CABLED SCIENCE OBSERVATORIES SOLUTIONS: BRINGING POWER AND BROADBAND COMMUNICATION TO THE OCEAN DEPTHS

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Abstract: To deliver high power and broadband communication to the ocean floor requires a number of changes to existing technology developed to bridge oceans from shore to shore. Adapting this well mastered dry-dry solution to become dry-wet represents a major technical challenge. The cabled observatory system developed for the Canadian part of the North-East Pacific Time-series Undersea Networked Experiment (NEPTUNE) encompasses major breakthroughs in several areas, including optical transmission, ocean engineering and powering.

This paper discusses how an industrial team led by Alcatel-Lucent along with partners L-3 Communications MariPro and Texcel Technology have managed the design and development effort in all these fields.

The capabilities of this design to be extended to cover the needs of the full NEPTUNE Regional Cabled Observatory (RCO) or to be deployed for other applications such as undersea neutrino telescopes or tsunami detection systems is also assessed.

1 INTRODUCTION

Submarine cable telecommunication networks traditionally bridge dry land to dry land with primary focus on high quality, low latency, high availability broadband communications. Recently, this technology has been adapted to allow delivery of communications with the same qualities to floating devices such as offshore platforms or Floating Production Storage and Offloading units (FPSOs) [1]. A much bigger challenge lies with the adaptation of this submarine telecommunication technology to bring communication and power to undersea structures lying on the sea bottom [2].

An industrial team, led by Alcatel-Lucent, was awarded, in October 2005, after a thorough selection process, the contract for the infrastructure of the NEPTUNE Canada project issued by the University of Victoria. NEPTUNE Canada is the first regional scale application of this new concept where a number of areas of scientific interest in the Juan de Fuca tectonic plate in the north east Pacific will be equipped with science nodes bringing power and broadband connection to different science instruments. Refer to **Figure 1** providing a layout of NEPTUNE Canada.

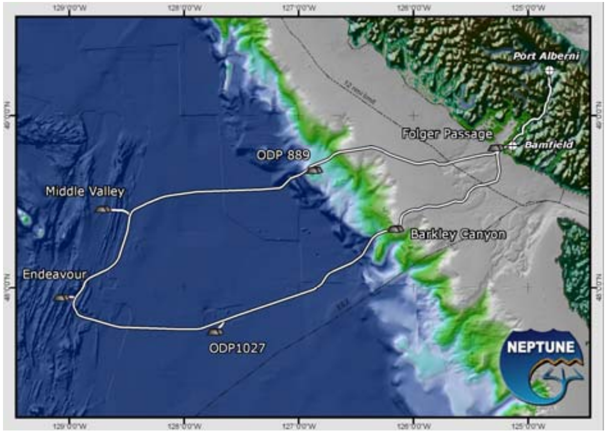

Fig 1: NEPTUNE Canada Layout

2 NETWORK ARCHITECTURE

Design trade-off studies were performed during the initial NEPTUNE design phase to consider different options for the network architecture. Budget issues dictated utilization of Commercial Off The Shelf (COTS) components for the construction of the science nodes communications subsystem instead of custom built high-reliability hardened hardware such as what can be found in the wet plant of telecom systems. A meshed architecture where optical amplification would take place in the science node was initially considered. It has two major drawbacks: one would have to insert science nodes in the network to insure signal amplification or regeneration at places where science instrumentation would not necessarily be desired. Also, despite the meshing of the network, communication to a science node would depend on the correct operation of the previous nodes on the different paths from shore.

The retained architecture optimizes the use of existing field proven telecom products such as submarine cable, repeaters and Branching Units (BUs). It relies on a high reliability repeatered backbone ring with a dedicated BU for each science node. Only the science node is developed with COTS elements. The design of the distributed WDM add/drop function is such that if a science node fails to operate, it does not impact the operation of the other science nodes still allowing them to have duplicated paths to shore thanks to the ring concept.

