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 Base (ZB) and maintains a short resource usage history called Short History Base (SHB).**

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 local state of the resource availability within the zone (ZB) 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 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 used 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 data 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 [5,14] 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. 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 at a central location 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 balance of this 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. Section IV discusses the expected benefits of the proposed C2OBS architecture and of the C2OBS-RR reservation strategy by comparing it with the existing reservation paradigms. Finally, section V provides conclusions and highlights future work directions.

II. PROPOSED Co-OPERATIVE ARCHITECTURE

In the C2OBS architecture, the network is partitioned into overlapping zones/clusters as shown in Figure 1.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 in IPv4 header, or the HopLimit value 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 as shown in Figure 1 and 2. For example, in Figure 2, Copenhagen (COP) serves as a gateway between Z-3, Z-4 and Z-5 because it is common to the three zones. Similarly, Prague (PAR) 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 "Hell messages". The role of the ZH is further elaborated in section III. The other members of the zone are referred to as Zone Members (ZM).

The ZH is dynamically elected with a criterion as the node with the highest degree in the zone. The degree of a node is the number of connections or edges it has to other nodes in the zone (network). 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. 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 higher 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 higher 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.

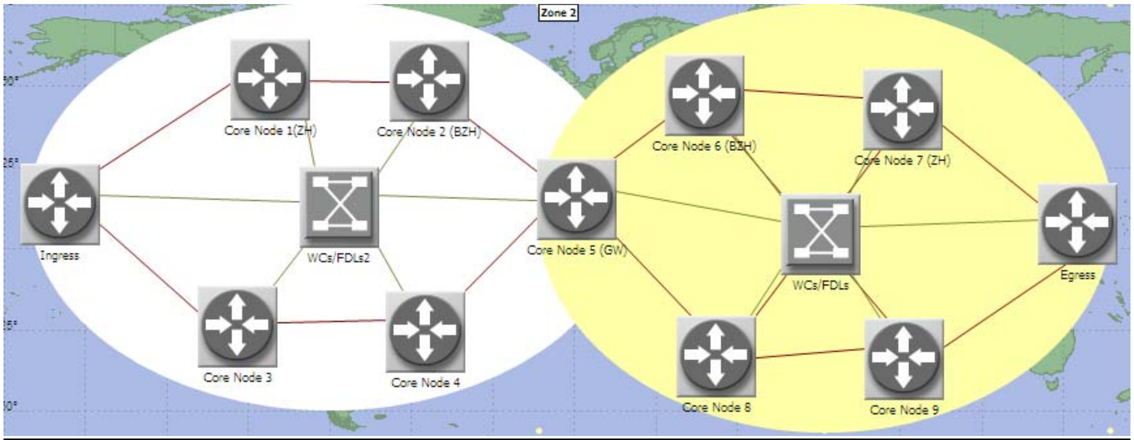

Figure 1: OBS Network Architecture showing ZH, BZH and shared WCs/FDLs

In OBS networks, where do we optimally place the WCs/FDLs is a vital question. 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 the optical 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 improve the utilization of this resource (WCs/FDLs). Since 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 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 same Divide and Conquer rule has been applied to European Optical Network (EON) [16, 17] as shown in Figure 2. The EON 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 elaborates 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.

