Cabled Ocean Science Observatories as Test Beds for Underwater Technology

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Abstract— **Owners of underwater systems for telecommunications, oil and gas production, exploration, or military use typically require a proven history of performance and/or extensive development and qualification prior to deployment. As a result, suppliers of such systems normally take a cautious and deliberate approach to the introduction of new technologies. Development involving the construction of a prototype and deployment at sea may last years. Even incremental improvements may require extensive qualification tests stretching over eighteen months or more. Entirely novel approaches may be shelved due to the cost of trials or test deployments.**

Science communities around the world are installing, or proposing to install, a new generation of cabled infrastructure that will provide standard communications and power interfaces in the deep ocean. The first of these large scale observatories, NEPTUNE Canada, is scheduled for final deployment in 2008. While the primary goal of cabled ocean observatories is observation of the ocean environment, engineering research is also encouraged, and facilities can be made available for use demonstration and qualification of new technologies.

The primary interfaces to NEPTUNE Canada are the node science ports. Each science port provides optical Gigabit Ethernet connection and up to 9 kW of power at 400 Volts DC. These interfaces are suitable for connection of equipment within a few kilometres of the node. For longer extensions, a power interface providing a direct connection to backbone power at 5 to 10 kV, and long reach optics are available.

The NEPTUNE Canada physical infrastructure consists of an 800 km loop beginning and ending at Port Alberni British Columbia. NEPTUNE nodes are located at depths ranging from 100m to 2700m, which encompasses the range at which most commercial subsea activity takes place. There are active hot volcanic vents, outcrops of gas hydrates and existing ODP drill holes adjacent to the planned node sites.

These capabilities make the new generation of ocean observatories, and NEPTUNE Canada in particular, an ideal test bed for any application requiring high bandwidth communication and hundreds or thousands of watts of electrical power.

Communication between the nodes and shore is provided via Ethernet and wavelength division multiplexed optics. A 10Gb/s backhaul link from Port Alberni to Victoria provides a connection to the Internet. VLANs and VPNs can be established to provide direct access to connected equipment.

***Index Terms*— NEPTUNE, Science, Underwater technology, Underwater communication cables**

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I. Introduction

Traditionally the deep ocean has been seen as a cold, quiet, dead place; a featureless dark abyss where life, if it exists at all, is marginal. However, as our capabilities have increased, and scientists and engineers have been able to penetrate the depths, it has become clear that the traditional concept is wrong; there are places in the deep ocean with vibrant life and extremes of heat. Even in the so-called abyss there is life, within the ocean crust, on the seabed and in the water column. There are also important geological issues there such as faults, submarine slope failures, oil, gas and gas hydrate deposits, seeps and volcanic "smokers", earthquakes and tsunamis.

Simultaneously with the increase in scientific interest, the offshore oil industry has been in transition from drilling on the continental shelves into drilling in the deep ocean. These two movements are, of course, related insofar as any investigation in the deep ocean requires a basic development of technology, and once a technology is developed it is available for many users.

Possibly unrelated, but a fortuitous coincidence (certainly for the scientists), is the sudden increase in the public's interest in questions on a planetary scale. Questions such as "is the planet warming?"; "why is the planet warming?"; "what is the effect of planetary warming on the oceans?"; "is man killing fish stocks?"; "can we predict tsunamis?", and "can we predict the next earthquake?". One of the effects of public interest is to loosen the public purse strings, providing an opportunity for ocean scientists and scientific institutions to invest in infrastructure to progress towards understanding some of these issues.

There seems to be consensus amongst scientists around the world that what are missing from their data are continuous long time series measurements and in situ, multidisciplinary experiments. Existing data are limited by the constraints of underwater battery packs, underwater memory devices and weather-prone ships. To get over these restrictions, scientists and marine institutions around the world are applying for funding to install cabled ocean observatories. [1], [2], [3].

II. The History of cabled ocean observatories

The Japanese seismologists were the first to cable their instruments back to shore, driven by the need for a better understanding of the earthquakes that regularly impact the Japanese people and their economy. The Japanese systems, built by the Japanese submarine telecommunications equipment providers, are primarily submarine telecommunications technology (low power, high data capacity optical systems) and are appropriate for seismic instruments, but of limited use for more general applications.