Another key high level aspect relates to the powering of the network. Here again a lot of initial studies came to the conclusion that the network had to be fed in Direct Current (DC) in a parallel mode similar to a distribution power grid with the return current borne by the sea water. This is somewhat new in the submarine telecom world where everything is designed around the concept of constant current in a series mode of operation. The traditional series mode with sea water return is well mastered for long linear cable systems and provides good protection against shunt faults which are the most common cable damage effects. Yet, it is not compatible with the required level of useable power at each node (up to 9 KW) and the ability to bring sizeable amounts of power kilometers away from the backbone cable route. This ability to provide power at locations distant from the backbone can prove to be a key factor as the science instruments may be located in active areas where a telecom cable would not normally be routed [3]. The ring architecture also simplifies the management of the power distribution within the network and provides easily the ability to electrically isolate a science node in the event of a failure.

3 COMMUNICATIONS AND LINE DESIGN

A new distributed WDM add/drop scheme is proposed using a new generation of BUs. The BUs use simple and very reliable coupling devices to add or drop wavelengths to or from the trunk spectrum. Wavelength selection is performed in the adjacent nodes, allowing a single spare BU to be used anywhere in the network. Each node is given a dedicated set of two wavelengths and a pair of single wavelength transponders. Using the ring architecture with dual paths back to shore, each transponder is only facing one direction: east or west.

The transponder comes from the metro WDM family of products from Alcatel-Lucent(1696MS) and a small form factor shelf is used containing two transponders and a few ancillary boards. Each transponder consists of a bi-directional plug-in unit at 2.5 Gbit/s with direct laser modulation and Forward Error Correction (FEC). The transponder also includes a mapping function that takes two Gigabit Ethernet (GigE) signals and maps them into an STM-16/OC-48 signal. However, no SDH or SONET protection mechanisms are used. Our extended expertise of dealing with DWM amplified lines at N x 2.5 and the simplicity to use a standard bit rate were key in selecting this wavelength signal rate.

The optical line design of the full NEPTUNE Canada network with over 700 km of submarine cable and six science nodes is such that the single fiber pair cable could be extended up to 1800 km and may include up to ten nodes. This may be an easy way to capture most of the scientific areas of interest in the Juan de Fuca tectonic plate allowing, with limited additional capital expenditure, to fulfill the initial vision of the NEPTUNE RCO.

The line design and the WDM scheme used may also make possible the upgrade of select nodes to 10 Gbit/s instead of 2.5 Gbit/s. This would require a new science node design capable of mitigating Chromatic Dispersion and non linear effects but would remain consistent with the current amplification scheme and channel spacing of NEPTUNE Canada.

4 IP AND PTP

The traffic protection in the network is performed at the Internet Protocol (IP) level using the latest Layer 2 functions such as the stacking of redundant switches and IEEE 802.3ad Link Aggregation Control Protocol (LACP). Each science node is equipped with two Alcatel-Lucent switches of the 6850 family providing each up to 24 ports at the GigE level. In the terminal station, two 48 port stacked 6850 switches are used in conjunction with Alcatel-Lucent routers of the 7450 family. A dedicated Network Management System is provided to configure and control the traffic over the dual star network architecture.

The terminal station is also fitted with a Precision Timing Protocol (PTP) server driven by a GPS clock. Some science instruments may be equipped with a PTP client to allow timing and synchronization with an accuracy orders of magnitude better than that which Network Timing Protocol (NTP) can provide.

The mechanisms used for the routing and management of the IP packets make the best use of the ring architecture and the redundancy of the hardware at all levels. They maximize bandwidth usage over the network with fast protection and provide the best accuracy for the PTP users by minimizing the PTP packets transmission delay.

As sensors or instruments can be located a few kilometers or a few tens of kilometers away from the node, short haul and long haul optical science interfaces are provided to optimize communications. The flexibility of choice is provided by the use of corresponding media converters or Small Form factor Pluggable (SFP) modules between the 6850 switches and the connectors of each science port.

5 POWERING

The powering of NEPTUNE is the most novel and challenging part of the network. While it is based on traditional one ohm per kilometer submarine cable with a maximum voltage of 10 KV DC, it requires the capability of each element to handle a line current of up to 8 A. As such, a thorough qualification effort has been performed to demonstrate the safe and reliable operation of the repeaters and BUs at a permanent direct current of 8 A.

