

Building Marine Infrastructure for Science

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Abstract-The NEPTUNE Canada cabled ocean observatory is a Canadian funded undersea utility whose sole purpose is to support research into the ocean depths. With 800 km of subsea cable, and five science sites with 10kW power and 4Gb/sec data transmission at each, it will represent the first of a new generation of cabled subsea observatories.

In many ways NEPTUNE Canada matches the utilities all of us use every day in that it supplies electricity and “telephone lines” to customers’ places of business. Both terrestrial and subsea utilities require major effort by specialised manufacturers and installers to build the infrastructure, and a knowledgeable management and engineering team to create specific requirements, protect the owner’s interests during construction and manage the manufacturers and installers.

However the management of the development and construction of undersea utilities for science differs significantly from the development and construction of more conventional utilities such as electrical grids and telephone networks. First and foremost, working in the marine environment versus on land changes the risk profile entirely. Whereas a failed piece of equipment in a terrestrial network may require two technicians and a cube van to drive out to a remote site, failures subsea will require months of planning, mobilisation of ROVs and ships, as well as significant expenditures of money, effort and customer goodwill. Therefore for an undersea system to be economical and successful through its working life, a significant portion of the funding has to be spent on ensuring long term reliability of the subsea plant prior to installation.

Secondly, NEPTUNE Canada is a utility dedicated to scientific use. The design of NEPTUNE Canada is driven jointly by the needs of scientists, funding issues and limits, and assessment of the current capabilities of the technologies. Terrestrial utility design is driven by commercial or regulatory requirements, which can usually be defined and fixed early in the project, so that requirements and specifications can be set prior to contract award. However some of the NEPTUNE Canada requirements have been deliberately kept flexible well into the development cycle, to allow accommodation of the scientists needs as those needs develop. This flexibility adds significantly to the challenge of risk identification and management.

Thirdly, at the start of the NEPTUNE Canada project, no technology existed that could meet the scientist’s requirements. Whereas terrestrial utilities tend to be a further step along a continuum of development, NEPTUNE Canada stepped boldly into an untried area. Managing this development risk with a capped budget would not have been possible without the support of the NEPTUNE Canada prime contractor, Alcatel Submarine Networks (ASN), a division of Alcatel-Lucent. The experience ASN brought from the submarine cable industry, plus its unmatched research

and development engineering capabilities, have enabled NEPTUNE Canada to pursue the scientists’ initial concept of high power and high bandwidth communications delivery to and from the deep ocean.

This paper will use the experiences gained so far in the funding, development, manufacture and installation of the world’s first multipurpose deepwater cabled ocean observatory to consider how useful the models of terrestrial power and communications utilities are when planning scientific utilities and infrastructure such as NEPTUNE Canada. It will discuss the challenges of managing the sometimes disparate interests and expectations of the groups and institutions involved. And it will identify some of the pitfalls that need to be avoided by anyone trying to build these types of infrastructure.

I. INTRODUCTION

The NEPTUNE Canada cabled ocean observatory is a \$100 million undersea utility funded by the Canada Foundation for Innovation and the British Columbia Knowledge Development Fund. Located off the west coast of Canada and spanning the Juan de Fuca tectonic plate, the primary purpose of the NEPTUNE Canada Observatory is to support Canadian and international research into deep ocean systems. As such, access to ports on the system and to the data stored in the Data Management and Archiving System (DMAS) is being offered to scientists and researchers around the world.

II. GENERAL DESCRIPTION OF NEPTUNE CANADA

The four major scientific research themes that have currently been identified for NEPTUNE Canada are the structure and seismic behaviour of the ocean crust; seabed chemistry and geology; ocean climate change and its effects on marine life at all depths; and the diversity of deep sea ecosystems. However scientists are encouraged to explore the capabilities of this facility and to propose additional scientific research areas.

NEPTUNE Canada’s unprecedented access to the deep sea world will increase our understanding of the oceans in the same way that the Hubble Telescope is revolutionizing our knowledge of outer space. This new knowledge will be applied to many global problems and opportunities, such as mitigating the effects of earthquakes and tsunamis, evaluating the sustainability of commercial fish stocks, improving models

of regional climate prediction, and searching for potential new energy sources.

