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Dimensioning Networks of High Degree ROADMs

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Abstract: *A network dimensioning scheme is proposed for transparent optical networks equipped with many high degree ROADM cluster nodes. It proactively uses network knowledge to determine the optimum degree of ROADM nodes as demand increases. The results show improved blocking rate and resource utilization in comparison with reactive schemes. ©2022 The Author(s)*

Introduction

Accommodating sustained exponential traffic growth in optical networks requires scaling the network capacity. As the capacity of single-mode fibres (SMFs) is limited, multiple SMFs or multi-core fibres (MCFs) are added to the network. With deployment of new fibres, the degrees of Reconfigurable Add-Drop Multiplexer (ROADM) nodes are changed as new Optical Multiplex Section (OMS) is created between the ROADMs. The key to better network efficiency is to plan where to add a new OMS. In some cases, an OMS is added to a link reactively based on the increased demand on that particular link. With the increase in the number of OMS, the ROADM nodes evolve to cluster nodes that feature flexible add/drop rates and node degrees of 10s to 100 [1]. For networks equipped with cluster ROADM nodes, reactive link-level approaches in capacity expansion may not guarantee a better utilization of network resources. In this paper, we propose a network planning methodology that use network-level information on all the links and their link budget constraint to determine and attain the optimum ROADM degree for the nodes as well as the optimum number of fibres (or OMSs) on each link. The resulting optimum network offers improved wavelength connection blocking and better per fibre wavelength utilization.

Network Model and its Parameters

We consider a modified network derived from the national fibre optic links of China [2]. The modification include consolidation of some of the smaller nodes into a larger node. It is assumed that each node of this network can be provisioned to any degree. The network shown in Fig. 1 has 26 nodes and 114 links (57 bi-directional). Each link is composed of one or many fibres and each fibre can carry at least 80 channels of 50GHz ITU grid. A link number has been assigned to each direction. For instance, link 1 connects node1 to node2 and link 58 connects node2 to node1. Each ROADM node is either a single chassis or a cluster node with many interconnected chassis (e.g., [1]). In the network of Fig. 1, there are 7

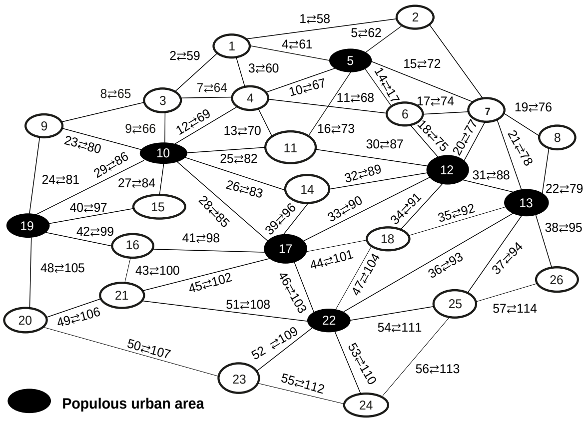

Fig. 1: A reference modified network.

large populous urban areas that could potentially deploy ROADM cluster nodes, defined as having degrees of more than 36 with one or many OMS on the links connecting the ROADM nodes.

To benchmark network performance, we first obtain the network blocking performance of Fig. 1 for both given degrees of nodes and number of fibres on each link. We assume that the connectivity demand from each ROADM node to all the other nodes is uniformly distributed. With this assumption, if traffic demand increases $n-fold$, with a reactive strategy, the number of fibres (or OMSs) on each link is increased by n to accommodate the overall demand.

Since the number of add/drop transponders, that form the source and destination pairs for the wavelength connections, are finite, we use Engset traffic modelling [3] to model wavelength connections demands. Each node i has finite number of transponders, T_i, determined as

$$T_i = C.\alpha_i.\sum_j f_{i,j} \quad , \qquad i = 1, \dots, 26 \qquad (1)$$

where C is the number of channels on a fibre, α_i is the add/drop rate of node i and $f_{i,j}$ is number of fibres on link j of node i. The time until an idle source attempts to make a connection is exponentially distributed with mean *1/λ* and the holding time of a connection is *1/μ*. If total number of active sources observed by a Poisson inspector at node i is A_i, then total offered load, Λ, is calculated as:

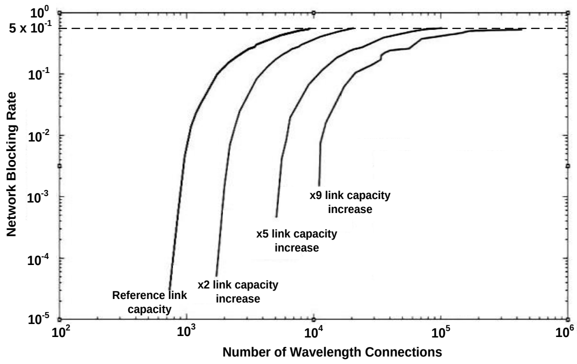

Fig. 2: Network blocking performance as capacity increases.