A revolutionary PFE has also been designed, providing up to 80 KW directly fed from the mains AC grid of the station. It saves the step down and step up functions required when the PFE is fed from 48 V DC and insures good reliability and availability when coupled with an Uninterruptible Power Supply (UPS). Two 80 KW negative feed modules are required to normally feed the two cable heads and a third positive feed module is also provided for network reconfiguration operations. A series of switches and interlocks allows, by respecting certain sequences, to connect any of the different modules to either cable end. **Figure 2** gives an overview of the NEPTUNE Canada PFE.

Fig 2: NEPTUNE Canada PFE

The parallel mode of operation of the network is such that the current will be different in the various sections of the backbone. Special care has been devoted to the possible operation of the amplifiers at a line current far below what is normally provided in a traditional network. A mechanism is implemented, thanks to the use of additional electrical loads in the nodes, to maintain at all time this minimum line current in all the sections of the backbone.

In addition to the novel characteristics of the NEPTUNE BU in terms of WDM add/drop function and also low and high current active amplification, it is also fitted with an enhanced power switching function. Compared to our field proven tri-state latching BU offered on systems such as SEA-ME-WE 4, an additional state with all legs ABC permanently connected has been added. This new ABC state is in fact the normal state of a NEPTUNE BU allowing the backbone to feed the corresponding node from current coming either from the west or the east side of the ring. The other states, AB, AC or BC are used for network re-configuration in case of cable fault or node fault. It is indeed very important to be able to isolate a node electrically from the backbone in case of shunt fault on the spur to allow the other nodes to be fed normally and continue to operate. This special mode also allows safe maintenance or repair operations to be carried out on the non powered spur cable or node.

Stepping down the 10 KV required for low loss power transport to a more useable 400 V is performed at each node by a totally new element called the Medium Voltage Converter (MVC). While, in principle, DC to DC voltage conversion is a common operation, its application in NEPTUNE is fairly complex due to the difficult functional and environmental conditions. This device is essential to the whole system hence needs to be safe and reliable. It must provide up to 9 KW of useable secondary power with various conditions of primary voltage levels and secondary loads variation. Finally, it must be performed on the sea bottom where thermal dissipation issues, hydrostatic pressure resistance and electrical isolation requirements are hard to combine [4].

Based on an adaptation of a publicly available design using a series and parallel arrangement of a number of individual lower power converters, the NEPTUNE Canada MVC relies on distributed redundancy to reach an acceptable reliability level. Significant engineering effort has been spent to develop and qualify the necessary control boards managing the synchronous behavior of the individual converters in all the different phases of the converter operation: ramp-up, shutdown, degraded modes. Indeed, developing such a complex electrical function at 10 KV for such a harsh environment represents a major technology breakthrough for our industry. Please refer to **Figure 3** showing the typical arrangement of the MVC in its dedicated pressure vessel.

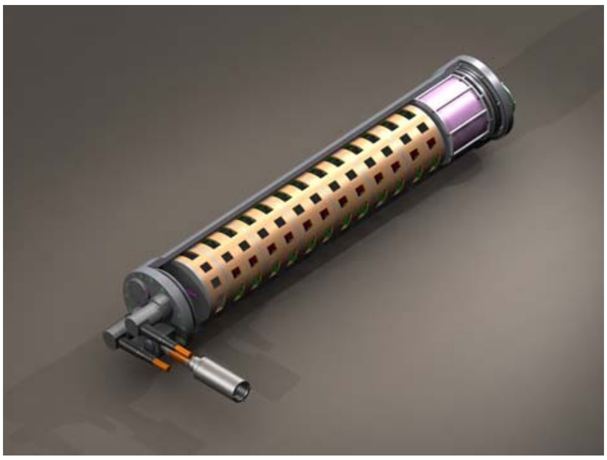

Fig 3: Typical layout of the MVC in its pressure vessel

Another important part of the powering system is the Low Voltage Power System (LVPS) allowing the management and distribution, within the node of the 400 V secondary voltage. Each science port is provided with a controlled two conductor 400 V output. The current draw on each 400 V port is monitored and compared to a preset value. Trip-out will occur should the current go beyond the given value on a port per port basis. The LVPS also converts the 400 V to lower voltages to insure the proper powering of the different active elements of the nodes such as the WDM transponders, the IP switches and the media converters. The LVPS also monitors a series of electrical and environmental parameters assessing, in real time, the sanity of the node major elements. **Figure 4** shows elements of the LVPS at the prototype level.

