Agile Filterless Submarine Ring Networks

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Abstract—Filterless submarine networks based on agile broadcast-and-select nodes equipped with coherent transceivers are promising options for flexible capacity allocation. In this paper, we propose a filterless network solution for an undersea ring network. The performance is compared with a conventional approach in terms of cost and wavelength consumption.

Keywords—underwater optical networks; gridless submarine networks; filterless ring architectures

I. INTRODUCTION

A new generation of high-capacity optical networks has been enabled by coherent detection and digital signal processing (DSP) technologies. Coherent transmission systems operating at 100 Gb/s are currently deployed over ultra-long distances for both terrestrial and transoceanic applications [1-3]. As the global traffic increases, the need for agile networking solutions becomes more and more important for optimizing the network resources.

In terrestrial networks, the agility is obtained by equipping the nodes with active photonic switching components such as reconfigurable optical add-drop multiplexers (ROADMs) based on wavelength selective switch (WSS) technologies. In today’s submarine networks, WSS-based ROADMs can be deployed at the cable landing stations (the dry plant) [4, 5]. However, the passive or power-switched fiber joints or fixed OADMs in the branching units (BUs) deployed in the wet plant for connecting the branches to the trunk of undersea networks employ a fixed, pre-determined wavelength arrangement and are not flexible in terms of connectivity, which limits the network reconfiguration and spectrum reassignment capability of undersea networks.

Due to the harsh deployment environment and the constraints of system repair, submarine transmission systems are expected to exhibit high reliability and a 25-year operating lifetime. This puts stringent limitations on the technology and qualification requirements for the components and subsystems that can be deployed in the wet plant [5]. Reconfigurable BUs based on passive interleaver/de-interleaver and WSS technologies have been proposed in [6] and [7], respectively. However, these devices still require several qualification tests (in terms of performance, robustness, lifetime and packaging) before they can be deployed under sea.

A filterless network architecture based on passive broadcast-and-select nodes and DSF-assisted coherent transceivers at the edge nodes has been proposed recently for introducing agility in submarine networks [4, 5]. In this paper, filterless architectures for an underwater ring optical network are presented and evaluated through comparative wavelength consumption and cost analysis.

II. UNDERWATER FILTERLESS RING NETWORKS

A. Underwater Ring Networks

It is obvious that optical networks (incl. submarine optical networks) must exhibit a high level of redundancy in order to minimize the impact of faults. This is why many submarine cable systems are deployed using a ring architecture. For example, the Southern Cross Cable Network (SCCN) is a 30,500-km protected ring network using up to 4 fiber pair (FP) cable line systems for interconnecting 9 cable landing stations with a system capacity of 12 Tb/s [8]. Similarly, the 21,000-km Pacific Crossing (PC-1) cable system has a ring configuration with two cable landing stations in both Japan and the United States and a capacity of 8.4 Tb/s [9]. Finally, the 4-FF Trans-Pacific Express (TPE) and the 2-FF Trans-Pacific (TPC-5 CN) networks are protected ring networks with five and six cable landing stations, respectively.

Fig. 1 illustrates a typical architecture for a conventional 11-node ring submarine network. The 3-FF cable line system is stretched over 17,000 km. The black FP provides the basic connectivity between the 11 nodes. The green and the blue FPs are used to connect the 8 trunk nodes as shown in the figure. In this example, the BUs used to connect the branches from cable landing stations 3, 5 and 11 to the main trunk are composed of passive fiber joints, providing a fixed connectivity between specific sets of terrestrial nodes. The submarine line terminal equipment (SLTE) includes the coherent transponders, as well as WSS and mux/demux devices [4, 5].

B. Proposed Filterless Networks with Ring Topology

Figs. 2 and 3 show two proposed filterless solutions for the submarine ring network shown in Fig. 1. In the filterless architecture, the WSS and mux/demux devices are replaced by passive splitters and combiners, leading to a significant cost

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In the conventional solution, dedicated FPs are used to carry the traffic between specific node pairs, which corresponds to the realistic case where the 3 FPs would be used by different network operators. In the filterless solutions, approximately 50% of the total traffic is routed on the first FP ring and the rest of the total traffic on the second FP ring. For this purpose, the total traffic matrix is divided into two sub-matrices in such a way that the minimum number of lightpaths is regenerated. For example, lightpaths (demands) between nodes 1 and 6 are routed on the first FP ring (Fig. 2a) as routing on second FP ring (Fig. 2b) would require regeneration at node 4. Fig. 4 shows that the capacity limit of the 2-FP filterless solutions is approximately 45% lower than that of the 3-FP conventional solution. However, by utilizing a flexible spectrum allocation, a 20 to 30% spectrum saving can be achieved in the filterless solutions at no additional cost [5]. The additional amount of spectrum enabled by the filterless network architecture can be used to add more channels in submarine networks, which can compensate for the wasted spectrum caused by the unfiltered channels.