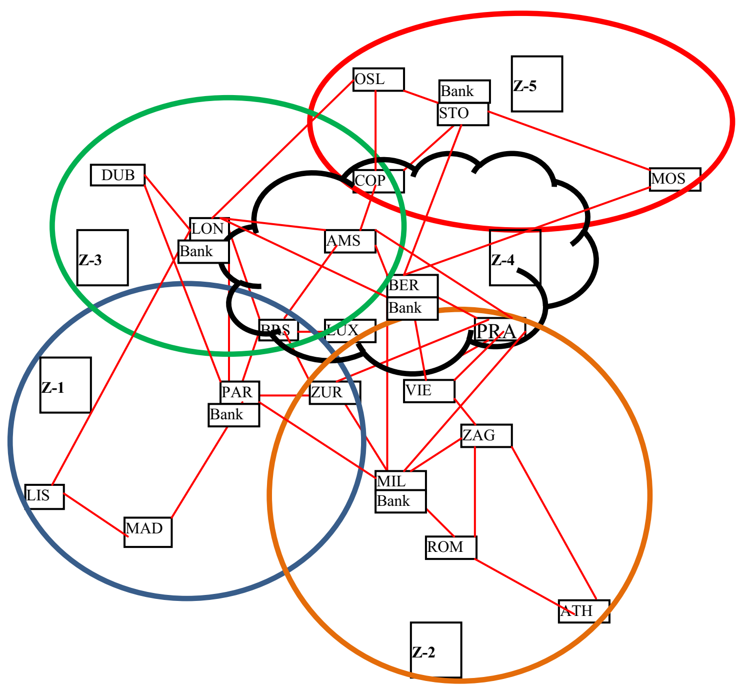

Figure 2: Cooperative Clustered OBS Network Architecture for EON

III. PROPOSED RESOURCE RESERVATION STRATEGY

This novel resource reservation strategy for the clustered OBS architecture (C2OBS-RR) aims to address the problems introduced by both centralized and distributed resource reservation techniques and combining the best features of both approaches. The centralized technique introduces more delay because of two way reservations as compared to one way resource reservation technique (TAG)

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

and is more complex to implement. It adds more processing burden on a single central node whereas the distributed resource reservation scheme (TAG; JET, JIT, JIT+ and E-JIT) suffers from a relatively high burst loss probability because the knowledge of each node about resource availability is limited to its adjacent links. So the lack of global knowledge about the resource reservation is responsible for relatively high burst drop probability. The main aim of C2OBS-RR is to lessen the limitations of centralized and distributed reservation schemes. The C2OBS-RR will have lower delay as compared to centralized technique and resources will be reserved based on zonal information embedded in the ZH to reduce the wavelength contention at the core nodes by assigning offset time intelligently at the ingress node.

In the proposed strategy, the ingress node does not have to wait for the confirmation of resource reservation that an end-to-end connection has been setup; instead it starts transmitting the data burst after an offset time plus a small delay, waiting for the response from the ZH. However, this delay will be much less than the end-to-end Round Trip Time (RTT) between ingress and egress node, as is in case of the distributed TAW and RTT between the ingress node and central controlling node as in WROBS. This is because; the ZH and the ingress node are in close proximity within the zone as the ZH has a highest degree in the zone. In contrast, it is not necessary that the central node & ingress nodes in the centralized reservation technique & ingress and egress node in case of TAW will be in close vicinity of each other.

Upon receiving the BHP, the ZH provides the routing, initial wavelength and offset value to the ingress node. The ZH has a routing table that contains k-shortest paths and a disjoint path for every source-destination pair. The ZH checks among these routes whether a single wavelength channel without contention at the intermediate nodes within the zone is available. The routing and wavelength assignment problem will be discussed in length in another article and in this article; details about resource reservation and offset assignment strategy to reduce the resource contention at core node is presented.

In this work, the traffic where the source (ingress node) and the destination (egress node) are within the same zone is referred as IntraZonal traffic while the traffic where the ingress node and egress nodes are within different zones is denoted as InterZonal traffic.

In case of IntraZonal traffic e.g. when an ingress node at Lisbon has a burst for Madrid (both Lisbon and Madrid are in Z-1 (Figure.2)), the ingress node at Lisbon sends BHP including length of data burst, Class of Service (CoS) and address of source and destination to the ZH (node at Paris, having highest degree in Z-1). The ZH looks at the BHP and examines its Zonal Base (ZB), containing the wavelength & routing information. The ZH selects a routing path, wavelength and offset time for this burst.

In the already published work, the offset time is calculated by the ingress node using

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

Where k is the number of hops along the path from ingress node to egress node, T_{BHP} is the header processing time, and T_{SW} is the switch configuration time. So the ingress node can use any value equal to or larger than this value [5].