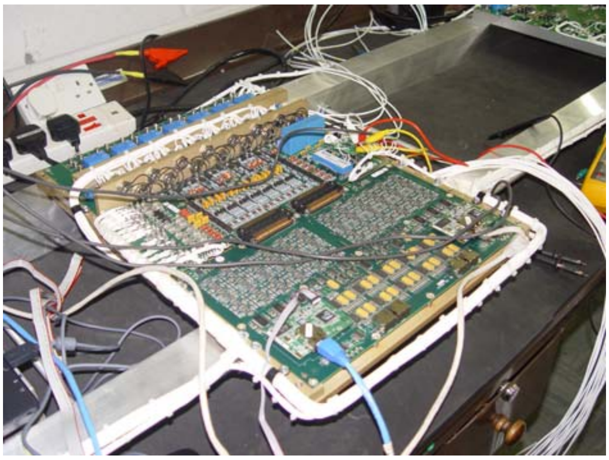

Fig 4: Elements of the LVPS being tested

A sophisticated Network Management System, able to monitor and send commands to the key elements of the network such as the PFE, the repeaters, the BUs and the LVPS modules in each science node, allows a centralized control of this dynamic power distribution network.

6 OCEAN ENGINEERING

The COTS equipment housed within the science nodes are not yet designed or qualified to traditional submarine telecom standards and are known to be less reliable than the associated backbone cable components. Maintenance at the bottom of the ocean is a costly and complex task. Therefore, cost effective maintenance solutions have had to be found that do not require the use of a Cable lay Vessels (C/V) once initial installation and commissioning has been completed. To address this need for cost effective servicing of the science node, a ROV serviceable science node has been developed that allows the power and communications equipment housed within the node to be easily recovered and replaced by the same ROV equipped Research Vessel (R/V) used for deploying and servicing the science instruments [5]. **Figure 5** gives an illustrated view of ROV operation with the node.

Fig 5: ROV Serviceable Node concept

The node itself is composed of two parts: the Trawl Resistant Frame (TRF) and the Node Module (NM). The NM contains the active parts and is designed to gracefully lodge into the TRF and is made almost neutrally buoyant so that it can be handled gently with an ROV while immersed. Please refer to **Figure 6** showing the typical layout of the NM.

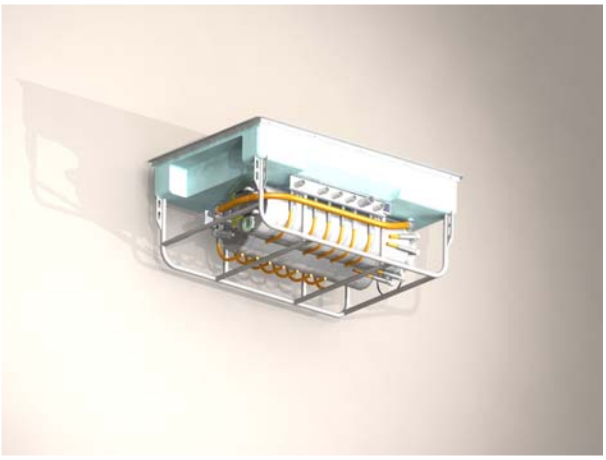

Fig 6: Typical Node Module Layout

Attached to the TRF a Cable Termination Assembly (CTA) provides the actual splitting of the power conductor and the four optical fibers in two separate oil filled hoses each terminated by a wet mate connector. The NEPTUNE Canada team has developed and qualified with ODI a special version of an ROV type electrical wet mate connector able to deal with up to 10 KV of DC voltage. The CTA also includes the earth electrode used for the sea return of the MVC primary voltage.

A great deal of mechanical and thermal engineering has been used to design the two pressure vessels of the node module. The MVC represents a relatively short diameter but long body canister while the LVCom, due to the different form factors it needs to house, requires a larger diameter cylinder.