The Japanese experience prompted a group of North American scientists [4, 5, 6] to start imagining a cabled observatory that would ring the Juan De Fuca tectonic plate off the coast of southwest Canada with Internet and power outlets, and make it accessible to all scientists. These scientists believed that significantly higher power delivery would be required to satisfy the needs of a wide range of scientific interests, and proposed 10kW per site, or 100kW for a network, and 8Gb/sec data, as the goal.

III. The Submarine Telecommunications System Providers

The submarine telecommunications system providers were an obvious choice to design and build cabled ocean observatories. They own cable factories capable of producing the hundreds of km of fibre optic cable required; they have the amplifiers and branching units that will be required; they have the cable ships and the experienced crews; and they have the laboratories, test set-ups and manufacturing plants required to qualify, build and test the systems. The providers' core business is the development and provision of long haul trans-oceanic systems for the telecommunications industry. The industry is justifiably proud of its design, quality assurance, manufacturing and marine capabilities.

However the industry is based on a manufacturing model. It designs, qualifies and manufactures products which it can use on multiple projects. This model does not lend itself well to delivery of specialized, one-off units. Any purchaser who intends to use the services of a submarine telecommunications system provider needs to be aware of this limitation, and to work with the provider to investigate other uses for the units being developed.

Purchasers also need to be aware that the industry has established methods of managing its projects and interacting with its clients. Some of these methods are unique to the industry and not well known or understood by those outside the industry. These management structures stem, in large part, from dealing with owners who are consortia of many of the world's largest telecommunications companies, and are appropriate in that context. However these management structures are often viewed negatively when the providers work with other cultures such as the offshore oil industry or academia.

"Regional Cabled Observatories" (RCOs) are relatively modest projects, with budgets for the submarine networks of between $50M and $150M. There are four systems well advanced in development, and, once the technology has been proven, likely to be more. The technology requirements are fundamentally different from telecommunications systems. The communications system for an RCO, rather than sending the maximum amount of data (terabits per second) from one shore station to another, is required to consolidate relatively modest amounts of data (tens of gigabits per second) from sources on the seabed, and deliver that data to shore. The power system is even more different; rather than delivering minimal and constant power to keep the line amplifiers operational, the network in an RCO must provide the maximum power possible to a variety of seabed locations, and accommodate unlimited variations in that power draw.

IV. Scientific Cabled Ocean Observatories

The first of the next generation RCOs will be NEPTUNE Canada, the Canadian Stage I of a joint Canada-US project that, once US funding is available, will stretch down the west coast of North America from southern Canada to northern California. The NEPTUNE Canada RCO consists of an 800km loop servicing 6 science sites, and is scheduled to be fully operational at the end of summer 2008. Fig. 1

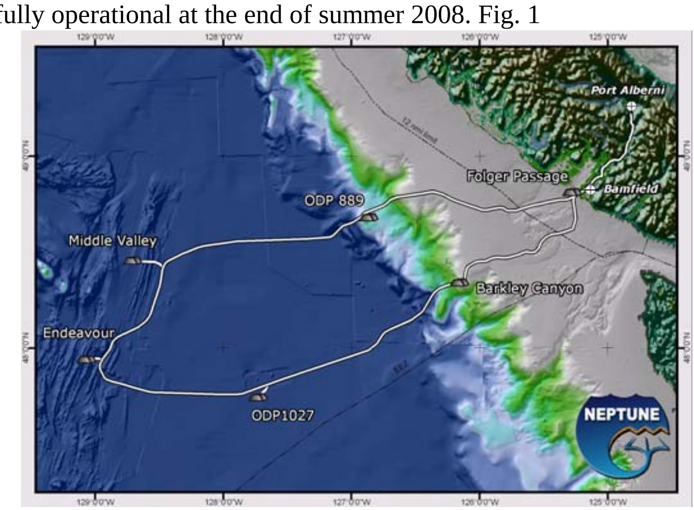

Figure 1 – NEPTUNE Canada layout

The architecture adopted for NEPTUNE Canada is a trunk and branch topology as illustrated in Fig. 2. 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; the initial implementation of NEPTUNE Stage I will have six branching units and five equipped nodes along an 825 km cable route.