In the C2OBS-RR strategy, the ingress node within the zone request the ZH before the burst transmission and ZH assign routing path, wavelength and offset time. In this way, the ZH has a Short History Base (SHB) about the utilization of wavelength resources in each intermediate node within the zone. So when another ingress node (or may be same ingress node) requests for the transmission of a new burst, the ZH examines it's ZB (for selecting path) and SHB (for wavelength usage along the path). It returns an amended BHP containing path from the ingress to egress node within the zone (both nodes being in same zone, IntraZonel traffic) along with the assignment of initial wavelength channel and an offset time. The path represents a list of intermediate nodes from ingress to the destination egress node. The wavelength channel has been named as "initial wavelength channel" because along the path there might arise a need to change wavelength by using WCs bank to avoid contention. However, the ZH tries to select a wavelength along a route which does not have contention at any intermediate node, but if the contention cannot be avoided, the ZH adds δT to the offset time to avoid contention

$$T_{offset}(X) = kT_{BHP} + T_{SW} + \delta T \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The δT is used to isolate traffic from different ingress nodes that are using overlapping path (link).

The ZH forwards the amended BHP to the ingress node and multicast the same to the intermediate nodes in the zone for resource reservation. The intermediate nodes checks the value of δT in amended BHP and its position in the routing path to find value of "k". Having knowledge about T_{BHP} and T_{SW} and by using (2), the intermediate nodes calculate the estimated time at which the burst will arrive. The intermediate nodes perform delayed reservation and early release of the wavelength channel. The early release is possible because the amended BHP contains the length of burst.

Since, the ingress nodes within the zone are in close proximity and ZH has the highest degree in the zone, which enables mostly direct connectivity between ingress node and ZH. This feature will ensure low latency as compared to the centralized and the distributed (TAW) resource reservation techniques. So, the overall advantage of C2OBS-RR scheme is that the ZH will provide initial wavelength along the routing path and offset time to isolate traffic form different ingress node that are using overlapping path (link) through the network.

In case of the InterZonal traffic e.g. for burst traffic from Lisbon (Z-1) to Amsterdam (Z-3) as shown in Figure 2, the last address on the path will be of an intermediate node i.e. Brussels which is a member of Z-1 and Z-3 and will act as a gateway between Z-1 & Z-3. As the gateway node (Brussels node) receives amended BHP with the destination address of Amsterdam (egress node). The gateway forwards the BHP to new Zone Head (NZH) i.e. London with the information about wavelength on which the burst in expected. The NZH, looking at the destination address and preferred wavelength channel information, checks its own ZB, and classify the traffic as IntraZonal and InterZonal traffic. Since the traffic in this example is now IntraZonal, the NZH checks its ZB and SHB to check whether the path within the new zone on the same wavelength is available. If it is available, the NZH returns amended BHP to the gateway and multicast the same BHP to the intermediate nodes and egress node (Amsterdam) for resource reservation. If the desired wavelength channel is not available at that time, looking at the CoS, the NZH either add δT to its new offset time and includes the first node in the path as the address of the bank of FDLs for delay insensitive traffic or returns either new wavelength channel information back to gateway for delay sensitive traffic and includes the first node in the path as the address of the WC's bank. When the data burst arrive at the gateway, it is transparently forwarded towards the destination egress node. So using the above mentioned resource reservation strategy, the resources are reserved and released as the burst progresses through the network.

IV. EXPECTED BENEFITS of C2OBS

The aim of this section is to discuss the 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 ZB and SHB. This information is utilized for effective reservation of resources. As compared to the distributed resource reservation protocols like JIT, JIT+, E-JIT, JET, and Horizon, where the knowledge of each node (ingress or intermediate core nodes) about resource availability is limited only to adjacent links, the ZH in C2OBS has the information about the ZMs, Gateway(s) and resources available on these nodes within the zone. This zonal information can be effectively utilized to avoid contention at intermediate nodes and to reduce the burst drop probability in the overall network.

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 and BZHs 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 contract, in the C2OBS architecture and reservation scheme, failure of a ZH will affect a single zone within the network till the BZH takes responsibility of ZH.

Another 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 like 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.

Since, wavelength convertors are still immature and expensive, full wavelength conversion 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 node 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 seems 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. CONCLUSIONS AND FUTURE WORK

In this article, a Divide and Conquer approach has been applied to OBS network by splitting the whole network into small more manageable small units called zones. Each zone has a Zone Based information repository in the Zone Head. 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 central 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.

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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