

A NEW CHALLENGE AND OPPORTUNITY FOR THE SUBMARINE TELECOMMUNICATIONS INDUSTRY – OCEAN OBSERVATORY NETWORKS

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Abstract The ocean sciences are beginning a new phase in which scientists will enter the ocean environment and adaptively observe the earth-ocean system using innovative facilities called ocean observatories. This represents a new opportunity for the submarine telecommunications industry, but at the same time presents new challenges, in part because most of the principal design drivers for ocean observatories differ from those for commercial submarine telecommunications systems. This paper discusses the nature of ocean observatories and describes some of the design issues using the NEPTUNE regional cabled observatory as an example.

1 INTRODUCTION

In 1872, a converted warship, HMS Challenger, set out on the first major oceanographic expedition. This cruise was equipped to explore the depths of the world oceans during its 4-year circumnavigation of the globe. Ever since, ocean scientists have been mapping and sampling the deep waters that surround us during relatively short cruises aboard specialist research vessels. They have now started to make the transition from this initial, exploration phase to the emerging understanding phase, where the focus is on temporal variability of episodic processes, and hence a permanent presence on the sea floor is required to monitor both sporadic short-term events such as earthquakes and long-term trends such as global warming.

2 SCIENTIFIC PROJECTS

The science problems are wide, varied, and inherently multidisciplinary. Geophysicists wish to monitor oceanic plate deformation patterns and volcanic eruptions; biologists would like to search for new forms of life and study the migration of fish stocks and marine mammals; geochemists want to understand the global carbon cycle; physical oceanographers may focus on climate variability. A new generation of oceanographers will work across the boundaries of these disciplines. Going beyond the ocean sciences, astrophysicists wish to map the sky with deep-water neutrino telescopes. These multidisciplinary projects require the long-term, 24/7, flow of reliable, high quality and timely data from sea bottom instruments and platforms to the scientists ashore via the Internet, and the supply of electrical power and command data to the submerged equipment.

3 THE FIRST DEEP WATER CABLED OBSERVATORIES

A few successful attempts have been made to observe isolated deep-sea phenomena using out-of-service

analog or new fiber optic cables. In 1997, a geophysical ocean bottom observatory was inserted into the Guam-Ninomiya section of TPC-1 [1]. In 1998 a sea floor observatory, H2O, was installed on the Hawaii-2 cable [2]. A multidisciplinary cabled coastal observatory has been operational off New Jersey for over 7 years. [3]. Three cabled deep-water neutrino telescopes have been installed in the Mediterranean [4, 5, 6].

4 PLANNED SYSTEMS

Following on these successes, several academic institutions from Europe, Japan and North America are planning the establishment of large and small-scale permanent observatories on the seabed using submarine fiber optic cables. For example, two smaller, long-term observatories off North America will shortly be under construction. The MARS [7] project will initially deploy a single deep-water science node 63km off Monterey Bay, California. The Canadian VENUS [8] project is deploying three shallow water nodes near Vancouver Island.

Larger undersea meshed networks such as ARENA, which would monitor the 4 tectonic plates that form the Japanese archipelago, is at the feasibility study stage [9]. Funding has been acquired for the first phase of the NEPTUNE project, which plans to connect 26 science nodes around the Juan de Fuca plate off northwest North America [10]. Smaller coordinated networks or consortia of short- and long-term seafloor science observatories are also being planned in Europe such as ESONET, with targeted areas of interest such as the Mid-Atlantic Ridge, Iberian and Norwegian Margins [11]. There are international consortium proposals for a larger scale (1 km³) neutrino telescope in the Mediterranean (VLVnT) [12], which plan to build on the experience of the previous 3 deep-water telescopes. The submarine infrastructure required to supply power and communications to these projects include thousands of kilometers of medium voltage fibre optic cable and terminations, transmission equipment, branching units,

communications interfaces, power converter modules, science instrument interfaces, trawler resistant nodes, and ROV wet-mate connectors, with associated precision marine deployment. The special design requirements for these systems are further discussed below.

5 SCIENCE SYSTEM DESIGN DRIVERS

Many of the principal design drivers for ocean observatories differ from those for conventional submarine telecommunications systems. First, ocean observatories require data to be input and output (i.e., switched and aggregated) at one or more seafloor nodes rather than at a few land terminuses. Second, ocean observatories must distribute a lot of power (typically, multiple kW per node) to the seafloor at variable and fluctuating rates to supply both seafloor instruments and the observatory hotel load. Third, science requires the delivery of accurate (order 1 microsecond in an absolute sense) time to seafloor instruments which have no counterpart in the commercial world. Fourth, the seafloor infrastructure for an ocean observatory is inherently dynamic, and hence the wet plant has to be expandable and re-configurable to meet changing science needs. Finally, because the wet communications and power infrastructure is comparatively complex, ocean observatory infrastructure must be designed for low cost maintenance and upgradeability.