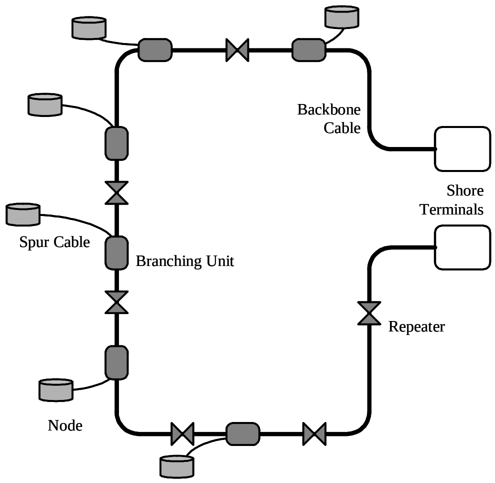

Figure 2 – Architecture

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, naturally forming a ring. The network design could easily be adapted so that the backbone stretches between two landing points, with terrestrial communications channels closing the ring to provide diversity.

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. Each node provides six interface ports for connection of science platforms or extensions. Each port provides dual optical gigabit 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 supplied to the nodes at 10kV DC, and delivered to the science ports at 400 VDC. Underwater wet mate connectors from ODI are used to allow Remotely Operated Vehicles (ROVs) to make the necessary connections between the node and extension cables.

The technology qualification status varies across the spectrum; the fully proven (the cable and cable jointing); the adaptations of proven (repeaters and branching units modified to handle 8A current); the use of COTS equipment in novel environments (switches and SONET equipment in the nodes); to the novel and untried (the 10kV to 400V DC-DC converter). A great deal of experience will be gained on NEPTUNE Canada as the first observatory. Some will be good, some bad, but all will be instructive to those who wish to put equipment and controls on the seabed.

NEPTUNE Canada is well advanced towards deployment. A shore station was purchased in August 2004. The contract with the system provider, Alcatel-Lucent, was signed in October 2005. The cable repeaters and branching units have been manufactured, and the system is being prepared for pre-load testing. The node equipment, including the converters, is going through final prototyping. Detailed route surveys have been completed. The first set of science experiments have been selected and funded, and production of instruments has begun.

V. The Oil Industry and Power and Communications to the Seabed

Since at least 2000, the offshore oil industry has been working towards “Smart Oilfield” instrumentation [7]. Smart oilfield technology is already commonplace in land-based fields, where it has proven to be extremely cost effective. A network of sensors in an oilfield would enable detailed planning of such things as oil recovery operations, using cabled instruments over a wide area to provide real time data to engineers at the shore base and on the production platform. Such sensor nets to increase production in offshore fields continue to be discussed, but the development and qualification of the technology to build a suitable reliable cabled network has been holding back progress.

In addition, as seabed infrastructure moves further from platforms, traditional approaches using long hydraulic umbilicals become less feasible. As the industry moves towards smart oilfields and increased recovery, demands for high bandwidth communications on the seabed will increase. As oilfields move into more inhospitable areas, the need to develop oilfields without permanent platforms increases. These pressures are already moving companies away from AC power towards DC, and away from 9600 baud modems towards high capacity optical Ethernet systems.

Many papers have been presented stressing the requirement for DC power and optical communications. For example, a design [8] has been proposed for the Shtokman Field off Murmansk which includes a 680km step-out, fibre optic repeatered communications and 10kW DC power delivery to Cameron all electric trees. This design relies on development of a medium voltage (at least 5kV) DC power system and a repeatered optical communications system.

There are funds being invested in subsea communications networks. Besides the existing systems in the North Sea and the Gulf of Mexico, BP has announced plans [9] to spend $100m laying a 700km loop of fibre across its deepwater Gulf fields, entering the ocean in Freeport or Corpus Christi, Texas, and Pascagoula, Mississippi, in water depths of 3,000 to 8,000 feet. In addition there are plans for systems off Sakhalin and West Africa.

Looking ahead, the visionaries [10] have proposed many potential uses for power and communications on the seabed, including all-electric subsea fields operated from shore and resident ROVs permanently deployed at subsea trees and manifolds and operated from shore. Even the military are looking ahead with a program [11] to develop a fibre-optic and electrical cable system that provides “Wet Mate/De-Mate electro-optical inputs and outputs to static or dynamic subsea assets such as acoustical sensors, detection sensors, video imaging, and power/data transfer docking stations to enable new capabilities in anti-submarine warfare, mine detection and countermeasures, intelligence and surveillance, and sea-port security.”

