NETWORK MANAGEMENT CAPABILITIES FOR ADVANCED, OADM-BASED UNDERSEA FIBER OPTIC CABLE NETWORKS

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Abstract: Operators managing undersea fiber optic cable systems rely on Element and Network Management Systems (EMS and NMS) to address their ever-increasing need to reduce Operations, Administration and Maintenance (OAM) expenses and ensure high network availability. Efficient monitoring and accurate fault localization and isolation continue to be critical requirements. These management systems have evolved, and continue to do so, to support industry trends towards complex undersea network topologies with Optical Add Drop Multiplexers (OADM) based undersea network elements, and towards increased deployment of the Optical Transport Network (OTN) technology. This paper discusses a number of new EMS and NMS approaches that we have identified as very desirable to subsea cable operators.

1 INTRODUCTION

Undersea fiber optic cable systems form the backbone of the global communications network, and their expansive geographical span results in a large capital outlay by operators. Operation, administration, and maintenance (OAM) of these systems over their 25 year life, requires effective and efficient configuration and management of the network. Reducing the time to accurately diagnose and recover from faults and intuitively understanding the state of the overall system are top priorities for submarine cable system operators.

The Element and Network Management Systems (EMS and NMS)[1] that are used to manage submarine cable systems have steadily evolved to support advances in "dry plant" (terminal equipment) and "wet plant" (undersea) technologies. The natural evolution of the EMS and NMS systems and of Graphical User Interfaces has followed (i) operator expectation for more intuitive, easier-to-use tools, (ii) pertinent telecom standards, including those for the FCAPS (Fault, Configuration, Alarm, Performance, and Security) management of a variety of SLTE (Submarine Line Terminal Equipment) client interfaces (SDH, Ethernet, etc.) of various rates (10Gb/s, 40Gb/s, 100Gb/s), and (iii) advances in computing technologies. New network management challenges unique to the submarine cable industry are emerging, however, driven by the following: (i) management of wet plant fiber switching and reconfigurable OADM, and (ii) the fact that capacity is mostly sold in smaller increments than the SLTE line rates achievable with today's coherent optical technology [1].

Advances in EMS and NMS functions, therefore, are needed to address the higher complexity of today's submarine cable systems, if operators are to accurately identify, diagnose, analyse, log and where possible recover (at times automatically) from cable system or other faults.

[1] Operators routinely prefer EMS to be installed at each cable station to manage the terminal equipment at that station. The NMS is installed at a central NOC or cable station to manage the entire submarine cable system. The NMS and EMS instances exchange management information with each other via an on- or off-cable Data Communications Network (DCN).

Attractive new approaches for EMS and NMS include:

- Management of the agile and reconfigurable wet plant
- Implementation of GIS (Geographic Information Systems) based GUIs to represent the system as built
- Integration of line monitoring systems and GIS data
- High availability, full redundancy computing
- User partitioning options to address system or terminal equipment sharing
- OTN (Optical Transport Network) features
- EMS and NMS support of ROADM, which brings an unprecedented level of reconfigurability to the systems and warrants machine guidance to the system operations staff.
- Advanced GUI, supporting fault-management, configuration, performance reporting, and security features
- Web-based tools and user interfaces allowing access using generic computing interfaces (e.g., html browser, open source tools)
- Inventory self-discovery and inventory management[2]
- Automatic submarine network (trail) discovery at the NMS from the underlying EMS layer
- North Bound Interface (standardizing on SNMP) to customer provided OSS
- First alert reporting

While these capabilities have helped operators cope with some of the unique operational challenges in managing submarine cable systems, the advent of agile and flexible OADM-based wet plant, and other technological developments bring about special challenges in operating these systems efficiently, especially in accurately identifying, locating, and recovering from faults. Additional feature sets are required for effective management of these newer cable systems. Discussions with operators' station staff help identify new enhancements to the EMS/NMS systems and often result in implementation of these features.

2 KEY EMS/NMS TOOLS AND CAPABILITIES

A typical EMS/NMS architecture for current submarine cable systems is depicted in Figure 1.