An important secondary purpose for NEPTUNE Canada is to support and encourage the international, and in particular the Canadian, subsea industry. As part of this effort, NEPTUNE Canada has identified a fifth research theme which is engineering and computational research. As a part of its support for engineering research, NEPTUNE Canada is making ports available to developers and manufacturers of subsea equipment to give them the opportunity of testing their equipment in a real world, deep water environment, while being able to monitor the status of the equipment day by day and minute by minute from their workplaces.

NEPTUNE Canada is a development of the existing scientific and seismic cabled ocean observatories. The Japanese have led the way in this field, with Jamstec’s seismic observatories off the east coast of Japan. The Americans have moved forward on multi-use cabled observatories such as LEO15, Martha’s vineyard and MBARI’s new MARS observatory in Monterey Bay. Indeed, the concept for the NEPTUNE observatory was the initiative of Drs. John Delaney of the University of Washington and Alan Chave of Woods Hole Oceanographic Institution.

These previous cabled observatories have either been multi-use but geographically limited such as LEO15 and MARS or geographically large but primarily single purpose such as the JAMSTEC seismic observatories. NEPTUNE Canada, with 800 km of subsea cable, and five science sites with 10kW power and 4Gb/sec data transmission at each, represents the first of a new generation of cabled subsea observatories.

III. GENERAL ARCHITECTURE

The architecture adopted for NEPTUNE Stage I is a trunk and branch topology as illustrated in Fig. 1. This architecture achieves the desired functionality for both power distribution and communications. Most importantly, it allows the trunk or backbone to be constructed exclusively from components designed and qualified for use in commercial sub-sea telecommunications systems and leverages the many years of design experience and high reliability of these components. The architecture supports up to ten primary nodes attached to the backbone; in addition, NEPTUNE Canada is designed to be expanded to 40Gb/sec at each node.

The trunk or backbone cable forms a continuous loop from one landing point to another. For practical reasons, both NEPTUNE Stage I landings are at the same location in Port Alberni, BC.

The network nodes are placed at the ends of branches off the main backbone cable. The current design allows a distance of up to 24 km between the backbone cable and node. The nodes are designed to be recovered and repaired if necessary. Because the entire network does not depend on any single node, nodes are placed in areas where the risk of damage from underwater activity is relatively high, while the backbone has been laid in safer areas. Modifications, changes,

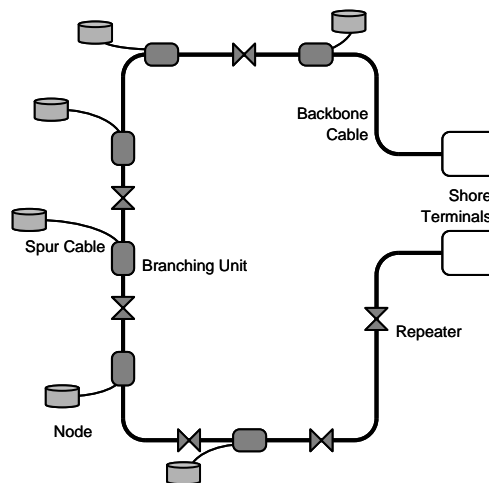


Figure 1. Layout of NEPTUNE Canada and upgrades to the network can be made by replacing the nodes, while the backbone remains unaffected.

Each node provides six interface ports for connection of science platforms or extensions. Each node port provides dual optical Ethernet links. A total of 9 kW of electrical power is shared among the ports; a single port can deliver the full 9 kW if desired. Electrical power is delivered at 400 VDC. In addition, two connection points to the backbone cable voltage are provided to support long extensions. Underwater wet mate connectors are used to allow Remotely Operated Vehicles (ROVs) to make the necessary connections between the node and extension cables.

It is unusual for instruments to connect directly to the node. Even large, multi-instrument devices such as the vertical profiler can be supported by Junction Boxes. These devices, designed and built for NEPTUNE Canada by OceanWorks of Vancouver, BC, support up to 10 instruments each and can be daisy-chained where necessary. A Junction box can accommodate both serial and 10/100 Ethernet instruments, and provides a variety of voltages (400V, 48V, 15V and 12V). In most cases a Junction Box will be the user’s first point of contact with the network.

