OPTICAL BURST SWITCHING CLUSTERED COOPERATIVE ARCHITECTURE

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Keywords: Optical Burst Switching, Optical Network Architecture, Contention Avoidance

Abstract: Resource contention in Optical Burst Switching (OBS) networks is a critical issue that leads to relatively high burst loss probability. In the existing OBS architecture, resource reservation is achieved by distributed, centralized and hybrid techniques. Both the distributed and hybrid techniques like intermediate node initiated (INI) lack global knowledge of network resources and suffer from relatively high burst blocking probability. On the other hand, the centralized reservation technique assigns resources after an end-to-end acknowledgement incurring in high delay. Therefore, a procedure is proposed to partition the optical network into smaller manageable and partially overlapping subnets of nodes called zones, resulting in the Clustered Cooperative OBS (C2OBS) network architecture.

The guiding principles behind this network architecture are that each zone has a controlling node called ZH, containing complete zonal resource information for effective resource reservation within the zone, which is generally available at one hop from other zone members to reduce reservation delay. The whole C2OBS network architecture has multiple ZHs serving their corresponding zones. The neighboring adjacent zones have one or more common nodes serving as zone gateways between adjacent zones, that cooperate for resource reservation for inter zonal traffic.

1 INTRODUCTION

The optical burst switching paradigm is seen as an interim compromise between optical circuit switching (OCS) and optical packet switching (OPS) networks. It tries to combine the benefits of both the switching paradigms by utilizing the resources more efficiently than OCS while using less complex technology than OPS. 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. 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- 4].

Optical Burst Switching is envisioned as one of the promising technology to fulfill the requirements of high bandwidth on demand bursty traffic applications running on the Internet. Unfortunately, resource contention is a major concern in OBS networks that leads to a relatively high burst loss probability. In the existing OBS network architecture, the probability of resource contention increases when both the traffic load and the number of nodes increase in the existing OBS network architecture. For the extant OBS architecture, the centralized [5], distributed [6] and the intermediate node initiated (INI) [7, 8] resource reservation techniques have been proposed, but these techniques have shortcomings. The centralized technique assigns resources after an end-to-end acknowledgement [5] which is not acceptable for delay sensitive traffic. Moreover, the central node also acts as a performance bottleneck in the network. The distributed and INI schemes do not have global knowledge of network resources in the network and suffer from relatively high burst loss probability. Therefore, an intelligent resource reservation mechanism for C2OBS architecture consisting of multiple zones has been proposed in [9] to reduce contention at the intermediate core nodes.

Here, a procedure for partitioning an optical network into several smaller manageable partially overlapping subsets of network nodes called zones is presented. The partitioning guidelines are that each zone has a controlling nodes called zone head (ZH) and backup zone head (BZH). The ZH is generally one hop away from the rest of the node within the zone, called zone members (ZMs). This reduces delay while resource reservation. The ZH keeps the resource information of all the zone members within its zone in the zonal information base (ZIB). The ZH also maintain a short history base (SHB) which dynamically updates information about the scheduled wavelength channels. Both the information bases are utilized for effective resource reservation when an ingress node requests the ZH for the transmission of an upcoming burst. Since the zones are overlapping, there is at least one node within the overlapping region. These nodes serve as zone gateway and cooperate with the ingress nodes for resource reservation in the adjacent neighboring zone. In case of multiple zone gateways, one of them is selected as a primary zone gateway (PZG) and the others acts as backup zone gateways (BZG). The BZG is either utilized in case of a failure of the PZG or if the PZG resources become scarce due to congestion. As the architecture is clustered and zone gateways cooperate for resource reservation in the adjacent neighboring zones, the architecture has been named as cooperative clustered OBS (C2OBS) network architecture.

Additionally, each zone has a shared wavelength convertors (WCs)/ fiber delay line (FDLs) bank for contention resolution, which is either located at a separate central location, or installed at the ZH within each zone. The proposed shared WCs/FDLs bank provides a reasonable alternative for the placement of WCs, and is more economical and efficient then dedicated WCs because the WCs/FDLs bank can be accessed by any incoming burst that needs wavelength conversion/buffering. This will make the OBS network economically more feasible as augmenting each node with WCs is an expensive solution [3, 10], as it increases the switch size and cost. This will also make the network planning simpler and more economical because the WCs/FDLs module can be upgraded when necessary independently of the optical switches.