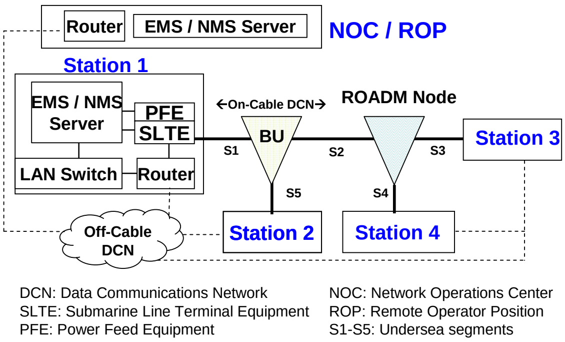

Figure 1 - Example Submarine Cable System EMS/NMS equipment and network architecture

Most EMS/NMS systems currently support at least the following features:

2.1 Management of the Agile and Intelligent Wet Plant

The concept of agility was, not so long ago, foreign to submarine cable systems. All segments in the system were static, and represented point to point connections with

[2] This includes management and reporting, using graphical user interface, of current and historical information and status of the various types of field replaceable units (FRUs). See for example [7].

no fiber sharing amongst landing stations. The last few years witnessed the deployment of fixed OADM based wet plant branching technology [2], which enables spectrally efficient (allowing wavelength reuse) and cost-optimized bandwidth delivery to landing stations with mixed capacity needs. The fixed OADM systems introduced new challenges in network design and management due to the strong interdependence between the trunk and branch traffic from the sharing of optical bandwidth on the same fiber pair [3]. The EMS and NMS have addressed the needs of fixed OADM systems [2][4].

The maturing of WSS (Wavelength Selective Switch) optical components now allows design of agile and reconfigurable wet plants [5]. ROADM (Reconfigurable OADM) nodes that employ subsea qualified, reliable WSS optical components, as well as fiber switches, allow dynamic undersea channel/capacity reallocation and automatic fault recovery. Reallocating available capacity dynamically, either per individual wavelength or per band of wavelengths, helps operators optimize system bandwidth utilization and adapt to changes in demands for capacity. It also helps enable innovative business models by expanding system cost sharing options. Undersea ROADM impacts EMS and NMS in the areas of channel monitoring and fault management, leading to the following new features to simply operations:

- Channel monitoring and management: The ROADM node, with reconfigurable WSS optics and fiber switches, introduces a redefinition of the optical path for each wavelength and requires new EMS and NMS tool features to dynamically provision, monitor, and maintain this changing network state. As these network changes are introduced, these tools provision Tx/Rx line cards, loading equipment, WSSs in the ROADM nodes, and configuration tables to be reflective of the new state.

  The EMS/NMS evolution to support ROADM adds, at a minimum:
  - Configuration screens for channel allocation and management
  - Database management of pre-defined channel plans
  - Protection of the system from inadvertent, user initiated, outage-causing network configurations
  - Manage the SLTE to support OADM channel plan reconfigurations
  - Dynamic reconfiguration and display of network trails/circuits
  - Logging of configuration changes and significant events

- Fault management: Fixed OADM systems have already been implemented with OADM fault recovery features [2]. Specifically, the EMS and specialized SLTE features detect OADM system faults and provide rapid first order recovery from a traffic affecting fault. The recovery process is initiated when the EMS and SLTE detect a Loss of Frame (LOF) alarm signature. The recovery action may consist of changes to shore based optical loading tones, reconfiguration of undersea elements, or both.

  Fault detection and recovery in a ROADM node equipped system follows essentially the same principles as a fixed OADM system. However, new fault management challenges emerge from the interdependence between trunk and branch traffic changes with every wavelength reconfiguration. Managing the number of possible trunk and branch channel configuration plans becomes cumbersome when wavelength-level reconfiguration is introduced. Only the NMS, with its network level view, can analyze system-wide faults/alarms in conjunction with the current channel plan configuration and determine an appropriate recovery action.

The above requirements necessitate a new set of EMS/NMS features:

- ➢ A dynamic fault detection and recovery method
- ➢ Screens to configure above mentioned fault attributes and recovery actions
- ➢ Interactive dialogues to allow user intervention if desired

The emergence of Branching Units (BUs) which support gridless switching among fiber pairs in the undersea network with any modulation format and arbitrary channel spacing, further necessitates EMS/NMS orchestrated OADM fault recovery solutions[6].

2.2 Geographic Information Systems (GIS) Based Network Map Display

The graphical depiction of cable system components by current EMS/NMS implementations is a simple schematic representation that does not reflect the actual locations of the wet plant elements. As we evolve the undersea cable system to include OADM-based devices in need of control, a more sophisticated wet plant display mechanism is desired. Maintenance personnel often need to consult marine deployment details in order to precisely locate wet plant faults for repairs. Instead of having to review confusing "as-laid" tables and databases, operators ideally need speedy access to this data in the NMS using intuitive GUI tools.

An excellent way to depict this data is in the form of a layered network map, an example of which is shown in Figure 2.