IV. TIME DISTRIBUTION

The science requirements for NEPTUNE also include delivery of time and timing for use by instruments. Two time delivery protocols are used: Network Time Protocol (NTP) and IEEE 1588 / IEC 61588 Precision Time Protocol (PTP). Both protocols deliver time via Ethernet and provide methods of correcting for transmission latency. The stated objectives of these two are ± 1 millisecond error (also referred to as “dispersion”) for NTP and ± 10 μ second error for PTP with respect to Universal Time Coordinates (UTC).

In addition to making time information available to the instruments, data can also be time stamped with one-second accuracy via the DMAS software at shore station.

PTP is capable of accuracies within several hundred nanoseconds on Local Area Networks (LANs) and when used in conjunction with switches that implement PTP in hardware

(boundary clocks). Standard network switches degrade the accuracy of PTP, but early testing shows the accuracy available on NEPTUNE to be better than $\pm 5 \mu\text{s}$. As PTP becomes more widely used, network switches with the boundary clock function can be added to the nodes, either as part of a repair or as part of an upgrade; when this is done, the expected accuracy is on the order of $\pm 300 \text{ ns}$.

Many instruments (including serial instruments) may need a greater accuracy than 1 second and/or use the same time base, and an accurate clock inside the instrument will provide a better and more accurate solution than a post process time stamping and time drift correction with 1 second accuracy. Different but complementary solutions are being sought: to provide by hardware a very accurate solution for all the Ethernet and serial instruments which need a very high accuracy (PTP theoretical accuracy up to 100ns); to improve the 1 second accuracy for all the Ethernet and serial instruments by software without any modification inside instruments (expected accuracy, in some case, is up to 20 ms approximately); and to adjust the instrument clock drift in real time or in near real time and provide quality control information for all the Ethernet and serial instruments.

Because PTP is delivered via Ethernet, precision time is available to any instrument on the network provided it has the necessary equipment. Precision time can be acquired by instruments in a variety of ways. Instruments with a hardware PTP capability will achieve the best results; PTP implemented with off-the-shelf network interface cards (NICS) will be about an order of magnitude less accurate, but is still about two orders of magnitude better than Network Time Protocol (NTP), which is typically accurate to $\pm 2 \text{ ms}$. An adapter card which implements a PTP client and outputs a pulse-per-second (PPS) signal and can support other standard protocols is being studied by IFREMER to support existing instrument designs.

The requirements for time distribution vary with each experiment. Identifying the requirements and designing a system or systems to meet them has required lengthy discussions between network engineers, scientists, timing engineers and DMAS staff.

V. CONTROL

The primary function of the control system for NEPTUNE Canada is to monitor and control power to the science interfaces. Custom designed circuit boards are used to measure current, detect current imbalances, and to interrupt power to each science interface. A pair of control processors in each node communicates with the shore terminal over the Ethernet data network. A processor based in the shore terminal communicates with the control processors in each node and provides a Service Oriented Architecture (SOA) interface to NEPTUNE's Data Management and Archiving System (DMAS). There are additional processors in every junction box and in the more capable instruments.

Network management is accomplished through the use of the capabilities provide with each network element. The

Ethernet switches support a command line interface and HTML Graphical User Interface (GUI); the SONET/SDH equipment, repeaters, PSBUs, and submarine line terminals employ a conventional telecom network manager.

VI. SYSTEM INTEGRATION

On a complex system such as NEPTUNE Canada, system integration cannot be left to the end of the project, but needs to be considered from the beginning, with preparation for integration a continuum throughout the project and across all tasks. If integration is left to the end, it will either require significant compromises to allow the systems to be integrated, or significant costs and delays to modify the systems to allow integration.

This continuous integration requires integrated project management.

VII. INTEGRATED MANAGEMENT

In many ways NEPTUNE Canada matches the utilities used every day in homes, laboratories and offices. NEPTUNE Canada provides electric sockets and internet connections to "customers' places of business" – although in the case of NEPTUNE Canada, those places of business are deep in the ocean. There are commonalities between building the infrastructure for homes and offices and building the subsea infrastructure. Both terrestrial and subsea utilities require specialised manufacturers and installers to design build the infrastructure, and both require a knowledgeable management and engineering team to define users' specific requirements, protect the owner's interests during construction and manage the manufacturers and installers.