III. CAPACITY ANALYSIS

Fig. 4 shows the capacity limits of both the conventional and filterless solutions. The wavelength consumption was evaluated as a function of the total network traffic volume. The capacity limit is defined as the total traffic supported by the network when at least one of the fibers is fully loaded (here a total bandwidth of 4 THz was assumed in the C-band). The reach constraints were set to 8,000 km for a 100G DP-QPSK requiring 50 GHz bandwidth and 10,000 km for 100G dual carrier DP-BPSK requiring 100 GHz bandwidth. The initial traffic matrix (in 100G units) is non-uniform and includes a total of 200 demands.
TABLE I. COST ASSUMPTIONS [3, 4]

<table>
<thead>
<tr>
<th>Components</th>
<th>Unit cost * (arbitrary units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLTE</td>
<td></td>
</tr>
<tr>
<td>1 x 30 MUX, 1 x 32 Splitter</td>
<td>0.31; 0.16</td>
</tr>
<tr>
<td>EDFA</td>
<td>0.62</td>
</tr>
<tr>
<td>2/3/4-FP Cable (deep sea, continental shelf, armored)</td>
<td>(0.9, 1.1, 2.3) / (1.1, 1.3, 2.7)</td>
</tr>
<tr>
<td>2/3/4-FP Repeater</td>
<td>60/70/80</td>
</tr>
</tbody>
</table>

* The unit costs of SLTE and line system equipment are normalized to the cost of a 100G DP-QPSK modem and to the cost of a 3-FP deep-sea cable line system, respectively.

IV. COST ANALYSIS

A comparative cost analysis of filterless and conventional network solutions has been performed. The cost assumptions for the SLTE and line system equipment are listed in Table I. The cost of the cable line system and the cost of the repeaters depend on the number of FPs, as well as on the type of cable (i.e., deep sea, continental shelf or armored). The installed first cost (IFC) of the filterless solutions was calculated by considering a 2-FP cable line system (which was assumed to be the minimum cable size) as shown in Figs. 2 and 3. In the conventional solution, a 3-FP cable line system was considered to be installed at the initial deployment.

The cost evolution of the terminal equipment for both filterless and conventional solutions as a function of traffic is shown in Fig. 5a. A comparison of IFC shows 30% cost saving in terminal equipment in the filterless solutions for up to 47.6 Tb/s of total traffic, as a result of the reduced number of fiber pairs and the lower cost of passive nodes in the filterless network solutions.

The cost evolution of the optical line system for the filterless and conventional solutions is shown in Fig. 5b. A comparison of the IFC shows 11% cost saving in line system equipment for the filterless solution. A second 2-FP cable line system must be installed for the filterless solution when the total traffic reaches 59.8 Tb/s. For the conventional solution, an additional 3-FP cable line system must be deployed when the total traffic reaches 93.6 Tb/s.

Fig. 5c compares the cost evolution of the extra components in the filterless solutions. In the translucent filterless solution, extra transceivers are required for regeneration. In the transparent filterless solution, extra gridless WBS are used to allow for spectrum reuse.

V. CONCLUSIONS

In this paper, we have proposed a filterless solution for an 11-node submarine ring network that can accommodate up to approximately 60 Tb/s of traffic on two fiber pairs. The capacity limits of the 2-FP elastic filterless solutions are 45% lower than the conventional 3-FP solution. This is because a system comprising 2-FP trunk will have lower capacity than a system with 3-FP trunk. Another reason is that the ring architecture considered in this case study has very few branching units. Therefore, the wavelengths were assumed to be reused after almost every node in conventional architecture, whereas in filterless solutions the wavelengths were reused at every tree or after every WB. However, an additional 20-30% of the spectrum can be saved in the filterless network solutions through flexible spectrum allocation without the need to redeploys gridless active switching nodes.

A comparative cost analysis shows 30% and 11% savings in terminal and line equipment, respectively, for the filterless solutions at initial deployment. The results show that the filterless architecture can bring significant cost savings for both the terminals and line equipment at the initial deployment, without loss of agility.