The rest of the paper is structured as follows. In Section 2, a systematic procedure for converting an optical network into Cooperative Clustered Optical Burst Switching Network architecture is discussed. In Section 3, the proposed procedure is applied to the European Optical Network (EON) topology, the NSF network topology, and the COST 239 network topology for illustration. Section 4 compares the proposed architecture with the existing OBS architecture and discusses its expected benefits. Finally, section 5 provides conclusion and highlights future work directions.

2. C2OBS NETWORK ARCHITECTURE

The aim of this section is to explain how to convert a given set of nodes location and optical links to C2OBS network architecture. This is achieved by partitioning the whole network into small overlapping manageable zones with each zone having a controlling node called ZH. The ZH has the resource information within the zone only and is mostly available at one hop from other members of the zone (ZMs). This reduces reservation delay, a preferable characteristic for delay sensitive on demand Internet traffic. Moreover, there are multiple ZHs in the network that reduces processing burden than the centralized reservation technique which has a single controlling node. The other guideline is that the zones must be overlapping because the nodes that exist within the overlapping region serve as zone gateways which cooperate with the ingress nodes for resource reservation in the adjacent zones for inter zonal traffic. Thus in the C2OBS network architecture, the resource reservation is based on zonal information and is accomplished by multiple ZHs for their corresponding zones. This eliminates the drawbacks of distributed, centralized as well as INI resource reservation schemes.

The conversion procedure of an optical network to C2OBS architecture comprises of four main steps. In the first step, an optical network is partitioned into multiple overlapping zones and a node with the highest degree is assigned the task of ZH. In the second step, the nodes that belong to multiple adjacent zones are identified and assigned the task of ZGs. In the next step, BZHs for each zone is identified and finally WCs/FDLs bank is installed in each zone for contention resolution.

The first step for partitioning an optical network into zones is to find the degree of all nodes. Then select a small group of co-located connected nodes near a geographical edge of the network. Among these nodes, select one with the highest degree and name it as marked node (MN). Choose the MN and the nodes which are directly connected to this node and name this set of nodes as zone, say zone-one.

The MN becomes the ZH of zone-one and is one hop away from the rest of the ZMs. The objective of the initial step of the partitioning procedure is to avoid creating a zone that becomes disjoint from all other zones. Now select an adjacent node outside the existing zone having the highest degree and name it as distinguished node. Choose the distinguished node and the nodes that are directly connected to it and name them as a zone, say zone-two. The distinguished node becomes the ZH of this zone. Continue selecting distinguished nodes, outside the existing zones and having highest degree, and the nodes attached to them and call them zones. If at the end there remain some solitary nodes that are still not part of any zone, call them orphan nodes. Orphan nodes do not have direct inter-connectivity among them. Hence, they are included in the existing adjacent zones. These orphan nodes will be two hops away from the ZH. If an orphan node can become part of multiple zones, preference is given to the zone where the orphan node is not directly connected to the zone gateway (ZG). This constraint has been imposed to avoid adding further transmission burden of control information from the orphan nodes to the ZH and vice versa. The ZGs are already co-operating with the ingress nodes for resource reservation in the adjacent zones and the proposed constraint is suggested for performance improvement. This completes the partitioning procedure.

After completing the partitioning procedure, select the nodes belonging to the intersection of two or more adjacent zones and name them as zone gateways. In case of multiple ZGs between adjacent zones, one of them in marked as primary zone gateway (PZG) and the remaining ones as backup zone gateways (BZGs).

In the third step, select BZH which is the highest degree node in each zone that is neither a ZH nor a PZG. A BZH node of a zone cannot be selected for a similar task in another zone.

Finally, place the WCs/FDLs bank either at a central location or along the ZH within the zone for contention resolution.

3. C2OBS ARCHITECTURE EXAMPLES

The aim of this section is to illustrate the application of the proposed procedure for converting an optical network to C2OBS network architecture to several physical network topologies, namely, 20-nodes EON topology[11, 12], 24-nodes NSF network topology, and 11-nodes COST-239 network topology[13].

3.1 The EON Topology

The EON topology interconnects major cities within Europe spanning a large geographical area with a diameter in excess of 3000 kms, having 20 nodes and 38 links.

