits the burst after the offset time elapses, which propagates transparently along the route to the destination. As the burst passes through the intermediate nodes, the resources are released and the ZH updates its SHB accordingly so that the resources may be assigned efficiently to other subsequent burst.

In case of the inter-zonal traffic, e.g., for traffic from Lisbon (Z-1) to Amsterdam (Z-3), the last address along the path will be the zone gateway's address, Brussels, which is a member of both Z-1 and Z-3. As the gateway node (Brussels) receives the amended BHP with the destination address of Amsterdam (egress node), it forwards the BHP to the next Zone Head (NZH), London, with the information about the wavelength on which the burst will arrive. This wavelength is considered as "preferred" wavelength by the NZH. The NZH, looking at the destination address and preferred wavelength channel information in the BHP, checks its own ZIB, and classifies the traffic as intra-zonal or inter-zonal. Since the traffic is now intra-zonal, the NZH checks both its ZIB and SHB to decide whether the same wavelength channel is available on the path within the new zone. If it is available, the NZH returns the amended BHP to the gateway and multicasts the same BHP to the intermediate nodes and egress node (Amsterdam) for resource reservation. If the preferred wavelength channel is not free, the NZH checks the CoS of the burst to find whether the incoming burst belongs to either delay insensitive or delay sensitive class of service. For delay insensitive class, the NZH adds a suitable δT to the calculated offset time using equation (2) and directs the incoming burst to the shared FDL bank. For delay sensitive class, it assigns a new free wavelength to the incoming burst and directs it to the shared WCs bank. This reduces delay for delay sensitive traffic, thus ensuring Quality of Service provisioning. When the data burst arrive at the gateway, it is transparently forwarded towards the egress node.

In summary, the strategy of the C2OBS-RR scheme for contention avoidance is that the ZH should provide a routing path with a free wavelength, and an appropriate offset time to each burst to isolate traffic originating from different ingress nodes using overlapping paths.

IV. EXPECTED BENEFITS of C2OBS

The aim of this section is to discuss the expected benefits of the C2OBS architecture & the C2OBS-RR strategy and compare it with the extant reservation schemes. In C2OBS, the whole network has been divided into more manageable smaller units called zones, with a ZH that maintains both a ZIB and a SHB. The information contained in both these information-bases is utilized for effective reservation of resources. The C2OBS-RR strategy aims to lessen the inherent problems of both centralized and distributed resource reservation techniques while combining the best features of both approaches. The centralized two way resource reservation technique introduces longer delays, is more complex and adds more processing burden on a central node than the one way reservation technique. On the other hand, the distributed resource reservation schemes suffers from a relatively high burst loss probability because nodes have only partial knowledge about resource availability limited to its outgoing links.

The C2OBS-RR will have a shorter delay and will be easier to implement than the centralized reservation scheme because the ZH is normally located only one hop away from the ingress nodes within the zone and the processing burden is shared by multiple ZHs. On the other hand, the C2OBS-RR approach will have less wavelength contention compared to the distributed resource reservation schemes, because the ZH takes advantage of its complete resource availability knowledge within the zone for assigning suitable offset times such that contention is avoided among bursts using partially or totally overlapping paths.

As compared to the centralized reservation scheme, where all resource assignment is accomplished by a single central node, the proposed scheme is following a distributed strategy having ZHs in each zone for resource assignment and reservation. In the case of the centralized reservation scheme, when the central node fails, the whole network performance will be affected. So the central node becomes a performance bottleneck in the network. In contrast, in the C2OBS architecture and the C2OBS-RR scheme, failure of a ZH will affect a single zone within the network till the BZH takes the responsibility of ZH.

A further advantage of the proposed architecture is its scalability. If the number of nodes in the network is increased, the network can be redesigned by either adding the new node to an existing zone or creating a new zone to maintain the network performance. However, the distributed reservation protocols such as JET, JIT, JIT+, or E-JIT are not flexible to accommodate further nodes without deteriorating the network performance. Furthermore, the central node in case of central reservation scheme has a limited processing capability. The number of nodes offering load beyond this processing capacity will worsen the performance of the network as well.

Wavelength convertors are still immature and expensive, full wavelength conversion (i.e., any wavelength entering a node can exit on any free wavelength on any output fiber) [3][18] is still not a realistic solution. The alternative solution is to place the wavelength convertors sparsely. Optimal placement of sparse wavelength convertors in optical networks is a vital question but it has been shown to be NP-hard. The proposed shared WCs bank in the zone is comparatively a more feasible alternative because the WCs bank is either placed at a central location or at a node having the highest degree in the zone, which will mostly provide direct connectivity between any switching nodes and the bank. This solution is also attractive from network planning perspective because this module can be easily enhanced or replaced keeping in view the future estimated traffic load. In existing architecture where wavelength convertors are an integral part of the switch, there is no such flexibility.

Finally, in the proposed resource reservation strategy, the ingress node does not have to wait for resource reservation acknowledgment as in TAW where acknowledgement delay is equal to RTT between ingress & egress node. Additionally, unlike the central reservation scheme, the ingress node does not have to wait for RTT between ingress node and central node for resource confirmation. In this work, the ZH is mostly available at one hop from the ingress node as the ZH has a highest degree in the zone; the latency is comparatively low as compared to TAW and central reservation technique which is comparatively suitable for real time delay sensitive traffic.

Based on the above comparative analysis with existing reservation techniques, it appears that the proposed scheme is both more flexible and scalable. It is also expected that the C2OBS-RR will offer less delay as compared to TAW and centralized reservation schemes. Moreover, the blocking probability is also expected to be lower than that of TAG (JET, JIT, JIT+, E-JIT, and Horizon).

V. CONCLUSION AND FUTURE WORK

In this article, a divide and conquer approach has been applied to OBS networks by splitting the whole network into more manageable small units called zones. Each zone has a Zone Based information repository and Short History Base in the Zone Head. The ZIB contains information about routing and wavelength assignment while SHB dynamically records information about scheduled channels. Since it is not realistic to provide full wavelength conversion in the optical networks, an improvement in the network architecture has been suggested by implementing the bank of WCs/FDLs as a separate module from the switch within the zone and all zone members can use the same bank when required.

A resource reservation strategy for C2OBS network architecture with the focus on gathering the advantages of both the centralized and the distributed reservation mechanism has been presented. It will help to reduce the burst drop probability. The innovative methodology uses the zonal state of resource availability in the zone such that the bursts at the ingress nodes in the same part of the network, having being assigned the same wavelength, are assigned different offset to avoid contention.

It is expected that the proposed scheme will shorter the delay and will be easier to implement then the reservation scheme proposed for WROBS networks. Furthermore, it will have less probability of wavelength contention at the intermediate nodes as compared to distributed resource reservation schemes. The proposed scheme appears more scalable and flexible as compared to both extent centralized and distributed schemes.

As for as future work is concerned, the next objective is to implement a simulation model for analyzing the performance of the C2OBS network architecture and the C2OBS-RR strategy, and compare it with the extant resource reservation schemes for verification and validation.

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