$$\Lambda = \left(\frac{\lambda}{\mu}\right)\sum_{i=1}^{26} A_i. \qquad (2)$$

A connection is blocked when there is no available transponder at the destination node for an active source (called access blocking, B_{access}) or when there is no same wavelength available on all the links of the network that connects an active source to its desired destination node (called network blocking). As we are interested in the network blocking, the offered load in the simulation modelling is modified as $\Lambda(1 - B_{access})$. While any routing and spectrum assignment can be used, for illustration purposes, we consider fixed routing and first fit wavelength assignment. We choose link loss as the routing metric. In general, this metric can also be Optical Signal to Noise Ratio (OSNR), distance or hop counts.

Fig. 2 shows a set of blocking results obtained for this network as a function of offered load, i.e., wavelength connection requests. The add-drop rate α_i for nodes $i = 1, \ldots, 26$ in equation (1) is assumed to be 50%. The first set is the blocking rate for the reference network. The other sets assumes that the network demand has increased by a factor of *x2*, *x5* and *x9* with uniform distribution for the demands. In response to the demand increase, the number of OMSs on each link has also increased by *x2, x5* and *x9*, respectively. As seen, by reactive increase in fibre capacity, the blocking curve is only shifted horizontally, hence, allowing more wavelength connections to be carried out through the network. However, the capacity expansion has no (vertical) impact on the blocking rate. What is observed is that, for all cases, the blocking reaches about 50% at higher network loading, which is in line with the results obtained for other similar size networks in the literature (e.g., [4-5]).

Proposed Scheme

We use network-level knowledge, such as link utilization frequency derived from routing, to engineer *a priori* the network dimension in terms of optimum number of fibres per link and optimum degree for the ROADM nodes. For brown-field deployments, assuming the new OMSs are added with no disruption to the existing connections, the proposed scheme is applied to the allocation of the new capacity. Whereas for green-field networks, network planners can engineer an optimum network from the scratch and continuously upgrade as demand increase. The following steps are performed for an optical network with N ROADM as traffic increases:

1. Determine all possible $\boldsymbol{N(N-1)}$ source-destination path calculated by the network routing based on one or many metrics of: link loss, hop count, and OSNR.
2. For each of $\boldsymbol{N(N-1)}$ path, determine all the involved links that are part of the path that connects a source to a destination.
3. Determine usage frequency, $\boldsymbol{U}$, representing the number of times a link has been used for all $\boldsymbol{N(N-1)}$ path. For $\boldsymbol{k}$-shortest path routing, $\boldsymbol{k}$ usage frequency is obtained.
4. Quantize the usage frequency to $\boldsymbol{Q}$ levels and assign a range to each level.
5. Map each range to a number of fibres (OMS).
6. Update the degree of each ROADM and the number of fibres (OMSs) on each link. Then evaluate network performance.
7. Change $\boldsymbol{Q}$ and/or the mapping of number of fibres to each range. Repeat steps 4 to 7 until optimal performance is achieved for a practical set of $\boldsymbol{Q}$ and ranges.

The above method is applied to the network of Fig. 1 with *9-fold* traffic increase. Fig. 3 shows the results of the above steps. After many iterations, it resulted in $Q = 7$ levels, mapping each level to a range, U, and assigning a number of fibres to each range. For instance, utilization frequency for links 21 (78), 29 (86) and 36 (93) is between 30 and 35 and, hence, 17 fibres have been assigned to these links. It is noted that the usage frequency for links 1 to 57 and links 58 to 114 are identical as the link loss is assumed to be the same for both directions.

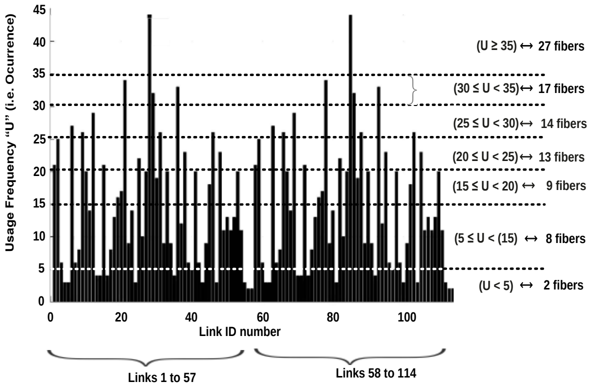

Fig. 3: Assigning a number of fibres to each link.