The proposed procedural steps described in Section 2 are applied to the EON topology to convert it to C2OBS network architecture. The first step is to partition the EON topology into overlapping zones and assigning a ZH to each zone. To achieve this goal, the degree of each node in the EON topology is found as depicted in Table 1. Then a small group of co-located connected nodes near a geographical edge of the network are selected as indicated by right arrow in Figure 1. Among this group of nodes, the London node has the highest degree (7) and is named as marked node (MN). The MN and the nodes directly connected to it form zone-one as shown by square dots in Figure 1. Now, another node outside zone-one is selected which is adjacent to this zone and having highest degree. The Milan node is marked as a distinguished node because it has the highest degree (6).

Table 1: Nodes Description for EON Topology

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 & Z-2	PZG	**6**
4.	Brussels (BRS)	Z-1	ZM	5
5.	Zurich (ZUR)	Z-2	ZM	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	BZH	5
12.	London (LON)	Z-1	ZH	**7**
13.	Dublin (DUB)	Z-1	ZM	2
14.	Amsterdam (AMS)	Z-1	BZH	5
15.	Berlin (BER)	Z-1, Z-2, & Z-3	PZG_{23}, $BZG_{12,13}$	**7**
16.	Luxemburg (LUX)	Z-1	ZM	1
17.	Copenhagen (COP)	Z-3	BZH	3
18.	Moscow (MOS)	Z-3	ZM	2
19.	Stockholm (STO)	Z-3	ZH	**4**
20.	Oslo (OSO)	Z-1 & Z3	PZG	3

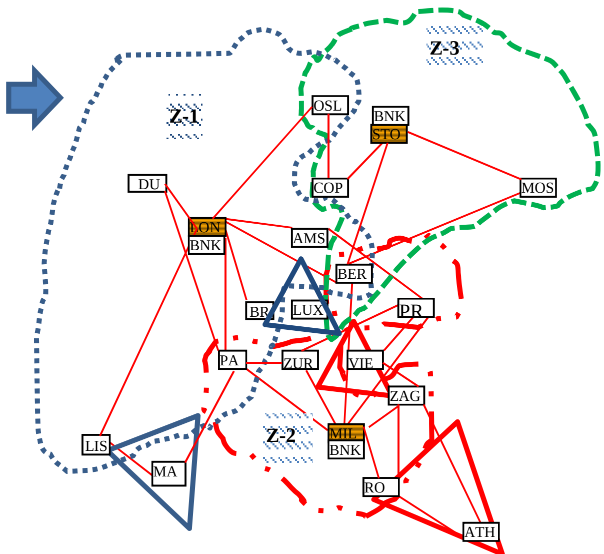

Figure 1: Cooperative Clustered OBS Network Architecture for European Optical Network Topology

The nodes directly connected to Milan constitute zone-two with Milan as ZH. Now, the node having highest degree and is either adjacent to zone-one or zone-two is searched to become a candidate for distinguished node. The node at Stockholm has the highest degree (4) and is adjacent to zone-one. This node becomes the distinguished node. The distinguished node and the nodes directly connected to it constitute zone-three with the Stockholm node as its ZH. Now there are four orphan nodes i.e. Madrid, Athens, Vienna, and Luxemburg. These orphan nodes are neither inter-connected with one another nor they are the part of any other zone and are shown by triangles in Figure 1. These orphan nodes need to be included in the existing zones. The node at Madrid can become member of both the zone-one and zone-two but based on preference, as mentioned in last section, it has been included in zone-one. Similarly, the nodes at Athens and Vienna have been included in zone-two while the node at Luxemburg has connectivity only with zone-one and has been included in zone-one. This completes the partitioning procedure.

Now in the next step, the nodes that are part of multiple zones are selected for the task of zone gateways. The Paris node is shared between both zone-one and zone-two while the node at Berlin in shared among zones one, two and three. The Paris node has been assigned the task of primary zone gateway (PZG) while the node at Berlin has been assigned the task of backup zone gateway (BZG) for zone one and two. Similarly, the node at Oslo is common between zone-one and zone-three and has been assigned the task of PZG. In the same way, Berlin node is a common node among zones one, two and three and has been made PZG between zone two and three. This node also acts as BZG between zones one and two and between zones one and three. This completes the second step of ZG identification.