All of these ideas will move significantly closer to reality with the installation of NEPTUNE Canada.

VI. Uses for Cabled Ocean Observatories

Users of these RCOs can be subdivided into several categories. The largest and most obvious category is scientists, educators and members of the public who wish to use the data from the RCO. A subset of this group is those scientists who wish to undertake experiments by deploying equipment onto the RCO facilities. A second category are those scientists, instrument developers and equipment manufacturers who wish to test and qualify their equipment in a known and relatively low risk environment prior to installing them elsewhere. A third category are those groups, whether from academia, government, the military or industry who wish to understand more about the issues related to installing, owning and operating a subsea communications system similar to an RCO.

To be a member of the first category is straightforward; in all but the most unusual cases, all data will be openly displayed to the public on the Internet. The raw data, and some data products, will be available for downloading and independent analysis. To be a member of the subset of the first category, those who wish to put their own instruments on an RCO, is also reasonably straightforward. NEPTUNE Canada encourages scientists and others from around the world to use the RCO infrastructure, and provided the associated equipment testing, installation and operations costs can be met most instruments will be suitable for deployment.

The intent of the experiments is to improve our understanding of the deep ocean, and of the interactions between the climate, the atmosphere and humans on the deep ocean. The data can be used to verify and improve ocean models, which can then be applied to oceans in other parts of the world. A more direct use of observatory data would be to monitor environmental impacts of marine activities on seabed and mid-ocean life. This requirement appears to be on the horizon for all users, whether military, shipping, offshore oil or fishers. A cabled observatory allowing real time measurements to be made in the field appears to meet or exceed the possible requirements of the regulators.

The use of RCOs to test and qualify equipment opens many opportunities for the rapid development of offshore technologies. RCOs provide power and Ethernet on the seabed and an opportunity to test and qualify equipment in real life situations at low cost and without risk to production facilities. RCOs are designed to accommodate third party instruments and equipment. The interfaces on the RCO are standard Ethernet and power at usable voltages and with well defined characteristics. Serial and other protocols can easily be accommodated using off the shelf Ethernet converters.

A device installed on an RCO in North America can be directly monitored and operated from Aberdeen or Houston, Dublin or Tokyo, Perth or Stavanger. Operations personnel can be trained on equipment in real life situations before making a commitment to the technology. Use of RCOs as test platforms will offer management the opportunity to commit to try bold new technologies without putting production streams at risk, which will speed up the acceptance of viable new technologies.

Some of the technologies required for the RCO are already being adopted by the offshore oil and other industries. Repeatered loops with branching units and spur cables are being used to provide reliable high bandwidth communications systems for platforms. However RCOs are taking this technology one step further, and putting the offshore end of the system on the seabed rather than on a platform, and taking the "smart oilfield" concept closer to reality. The devil is in the detail when committing equipment to the seabed for extended durations, and the lessons being learned during the current RCO development are irreplaceable.

NEPTUNE Canada will also be testing the viability of the use of many instruments with initially over 700 sensors in a range of subsea environments, and the means to store data from such instruments. Besides the expected current sensors, acoustic sensors and seismometers, there will be still and video cameras, water samplers and a small tracked ROV. All of these instruments will require some measure of adaptation for long term deployment, and each presents a separate challenge for the Data Management and Archive group.

The quality control, management and storage of the data and metadata from a subsea network are separate subjects that will not be covered here. However the challenge of managing these high volumes of data from disparate sources and presenting it to users in a usable form must not be underestimated.

VII. Conclusion

A new generation of RCOs is being developed and deployed. The first of this new generation is NEPTUNE Canada, scheduled for deployment off the west coast of Canada in 2008.

This new generation of RCOs is designed to accommodate up to 10 nodes per fibre pair, on a ring of standard fibre optic telecommunications cable up to 1800km long. Such a network requires the use of DC power to transmit 10kW to each location on the seabed, or up to 100kW system wide. The current communications design provides 2Gb/sec fully redundant at each node using multiple 2.5Gb/sec SONET wavelengths on a repeatered backbone network.

This network design meets many of the requirements for long offsets, Smart Oilfields and monitoring networks. RCOs also offer an economical platform for the development and qualification of new equipment prior to committing to it in a production environment.

The offshore oil industry and others wishing to work real time in the deep ocean will benefit from their involvement in the development of RCOs.

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