Despite these differences, a key design driver in both ocean observatory and commercial telecommunications system design is reliability. The primary reliability measure is the probability that data will be received on shore or at another seafloor node from a given science instrument on the seafloor, and the least reliable infrastructure components in this path inevitably are the node power and communications electronics. An immediate corollary is that there may be no reliability gain from combining some high cost, high reliability submarine telecommunications components with node electronic systems.

Taken together, these points suggest that the overall design of ocean observatories will be fundamentally different from that of submarine telecommunications systems. Understanding why this is true is facilitated by taking a system engineering view of the ocean observatory design process. This is inherently iterative; at the outset, functional and performance requirements may be posed by the user community that cannot be met with available technology. The requirements and design phases serve to improve the initial requirements and eliminate such problems. The science requirements for NEPTUNE [13] are the product of several such stages of iterative refinement, but are still considered to be in draft form until the detailed design phase is completed.

6 AN EXAMPLE

As an example, the backbone data communication science requirements for NEPTUNE will be reviewed. Where specific numbers appear, these represent forward-looking estimates of bandwidth and instrument needs.

From use scenarios and investigation of the communications requirements of a wide range of instruments, a preliminary estimate of both the aggregate bandwidth of NEPTUNE and the maximum data rate for an individual instrument can be derived. The aggregate bandwidth can then be scaled by a large factor (10 or more) to allow for future growth and technological development. Note that (2) states the data rate that must be delivered to the user at all times in the observatory life cycle to allow for aging effects. Finally, (3) specifies that instrument communications will utilize the standard Internet protocols, while (1) does not specify the protocol on the backbone because that is of less concern to a science user.

1. The data communication network shall support an aggregate backbone data rate of at least 8 Gb/s.
2. Each data communication node subsystem shall support an aggregate instrument data rate of at least 1 Gb/s exclusive of overhead for system functions such as (but not necessarily limited to) framing or re-transmission due to errors, at all times during the observatory life cycle.
3. Each data communication node subsystem shall support a minimum data rate from a single instrument of 100 Mb/s using standard Internet protocols, including (but not necessarily limited to) TCP/IP and standard application layer protocols.

The fourth and fifth science requirements state that the data communications system needs to be automatically fault-tolerant and capable of being changed to meet dynamic science needs; for example, it may be desired to require very low latency for a specific node where closed loop control is being employed. Most standard data communications protocols meet these requirements automatically.

4. The data communications node subsystem shall be capable of automatically reconfiguring itself to suppress fault propagation, and will automatically recover from faults.

5. The data communication network shall be remotely re-configurable to allow data transmission to and from each node to be scheduled and prioritised.

The sixth and seventh science requirements specify a need for remote monitoring and control of the data communications infrastructure. (6) is met automatically by most modern data transport protocols. (7) anticipates the standard use of backdoor access into communications hardware, and flows from reliability requirements and the remote deployment of complex hardware on the seafloor.

6. Each data communication node subsystem shall be

capable of being monitored and controlled over the data communication network using standard protocols.

7. Each data communication node subsystem shall be capable of being monitored and controlled over a high reliability, auxiliary channel.

The final data communications science requirement is derived from future-casting the current and emerging state-of-the-art in sensor network development. While the initial expectation for NEPTUNE was that communications would only occur between numerous seafloor instruments and a few land sites, recent developments in sensor networks suggest that this is very likely to change in the future. The design of distributed, intelligent, self-organizing sensor networks (e.g., "smart dust", "sensor webs") based on low cost, miniaturized (i.e., MEMS technology) sensors is an exciting and rapidly evolving area of research, and it is reasonable to expect that this will port to the seafloor in the not very distant future. Implementation requires minimum latency inter-sensor communications paths on the seafloor in addition to links to land.

8. The data communication network shall be designed to facilitate inter-node communication by science instruments with the minimum possible latency commensurate with inter-node propagation delay, with a goal of 2 ms.

7 OUT OF SERVICE CABLES

The first permanent deep water observatories utilised out of service coaxial analog cable systems donated by telecommunication operators. An opportunity now exists to use the recently decommissioned first generation of regenerative optical cable systems such as TAT-8 to TAT-11 and TPC-3 and 4 [14]. These gifts might provide suitable infrastructure for observatories far out to sea in the Atlantic and Pacific oceans. However time is running out and many issues such as operating costs, colocation, legal ownership and technical support still need to be resolved before the opportunity is lost.

8 FUTURE POSSIBILITIES

There is a possible need for existing submarine telecom cable systems owners to consider the requirements of the science community not only well in advance of decommissioning, but also at the planning stage. Scientists often ask if future generations of submarine cable systems could be built with pre-installed access nodes to allow for science observatories to be connected while the cable system is carrying commercial traffic, without effecting the transmission quality or system reliability. In this concept the science user only has to fund the additional submarine node equipment and a yearly transmission rate scaled to their needs.

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