The third step is about BZH assignment to each zone. Since Berlin and Paris having highest degrees but have been assigned the task of zone gateways, the nodes at Amsterdam and Brussels have the next higher degree (5). So the node at Amsterdam has been assigned the task of backup zone head (BZH) for zone-one. Similarly, for zone-two, Paris is the PZG between zone-one and zone-two while Berlin has also been assigned the job of ZG. So the node at Prague, having highest degree (5) after the ZH and ZGs in the zone-two, has been given the responsibility of BZH. Likewise, for zone-three, the node at Oslo is PZG between zone-one and zone-three while Berlin is also a ZG. Thus, the node at Copenhagen having degree 3 has been given the job of BZH for this zone.

Finally, the WC/FDL bank has been placed at the ZH in each zone for contention resolution and has been shown as BNK in Figure 1, thus successfully completing the conversion of the EON network topology to C2OBS network topology.

3.2 The NSFNET Topology

The NSFNET topology is a backbone network for the support of research and education institutions in USA. It initiated operations around 1986 with six sites and then gradually expanded. Here we have taken 24 nodes NSFNET topology for illustration. The network has been converted to C2OBS network architecture with six zones. Each zone has been assigned ZH, zone gateways, and BZH as shown in Figure 2.The status of each node is also depicted in Table 2.

The partitioning procedure has been started from the top-left side as shown by right arrow in Figure 2. Node 6 and 7 has the same degree (5), so node 6 has been chosen as marked node (MN) because it is nearer to the edge of the network. The MN and the nodes directly connected to it constitute zone-one (z-1) with node 6 as ZH. Now the adjacent nodes to this zone are nodes 3, 4, 8, 10, 12, and 15. Three of them have the same degree i.e. 4. So we choose node 3 as distinguished node, being nearer to the edge. The distinguished node and the nodes directly connected to it form zone-two with node 3 as ZH.

Table 2: Nodes Description for NSFNET Topology

Node Id	Zone Member	Member Status	Degree of Node
1	Z-1	BZH	2
2	Z-1 & Z-2	PZG12, BZG21	3
3	Z-2	ZH	**4**
4	Z-2	ZM/BZH	3
5	Z-2	ZM	3
6	Z-1	ZH	5
7	Z-1& Z-2	PZG21, BZH12	5
8	Z-3	ZM/BZH	3
9	Z-1,Z-3, & Z-5	PZG135	5
10	Z-3	ZH	**4**
11	Z-1, Z-5, & Z-6	PZG156, BZG15	5
12	Z-5	ZH	**4**
13	Z-3, Z-4,&Z-5	PZG345	4
14	Z-3	ZM	3
15	Z-6	ZH	**3**
16	Z-4,Z-5,&Z6	PZG56, BZG45	5
17	Z-4	ZH	5
18	Z-4	ZM	3
19	Z-6	ZM	**2**
20	Z-6	ZM/BZH	3
21	Z-6	ZM	3
22	Z-4	ZM/BZH	4
23	Z-4	ZM	3
24	Z-4	ZM	2

So we continue locating distinguished nodes and the nodes directly connected to them and mark them as zone three, four, five and six respectively. There remains three orphan nodes i.e. nodes 19, 21, and 24. The node 19 and 21 are included in zone-six while node 24 is made part of zone-four. This completes the partitioning procedure.

In the next step, the nodes that are common to multiple zones are identified and are assigned the tasks of zone gateway as indicated in Table 2. Subsequently, the nodes that are neither serving as ZH nor as primary zone gateway and having highest degree are assigned the task of BHZ in their respective zones.

Finally, the bank of WCs/FDLs is installed at the ZH for contention resolution and it successfully completes the conversion of the NSFNET topology to C2OBS network topology.

3.3 The COST-239 Network Topology

The COST 239 (Ultra-High Capacity Optical Transmission Networks) connects eleven major cities of Europe [14]. This network topology has been successfully converted to C2OBS network architecture by applying the proposed procedure discussed in Section 2. The resultant C2OBS architecture comprises three zones and has been shown in Figure 3.