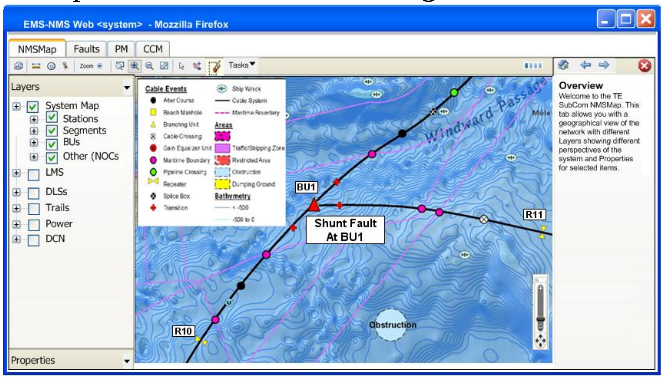

Figure 2: Example GIS-based Network Map Display

The primary requirement of a wet plant mapping system is to show the correct geo-location of the undersea devices and cable on a scaled map. Zooming and panning, and support for layering of information are typical of GIS systems. The operator therefore can view the entire system, including top level cable/repeater placement, as well as details of the exact locations of each BU, repeater, splice box and bathymetry. In some applications, the location of installations near the system could also be of interest, e.g., fishing, anchorages, pipelines and other cables. This information is routinely considered and known as part of system design.

The GIS-based wet plant network map display implemented in this example supports multiple layers each representing a specific management view of the cable system. The "base" layer shows physical entities such as cable segments, stations, BUs, repeaters, and NOCs (Network Operation Centers). A secondary layer shows complete wet plant device placement. Bathymetry layers are also available. In addition, the display can support additional layers for depicting other management views of the cable system such as the DLS (Digital Line Section) layer, transmission trails layers with dynamic alarm overlay, LMS (Line Monitoring System) layer, Power Path layer, and DCN layer views. This graphical representation is a useful tool for operators to visualize and understand the system status.

The top-level mapping architecture implemented in this example is shown in Figure 3. The implementation includes creation and management of the significant database required, and support of a flexible mapping display engine. In our implementation, we chose an open source mapping tool (MapGuide) which supports public domain maps. The "as laid" data from the marine cable lay information is converted to the MapGuide format. This data is visible to authorized users from connected locations via a web browser.

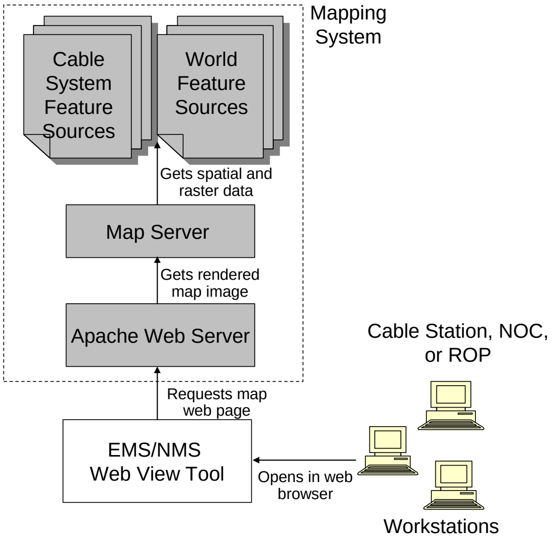

Figure 3 - Top Level Mapping Architecture

2.3 Automatic Line Monitoring System (LMS) Database Generation

In conjunction with the GIS mapping, NMS systems must report on the detailed health of the wet plant after performing a monitoring operation. Regardless of the method of monitoring, a database that represents the repeater configuration must be created from "as laid" information, typically route position lists (RPLs) and straight line diagrams of the wet plant. This can be a tedious process if done manually. As an example, multiple RPLs that represent the entire system can be automatically sewn together to create a LMS/wet plant database. On any repair, the new "as laid" data is simply re-read and the LMS database update is made.

In addition, reconfigurable OADM systems demand special line monitoring procedures where the LMS needs to consider the OADM configuration.

2.4 High Availability

Operators no longer accept loss of service in NMS servers, since it could translate into lost revenue. Support for hot-swappable, redundant power supplies, fans and mirrored-disks on a single server has been the standard but is no longer sufficient. A backup server that automatically takes over when the main server fails or is put into service mode is becoming a standard NMS system hardware requirement. In addition, the Data Communications Networks (DCNs) that are put in place to support today's cable systems are expected to have redundant routers that operate in a similar fashion. The use of open source high availability toolsets has allowed TE SubCom and others to implement high availability with minimum additional cost allowing the feature to become a "no-cost" option where a spare server is already included.