However the management of the development and construction of undersea utilities for science differs significantly from the development and construction of more conventional utilities such as electrical grids and telephone networks. First and foremost, working in the marine environment versus on land changes the risk profile entirely. Whereas a failed piece of equipment in a terrestrial network may require two technicians and a cube van to drive out to a remote site, failures subsea will require months of planning prior to the mobilisation of ROVs and ships. The cost of a subsea repair is high enough to require governance review and potentially a fundraising effort. The goodwill of the science users will be put at risk by repeated downtime while waiting for repairs to be completed. Therefore for an undersea system to be economical and successful through its working life, a significant portion of the capital funding and management effort has to be spent on a system wide drive to ensure long term reliability of the subsea plant. It is not sufficient to simply focus on the subsea infrastructure. As far as possible instrument reliability must match system reliability, since success of the system depends on the delivery of reliable and continuous data, and because the cost of instrument repair is very high. The control systems imbedded in DMAS must also

be reviewed, since it is possible to damage the subsea plant by sending unauthorised instructions to the subsea processors.

	DMAS System	Backhaul	Shore Station	Outside Plant	Beach Module	Marine Cable	Branching Units	Repetitors	Nodes	Extensions	Junction Boxes	Vertical Profiler	Wiggins	Frames	Instruments	Accounting	Administration
Science Objectives	✓																
Quality Assurance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Software	✓								✓	✓	✓	✓	✓	✓	✓	✓	✓
Computer Hardware	✓								✓	✓	✓	✓	✓	✓	✓	✓	✓
Internet Protocol	✓	✓							✓	✓	✓	✓	✓	✓	✓	✓	✓
SONET		✓					✓	✓	✓								
Optical transmission		✓					✓	✓	✓								
Electrical communication	✓		✓						✓	✓	✓	✓	✓	✓	✓	✓	✓
Electrical power			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Network Management	✓		✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Permitting			✓	✓	✓	✓			✓							✓	✓
Security	✓		✓	✓	✓	✓											✓
Materials and corrosion					✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Marine deployment				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Maintainability	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
External Aggression					✓	✓	✓	✓						✓	✓	✓	✓
Military			✓		✓					✓				✓	✓	✓	✓
Fishing				✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Diving					✓			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
ROV handling								✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Operating Costs	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Asset Management	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Figure 2 Skewer Diagram

The work involved in the implementation of NEPTUNE Canada has been subdivided into four management work groups: DMAS, wet plant, instruments and administration. While it is necessary to subdivide projects into management groups to keep each manager’s workload within bounds, it is important to recognise that these divisions are artificial. A cabled ocean observatory is a single networked system, and as the skewer diagram above shows, there are many cross-cutting technical requirements that must bridge the divide between the work groups.

A cabled ocean network is a single entity composed of many interrelated elements. A project management structure must be put in place at the start of the project that includes a means of encouraging and, when necessary, enforcing multi-level multi-technology skewers between the management silos of responsibility. This management structure requires the appointment of technical leads separate from the work group managers

VIII. ACADEMIA VS PRIVATE INDUSTRY

NEPTUNE Canada is an academic project. Its primary purpose is to meet the needs of scientists. However a very large component of NEPTUNE Canada, and any cabled observatory, is the cabled network itself. A question that often comes up is should the system be built as a science project, or as an engineering project? How much can the experience from industry in managing this type of complex development project be of value for this science-driven project?

An argument is put forward that a project such as NEPTUNE Canada can only succeed in meeting users needs and being adopted by the community if it is managed by scientists and academics, using their past experience and organizations as a template. An extension of this argument is

to reject experience from industry on the basis that academic projects are fundamentally different.

However I would argue that an infrastructure project such as NEPTUNE Canada is not fundamentally different to the provision of a Local Area Network (LAN) system on the campus of a university. The LAN is an academic venture, with scientists and academics as users. It’s structure and layout must take into account those users. However it is unlikely that anyone would propose that such a LAN would be built by the users. It will be built by a company experienced in building LANs in a variety of settings.

In the same way I would argue that the design and implementation of a cabled ocean observatory will be guided by user needs, and there will be ongoing oversight of the implementation by users and user groups, but that fundamentally the implementation itself needs to be done by a company or companies experienced in building subsea cabled networks and associated equipment.