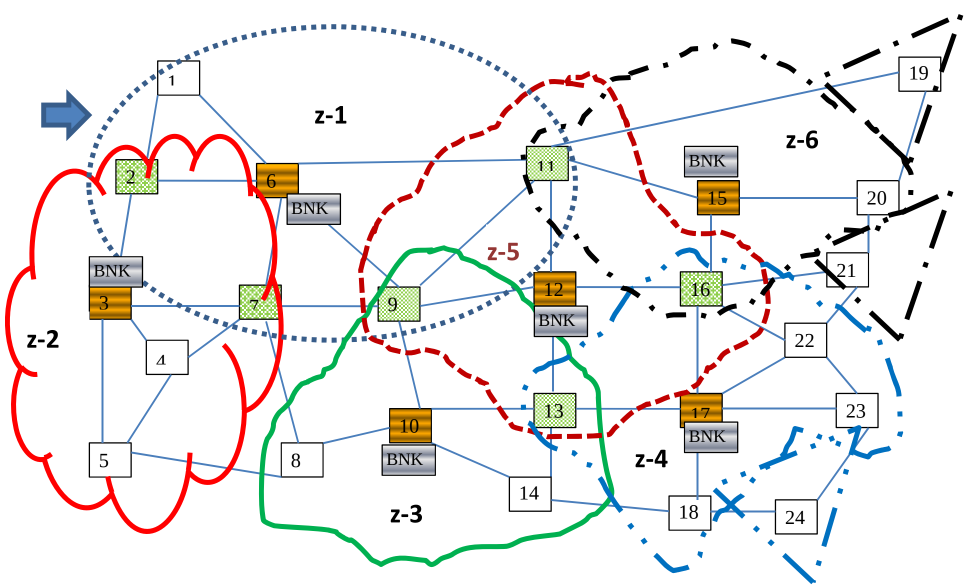

Figure 2: Cooperative Clustered OBS Network Architecture for NSF Network Topology

The partitioning procedure starts from the left side of the network as indicated by right arrow in Figure 3. The Paris node having highest degree in the selected group of nodes is the ZH of zone-one as shown by square dots. The role of each node within this zone is depicted in Table 3.

Similarly, the Amsterdam node becomes the distinguished node. This node has a degree 5 and is directly connected to the nodes at London, Brussels, Luxemburg, Berlin, and Copenhagen. All these nodes form zone-two with the node at Amsterdam as their ZH. The role of each node within the zone-two is depicted in Table 3.

Subsequently, the node at Prague becomes the distinguished node. This node has a degree 5. The distinguished node and the nodes directly connected to it form zone-three with the node at Prague as their ZH. The role of each node within the zone-three is given in Table 3.

Finally, the bank of WCs/FDLs is installed at the ZH for contention resolution and it completes the conversion of COST-239 network topology to C2OBS network topology.

Table 3: Nodes Description for COST-239 Network Topology

S.No	Location of Node	Zone Member	Member Status	Degree of Node
1.	London (LON)	Z-1 & Z-2	BZH(Z-2)	4
2.	Paris (PAR)	Z-1	ZH	6
3.	Brussels (BRU)	Z-1 & Z-2	PZG$_{12}$, BZG$_{21}$	**5**
4.	Amsterdam (AMS)	Z-2	ZH	5
5.	Luxemburg (LUX)	Z-1 & Z-2	PZG$_{21}$, BZG$_{12}$	5
6.	Copenhagen (COP)	Z-2 & Z-3	PZG$_{32}$, BZG$_{23}$	4
7.	Berlin (BER)	Z-1, Z-2 & Z-3	PZG$_{23}$, BZG$_{32}$, BZH(Z-1)	5
8.	Prague (PRA)	Z-3	ZH	5
9.	Vienna (VIE)	Z-3	BZH	4
10.	Zurich (ZUR)	Z-1 & Z-3	PZG$_{13}$, BZG$_{31}$	**5**
11.	Milan (MIL)	Z1 & Z-3	PZG$_{31}$, BZG$_{13}$	4

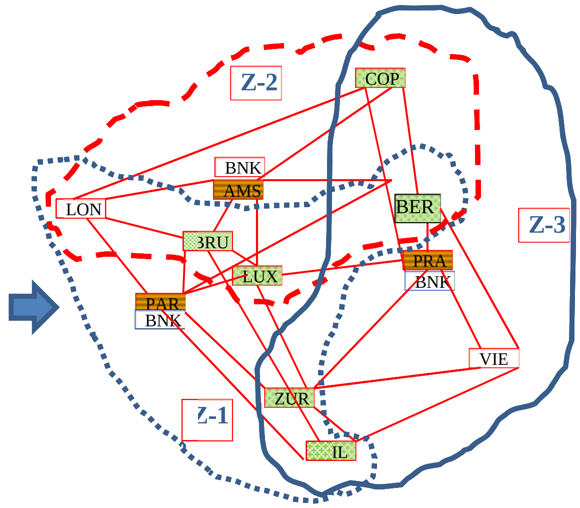

Figure 3: Cooperative Clustered OBS Network Architecture for COST-239 Network Topology

