Abstract: We present a sensitivity analysis of the average network availability for optical transport networks composed of both submerged and terrestrial links. Variations of reliability and availability data of submarine and terrestrial systems are observed by considering two case study networks with a different ratio between wet and dry plants. A heuristic planning tool is used to route path-protected static connections. Low and high priority traffic are also considered.

1. INTRODUCTION

Service availability is a key parameter of modern Optical Transport Networks (OTNs). In order to achieve for a network the availability level required by customers, node equipment and transmission systems must feature proper reliability performance, while efficient protection techniques may be adopted to readily overcome failure conditions.

WDM networks often include submarine systems, which can be treated and analyzed as parts of the network; therefore, availability estimations should also account for the contributions of wet and dry plant equipment of underwater links, besides those of terrestrial systems.

Modeling tools capable of analyzing different reliability parameters of undersea and dry network elements, as well as the relative weight in the overall network topology of submarine versus terrestrial network-parts, are essential in the operator-to-supplier relationship.

The availability sensitivity analysis, combined with network planning, allows identifying where to address efforts, with the target to efficiently improve the overall availability performance of a customer network.

Point-to-point WDM transmission systems have been thoroughly analyzed under the availability point of view [1], including protected versions and WDM rings [2]. Only recently availability assessment techniques have been applied to optical networks with complex mesh topology and various protection techniques [3]. In particular, a sensitivity analysis of optical connections availability versus components reliability has been presented in Ref. [4].

This paper aims at extending the availability analysis to include component parameters of wet and dry network elements of an integrated submarine and terrestrial OTN. The paper is organized as follows: sections 2 and 3 describe the modeling aspects of our approach, i.e. the general networking scenario and the physical reliability model; the analyzed case-studies are respectively presented and discussed in sections 4 and 5.

2. MODEL OF THE NETWORKING SCENARIO

In this work we are dealing with OTNs supporting static traffic, i.e. designed and optimized according to a known set of permanent optical-circuit point-to-point connections, as specified by a traffic matrix. All such connections are regarded as high-priority traffic, with severe requirements on their availability figures: in order to easily meet such targets with reasonable reliability values of any single network element, we assume that a Dedicated Path Protection (DPP) scheme is adopted for each connection, meaning that two link-disjoint lightpaths (working + protection, or a w/p pair) are setup per connection. We further assume 1:1 protection, i.e. traffic is switched to the protection lightpath only upon failure detection on the working lightpath. This gives the opportunity to exploit protection resources to carry a set of additional connections that follow the protection-lightpath pattern and that are preempted in case of failure. Thus, our model comprises two classes of traffic: protected premier-class hi-priority (hi-prio) connections and unprotected low-priority (lo-prio) optical circuits.

The physical topology of the network (set of WDM links and OTN-switching nodes) is assigned. Each link type, i.e. whether it is terrestrial (terr.) or submarine (sub.), and its length are also known. Any link is an optical cable with equipped fiber pairs and with the necessary set of Optical Line Amplifiers (OLAs) spaced by a preassigned span length. The total link capacity (number of deployed fiber-pairs times the wavelength count per fiber) and the span length vary according to the link type (terr. or sub.). Undersea links are terminated ashore: thus all nodes are dry. Nodes are also non-blocking and with wavelength conversion capability. Network planning (routing and wavelength
assignment of w/p pairs) is carried out through a computer-planning tool based on an efficient heuristic model [5]. Physical topology resources are assigned to w/p pairs minimizing total fiber usage. The condition that all the requested connections are satisfied is always respected.

The goal of this work is to evaluate the network availability sensitivity to parameter variations. Availability is therefore computed for each connection after network planning.

3. AVAILABILITY MODEL

The WDM channel of an OTN link is modeled as a series of components, all characterized in terms of their intrinsic reliability, calculated considering failures due exclusively to internal causes. We do not consider cable and fiber failures (usually caused by external aggressions), while the switching components of the nodes have negligible failure rate. Therefore, the availability of a WDM channel $c_i$ is given by:

$$ A(c_i) = \prod_{i} (1-A_{term Tx-Rx}) $$

where: $L_i$ is the length of link $c_i$ (in km), $L_{span}$ is the line length between two OLAs (in km, specialized for dry and wet plant), $A_{OLA Sub}$, $A_{OLA Terr}$, and $A_{term Tx-Rx}$ are the contributions respectively of the submerged or terrestrial and terminal to the overall availability.

The availability model of a lightpath is simply the series of the WDM channels assigned to it from source to destination. For protected hi-prio connections, the availability figure is calculated by considering the parallel of two series, representing working and protection lightpaths, respectively. Thus, according to well-known equations [6], the availability $A$ of a connection is given by:

$$ A_{hi-prio} = 1 - \left(1 - A_p\right) \left(1 - A_{term Tx-Rx}\right) $$

The availability of unprotected lo-prio connections is simply the availability of a single lightpath.