IX. CROSS-TIES

NEPTUNE Canada has always recognised the need for strong cross-tying the management categories. The original evaluation of the proposals for the underlying network technology was driven by many unrelated issues such as the needs of users, the technological status and diversity of instruments, known seabed conditions and limits in operating funds. More recent examples include the need for a uniform IP address scheme across DMAS, the subsea network, the junction boxes, the Vertical profiler and the scientists’ instruments; the need for the 400V supply system in the nodes, junction boxes and instruments to accommodate various connections to ground in a controlled and uniform fashion despite being supplied by multiple suppliers under separate unconnected agreements; the need for the permitting group to be informed of the details of the proposed experiments so they can be assessed for compliance with the environmental permits, and additional permits sought in a timely fashion; the need for both the network engineers and the DMAS group to fully understand the implications of the myriad requirements that scientists have for time at the instruments; the need for DMAS to accommodate the geographic engineering data that the operating group needs to manage and maintain the system; and the need for accounting systems to be modified to accommodate the cost coding required to give accurate predictions of current project completion costs.

Many of the requirements that stem from these cross-cutting discussions will be unpalatable to the individual work group managers. Those managers will be focused on their own tasks, and will be optimising the design of their work based on their own experience, and may not appreciate the importance of issues brought to the table by personnel working in other areas. Indeed, experience shows a tendency of work group managers to discourage open discussion between their personnel and those in other work groups with the honest goal

of minimising the chance for disruption of their carefully planned work.

Adding to the difficulty of managing the cross ties is the reality that construction of a cabled ocean science observatory requires two disparate groups to work together; industry and academia. Whereas the parties building a terrestrial system come from industry and are largely familiar with one another's processes and ways of working, the parties involved in a cabled ocean observatory are from two camps in which working environments are very different. In industry, project personnel work in structured teams with team leaders, and are focused on cost, schedule, risk reduction and compliant deliverables. Academics, on the other hand, tend more to collegial structures and committees, and focus on extending the boundaries of knowledge and understanding.

How to resolve these apparently intractable challenges? Let me first propose some underlying requirements:

- Technical leads to manage the "skewers", in addition to work area managers for each work area, are necessary for success in a major networked infrastructure such as a cabled ocean observatory.
- The compromises required to optimise the network across work areas are likely to be unpopular with some or all of the work area managers and their personnel.
- Maintenance of the technical skewers will require unalloyed buy in from senior management and all project personnel.
- Technical skewers require that management empower staff at all levels in the project to interact and propose solutions between management groups. Manager level interactions are insufficient to meet the requirement for skewers.

If we accept these as underlying requirements, then it is clear that the project cannot be managed using a conventional silo'ed structure of work areas and work area managers. Overlaid on the work area management structure must be the technical skewer layer, and suitable technical leads separate from the area managers must be assigned responsibility for each skewer. To be effective, those technical leads will need the authority to discuss crosscutting issues without having approval from the area managers. And the staff must feel confident to work with the technical leads even when their work area manager is not in favour of the direction the technical lead is pursuing.

This two layer management structure, with technical responsibilities cross cutting commercial responsibilities, may seem unmanageable to those more used to a conventional silo'ed management structure where each group answers to its manager, or to those used to the collegial and committee structure. However the two layer management structure is the structure employed in major multi-disciplinary technical

development projects in industry, and is responsible for many successful projects. In fact it was a requirement of one of the major suppliers that NEPTUNE Canada assure the supplier that such a structure was in place before the supplier would pursue a bid on NEPTUNE Canada.

X. CONCLUSIONS

What advice can be given based on the experience in the implementation of NEPTUNE Canada to date? Understand and fully accept that a cabled ocean observatory, including its web site, DMAS, wet plant and instruments, is so interdependent as to be a single network, and that while some subdivision will be required for management that such subdividing is artificial and threatens the whole. If you start with that basis, coming up with a workable organisation structure will be easier. Empower and trust your staff. Appoint technical leads in addition to and separate from area managers. Otherwise you run the risk of ending up with disconnected parts. Some fundamental decisions will be made at a detail level, and management needs to stand out of the way to encourage that to happen. Make sure staff and managers understand what their responsibilities are. It is unlikely that many of your staff, and in particular your managers, will have worked in this type of project in the past.