4. EXPECTED BENEFITS of C2OBS

The aim of this section is to discuss the expected benefits of the C2OBS network architecture and compare it with the extant OBS network architecture. It is expected that the proposed architecture will have a reduced resource contention than distributed resource reservation techniques. It is more scalable and flexible especially when the number of network nodes increases and maintaining network performance is crucial. Moreover, it is technically and economically more viable architecture. Furthermore, as compare to centralized reservation technique like WROBS employed on existing OBS architecture, it is more resilient and offers less delay during resource reservation.

In the existing architecture, the distributed resource reservation technique lacks global information about resource availability and suffers from high resource contention. In the proposed architecture, the ZH has complete zone information and thus reduces the blocking probability. Even in case of inter zonal traffic, the ZG cooperate with the ingress node for resource reservation in the adjacent neighboring zone and thus reduces the probability of blocking.

A further advantage of the proposed architecture is its scalability and flexibility. In the existing architecture, both the distributed and the centralized resource reservation technique are not flexible enough to accommodate further traffic or number of nodes without deteriorating the network performance [15]. Furthermore, the controlling node in case of central reservation scheme like in WROBS has a limited processing capability and if the number of nodes is increased beyond its processing capacity, the network performance deteriorates. In the proposed C2OBS network architecture, if the number of nodes or traffic in the network increases, the network can be redesigned by either adding the new nodes to an existing adjacent neighboring zones or creating a new zone to maintain the network performance. In case of increase of a few nodes, it is advisable to include the new nodes within existing zones but if many nodes are added in the existing network, a new zone is created having its own ZH and zonal gateways. Furthermore, because of multiple ZHs and having small number of nodes within each zone, there is not a single node in the network acting as a performance bottleneck.

The proposed architecture offers less resource reservation delay as compared to WROBS [5], a centralized resource reservation technique. In WROBS network architecture, there is a single node assigning resources after getting an end-to-end acknowledgement incurring high delay. In contrast, in the C2OBS network architecture, there are multiple ZH which are available mostly at one hop distance from the ZMs. The ZH assigns resources for the upcoming burst after referring to its own information bases (ZIB and SHB) and do not require an end-to-end acknowledgement. These two characteristic reduces resource reservation delay which is suitable for delay sensitive traffic.

Moreover, the proposed architecture is resilient as compared to WROBS network architecture. In case of WROBS architecture, if the controlling node fails, the whole network performance is affected. In contrast, in the C2OBS architecture, failure of a ZH will affect a single zone only till the BZH takes the responsibility of ZH, making the proposed architecture resilient to controlling node failure.

Finally, the proposed architecture is technically and economic more attractive as far as placement of wavelength convertors in an OBS network is concerned. 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][16] 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 the ZH, 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.

5. CONCLUSION AND FUTURE WORK

In this article, a procedure to convert an optical network to the C2OBS network architecture has been presented. It has been illustrated by applying the conversion procedure successfully on three physical topologies namely: the EON network topology, the NSF network topology and the COST-239 network topology. The proposed C2OBS network architecture reduces the resource contention at the intermediate core node thus reducing blocking probability which is a main issue in existing OBS architecture. Moreover, the C2OBS architecture is more scalable, flexible and resilient. Furthermore, an improvement to the existing network architecture has also 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. This will make the OBS network economically more feasible as augmenting each node with WCs is an expensive solution, as it increases the switch size and cost. This will also make the network planning simpler and more economical because the WCs/FDLs module can be upgraded when necessary independently of the optical switches.

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 compare it with the extant OBS network architecture for verification and validation.

ACKNOWLEDGEMENT

The authors wish to acknowledge the support of FCT (Ministry of Science, Technology and Higher Education, Portugal), under the Associated Laboratory contract with INESC Porto, Portugal.

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