While the MVC is cooled using an FC77 type fluid due to the high density individual converter thermal profiles, it has been possible to design a dry pressure vessel for the LVCom using special conducting cooling techniques such as thermal drains or direct bulkhead mounting. **Figure 7** shows the typical layout of the LVCom pressure vessel.

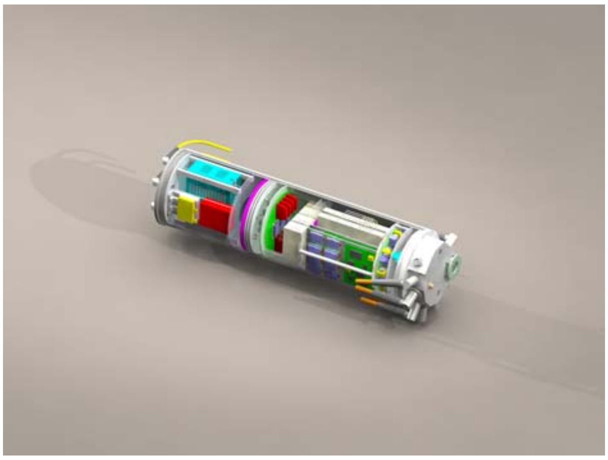

Fig 7: Typical LVCom Pressure Vessel Layout

Oil filled hoses and harnesses allow the different connections between the pressure vessels and the wet mate connectors (to the cable and to the science or extension ports) as well as between the two canisters themselves. Another cable connects to the Current Sustaining Load (CSL) device.

7 CONCLUSIONS

With the continued support and involvement of the experts and scientists of UVic, the Alcatel-Lucent team is developing a true premier multidisciplinary system solution with challenges in every domain, communications and IP, powering and ocean engineering. When deployed, NEPTUNE Canada will represent a paradigm shift for oceanography allowing real-time monitoring of critical science parameters and events over long time series. This is clearly unprecedented for regional scale cabled observatories [6].

This newly developed technology could be applied or adapted to many other fields or other scales. According to the location and the area to be covered cost effective solutions could be derived without the need for repeaters for instance. The use of less powerful, cost reduced DC/DC converters could also open new possibilities in terms of coastal observatories.

In Europe, observatories are being developed within the ESONIM Network of Excellence, based on the ESONET concept gathering a series of cabled infrastructures [7]. In Asia, sophisticated real time tsunami detection networks based on this technology are being considered. Large scale undersea neutrinos telescopes are currently being built in the Mediterranean using products or technology similar to those developed for NEPTUNE. The control of offshore oil and gas undersea structures could also use techniques based on the same principles when the use of a fixed or floating platform or FPSO is not possible or economical.

The technology breakthroughs brought by this cabled observatory solution are poised to further extend the field of applications of products initially designed for submarine telecom networks. Many initiatives are currently been envisaged based on these new technologies in the scientific and energy sectors. It is our opinion that these non-telecom applications will contribute greatly to the benefit of our industry in the coming years.

8 ACKNOWLEDGMENTS

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9 REFERENCES

[1] Which technology for your offshore network: unrepeatered or unrelentingly repeatered?, M. Fullebaum et al., Suboptic'07

[2] Connecting Long Term Sea Floor Observatories to the Shore, G. Waterworth et al., Sea Technology, September 2004

[3] To boldly go where no system has gone before,: S. O'Bow-Hove et al., Suboptic'07

[4] Industrial Solutions for Regional Cabled Ocean Observatories, G. Waterworth et al., Europe Oceans 2005

[5] ROV Serviceable Science Node for Cabled Ocean Observatories, N. Shaheen et al., MTS/IEEE OCEANS, September 2005

[6] NEPTUNE Canada (NEPTUNE Stage I) and the opportunities presented, P. Phibbs et al, Suboptic'07

[7] Design of the scientific cabled network between Ireland and Porcupine Seabight and Abyssal Plain, study site of the European Seafloor Observatory Network Implementation Model (ESONIM), J-F. Rolin et al., Suboptic'07

[8] MARS web site: http://www.mbari.org/mars/

[9] NEPTUNE US web site: http://www.neptune.washington.edu/

[10] NEPTUNE Canada web site: http://www.neptunecanada.com/