(a)

Node ID #	un-Optimized Degree	Optimized Degree
1	36	37
2	27	29
3	36	44
4	54	53
5	54	34
6	36	26
7	54	70
8	18	17
9	27	18
10	72	114
11	36	26
12	63	69
13	63	71
14	27	24
15	18	21
16	27	23
17	63	92
18	36	20
19	45	48
20	27	23
21	36	27
22	63	70
23	27	12
24	27	17
25	36	20
26	18	15

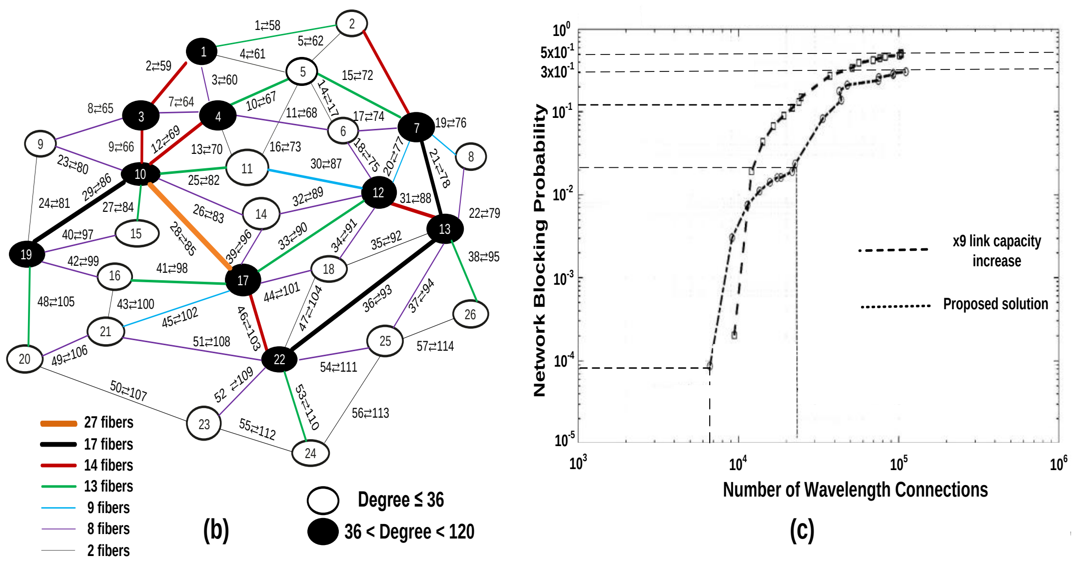

Fig. 4: (a) ROADM degree for un-optimized and optimized cases, (b) Optimized network and (c) Performance comparison.

Performance Results and Comparison

For comparison reason, we keep the total number of OMS on the new optimized network to 1026, which is the same as the un-optimized network of Fig. 1 for *9-fold* traffic increase. Fig. 4(a) compares the ROADM node degrees for both optimized and un-optimized cases. The optimized network has 10 ROADM cluster nodes with degrees of more than 36 whereas the un-optimized network has 7 cluster node. It is noted that only 6 of the 7 urban centres in Fig. 1 have been qualified for cluster node in the optimized solution. In addition, there are 4 new nodes (nodes 1, 3, 4 and 7) that was determined to be cluster nodes in the optimized network. Fig. 4(b) shows the optimized network with $Q = 7$ levels of fibre (OMS) allocation to the links ranging from 2 fibres to 27 fibres per link. Fig. 4(c) compares the blocking performance of optimized network with that of un-optimized one. As it can be seen the blocking performance shows significant improvement at heavy load with the worst case network blocking of about 30%. The improvement in blocking probability is translated to better network capacity utilization. Fig. 5 compares the percentage utilization of all 1026 OMSs as a function of carried wavelength connections. On average, the utilization of each of 1026 OMS has increased by 3.1% for the optimized network. Increasing the quantization level, Q, may improve performance slightly and results in a more smooth blocking performance.

Conclusions

A method for network dimensioning of next generation optical networks is proposed that uses network knowledge to proactively adjust the network size as traffic demand increases. The proposed method shows improved network blocking performance particularly at higher load and yields an average of 3.1% more utilization for each OMS. This is equivalent to an additional 2.5 channels per OMS for 50GHz ITU grid.

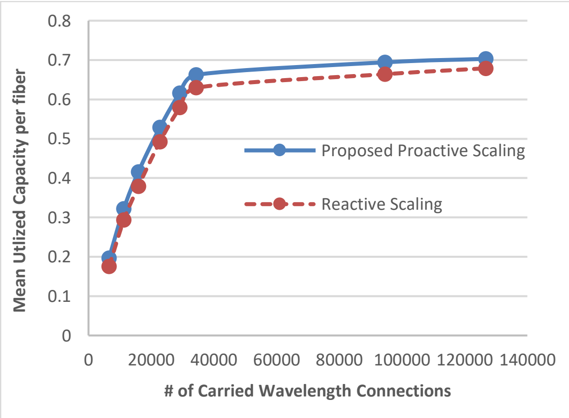

Fig. 5: Network Utilization Comparison.

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