2.5 User Partitioning

The current global economic conditions encourage efficient sharing of cable system and resources among multiple operators (e.g., fiber-pair sharing wherein the fiber-pairs with in a cable are shared among the members of a consortium). This approach demands advanced user management features at the EMS and NMS. OADM support further complicates partitioning issues.

Cable system sharing can take numerous forms. Some operators may have full control of portions of the system, while other operators or a consortium may operate the overall system or portions of the system.

User Partitioning allows system administrators to provision users to view or access only those portions of the network appropriate for them. For instance, users who require only access to a particular Power Feed Equipment (PFE) alarm and associated performance data, or to a specific fiber pair Line Terminating Equipment (LTE) data, may be provisioned accordingly. This feature is especially useful for cable system operators that need to provide their customers with access to alarm and/or performance metrics for only those portions of the network of interest (for example, dedicated fiber pairs). Ideally, the EMS/NMS would allow partitioning of a fiber pair down to a single wavelength level, and further down to the client port level (e.g. 100G wave partitioned in multiple groups of several 10G each). This includes partitioning of alarms and performance management data.

To illustrate this, Figure 4 shows multiple customers of a jointly owned cable system viewing the status of the portion of the network that they individually own. Customer 1 has full control and visibility of fiber pair 1 and the associated SLTE equipment. Customer 2 has full control and visibility of fiber pair 2. Neither customer has control or visibility of each other's equipment or fibers. However, both customers have visibility into the repeater status, and the status of the PFE. It is also possible that control of the PFE and branch power feeds needed for restoration, be accessible to only one designated operator in order to ensure a coordinated system operation.

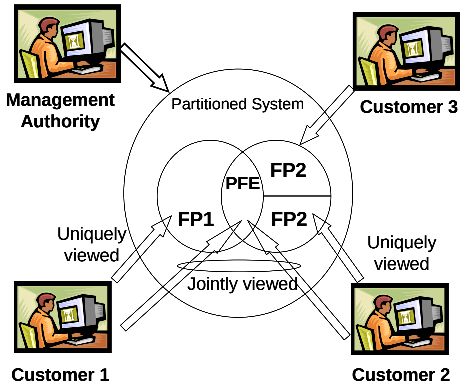

Figure 4: User partitioning Example

OADM systems impose additional complexity on partitioning. Consider a consortium of customers who share portions of a system: One customer owns an entire fiber pair, but the second fiber pair is split between customers sharing OADM bandwidth. Partitioning must be flexible, capable of resolution down to a single wavelength. In addition, subset and supersets of partitioned entities need to be simultaneously supported. In some cases, the central management authority of a consortium may have overall management responsibility for the entire system, and each member desires full access to the portion of the system it owns. This same member would oppose visibility of the same data by other members. As companies increasingly join forces to reduce the overall cost of submarine cable systems, the complexity of network management of OADM partitioning will continue to increase. Reconfigurable

OADM adds variability to the same problem as the system changes state dynamically, and invalid modes (those which are not consistent with privacy/partitioning constraints) must be avoided as well.

2.6 OTN based client traffic handoff

OTN [8], with its superior OAM capabilities, has become the preferred client interface protocol to handoff traffic between the terrestrial and submarine links. Also, with its support for full transparency to client signals, OTN is the preferred digital framing method to transport client signals between SLTEs. Support for OTN client interfaces (OTU2, OTU4, etc.) at the SLTE necessitates new EMS/NMS features for provisioning and monitoring the OTU Section, ODU Path, and Tandem Connection Monitoring (TCM) layers corresponding to these interfaces.

The provisioning controls at the EMS/NMS include Trail Trace Identifier related parameters (enabling/disabling of trace insertion, expected trail trace identifier, etc.) at each of the above layers. The fault conditions monitored at the EMS/NMS include LOF, Signal Degrade, Trace-Id-Mismatch, Loss of Tandem Connection, etc. The performance parameters monitored include near-end and far-end counters for Errored Seconds, Severely Errored Seconds, Background Block Error Count, etc. The EMS for 100 Gb/s SLTEs should include management of OTN client interfaces using intuitive GUIs, enabling operators to effectively and accurately identify and localize faults and performance issues in the system.

3 CONCLUSIONS

Submarine systems have unique needs with respect to EMS/NMS and its support of ROADM functionality. The system robustness expected in the event of cable cuts or branch power failures demands new EMS/NMS functions and simplification of the interfaces for the operations teams. In this paper, we have identified a few key EMS/NMS features that will help operators manage the next-generation agile and intelligent wet plant with improved visibility both at system and network element levels.

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