4. CASE STUDY DEFINITION

By comparing operators' requirements and vendors' specifications, we have identified a set of reliability/availability figures (tab. 1), applicable to the components of WDM channels belonging to a terrestrial or a submarine link. Only the line section of the link is differentiated between terrestrial and submarine, since submarine links are terminated ashore.

<table>
<thead>
<tr>
<th>$MTBF_{OLA Sub}$</th>
<th>$MTTR_{OLA Sub}$</th>
<th>$MTBF_{OLA Terr}$</th>
<th>$MTTR_{OLA Terr}$</th>
<th>$MTBF_{term Tx-Rx}$</th>
<th>$MTTR_{term Tx-Rx}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>211.000</td>
<td>4</td>
<td>20.000.000</td>
<td>336</td>
<td>44.365</td>
<td></td>
</tr>
</tbody>
</table>

Tab. 1 Set of reliability/availability figures in hours

$L_{span}$ is 57 km for submarine links and 100 km for terrestrial links.

We will show the results obtained by applying the described planning and evaluation method on two realistic Italian Networks (INet1 and INet2). INet1, defined in Ref. [7], features 32 nodes, 62 dry and 10 underwater links. INet2, a slight modification of the topology reported in Ref. [8], has 21 nodes, 31 dry and 8 underwater links. The two networks differ in the mean node degree (2.25 and 1.85) and in the dry-to-submerged cable-length ratio (T/S = 2.66 and = 1.67). For these features, INet2 can be regarded as “smaller” than INet1. The two networks are respectively loaded with 496 and 230 hi-prio unidirectional connection-requests. These requests are distributed among the node-pairs according to a realistic traffic-forecast matrix.

In the following case-study analysis two figures of merit are considered: the average unavailability ($U_{hi-prio}$) of hi-prio connections and the percentage of connections of each class ($X_{hi-prio}$ and $X_{lo-prio}$) having availability over a given threshold (expressed in terms of x-nines).

5. DISCUSSION OF RESULTS

Fig. 1 shows the sensitivity of the average hi-prio connection unavailability to variations of reliability parameters. On the abscissa the parameter variation factor $f_p$ is reported, defined for each component availability parameter as the ratio between its varied value and the corresponding reference value shown in Tab.1. The most significant variations on the overall unavailability figure are observed when changing $MTBF_{term Tx-Rx}$ and $MTTR_{OLA}$.

The studied case allows identifying a range of variation in which $MTBF_{OLA Sub}$ worsening can be compensated by an improvement of $MTTR_{OLA}$.

The same analysis was performed on ITNet2; only the curve relative to $MTBF_{OLA Sub}$ parameter shows a slope change, likely due to the network topology differences ($T/S$ ratio). The other curves remain substantially the same.

The highlighted points in Fig. 2 correspond to the reference values of $MTBF_{OLA Sub}$ and $MTBF_{OLA}$ reliability figures reported in Tab.1. They represent the “optimum points”: the curves show that an improvement of the reliability performance for the
amplifiers does not produce a significant benefit to the overall network unavailability. On the other side, relaxing amplifiers reliability requirements rapidly worsens connection unavailability to such an extent that it could be hardly compensated by changing the other parameters.

In order to better identify the acceptable range of parameter relaxation, $X_{5-nines}$ has been evaluated by considering 5-nines as threshold availability.

Fig. 2 Hi-prio unavailability sensitivity to MTBF$_{OLA_{x_{xx}}}$ Variations

Fig. 3 shows a wide range where reliability parameters changes do not affect the 100% of 5-nines high-priority connections. On the contrary, Fig. 4 shows an abrupt variation of low-priority connection percentage having availability over 3-nines, even with a little fp shift. Further analysis has been carried out increasing the amount of connections (traffic load) while preserving both the traffic distribution (according to the forecast matrix) and the condition to mandatory route all the w/p pairs. The sensitivity analysis (not shown for brevity) shows very small differences compared to the ones presented above (load=1) in both INet1 and INet2. Network availability-performance is thus, for this net, rather insensitive to traffic load, provided that the network can accommodate all the requested working lightpaths and their corresponding protection lightpaths.

5. CONCLUSIONS
We analyzed the sensitivity of the average availability of optical transport networks through a novel approach that considers both submerged and terrestrial links.

The dedicated network analysis performed is useful to investigate the trade off between reliability and availability parameters that permit to fine tune the overall network Quality of Service.

The application of such a procedure for each network is an input for cost analysis in order to save costs while being compliant to QoS network-performance requirements.

6. REFERENCES