

# NEPTUNE Regional Observatory System Design

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**Abstract**—A team from the University of Washington (UW), the Woods Hole Oceanographic Institute (WHOI), the Monterey Bay Aquarium Research Institute (MBARI), the Jet Propulsion Laboratory (JPL), and the Institute for Pacific Ocean Science and Technology (IPOST) of Canada is jointly developing the North East Pacific Time-series Underwater Networked Experiment (NEPTUNE). NEPTUNE is being designed as a long-lived, highly reliable underwater observatory. Its basic intent is to instrument the Juan de Fuca tectonic plate, which lies just off the coasts of Washington, Oregon, and British Columbia. NEPTUNE will use standard telecommunication fiber optic cable to provide a communication and power infrastructure. A high-speed data link (up to 1 Gb/second) and high power (at least 5 kW/node) will be available at 30 nodes spaced at approximately 100-km intervals over the tectonic plate. Each node will act as a local relay point for scientific instruments and experiments that will be deployed on the sea floor and in the water column above it. The installation of such instruments will be on a “plug and play” basis, which will allow for expansion of capability as new instruments are developed and instruments that need repair or have completed their experiments are removed. The scientific investigations enabled by the NEPTUNE observatory are very diverse. This paper presents the current design of the observatory, including descriptions of the key subsystems. Innovative approaches are being developed to provide high power, broadband communications, data archiving, and accurate timing and control. The methodology for ensuring the reliability and affordability of the observatory is discussed.

## I. INTRODUCTION

Humankind has had a close interest in the oceans for millennia. In the past, access was limited to the surface and depths of perhaps a few tens of feet—whatever could be accomplished by free diving. The oceans’ depths were as remote as the planets and subject to the same kinds of myths and misunderstandings. In fact, knowledge of the planets grew faster than that of the deep ocean until very recent

times. It is often noted that we have better maps of the surface of Venus than the seabed of our own planet.

In recent decades we have learned much about the oceans, both the surface and the deep [1]. Over two decades ago, deep-sea exploration discovered “black smoker” geothermal sites and their unique chemosynthetic biological communities. Yet exploration of the deeps continues to be done in an “expeditionary style.” Typically, research groups go to a target site once a year or so and take measurements with ships and Remotely Operated Vehicles (ROVs). They then return to their laboratories to process the data and prepare for the next expedition.

In many cases this expeditionary approach is inadequate. Some natural processes such as volcanic eruptions, biological blooms, large earthquakes, and the severest storms occur relatively infrequently and unpredictably. Other processes, such as the strain accumulation due to the motions of tectonic plates, climate change, and many ecological interactions are inherently slow and can be resolved only by systematic long-term observations. Satellites, combined with the Tropical Ocean Global Atmosphere (TOGA) “TOA” buoys, now allow routine prediction of the El Niño events [2].

The goal of NEPTUNE is to provide a radically different approach: long-term, high-power, high data-rate continuous monitoring of areas of interest with event-driven response capability. NEPTUNE will be capable of expansion to provide access to a larger physical set of sites with more diverse science instruments as they are developed. We plan simple desktop access for PIs and other users with a data management approach that enables quick and reliable instrument commanding and data retrieval. Proprietary rights can be safeguarded, while the needs of data miners are accommodated in accessing the 4D data sets. Physically, NEPTUNE is a network of interconnected nodes or junction boxes, with multiple shore stations and a central control and data archiving system, all connected to the user via the Internet [3].

This paper summarizes some of the scientific opportunities, then discusses the approach we are taking toward the system design.

## II. SCIENTIFIC OPPORTUNITIES

The NEPTUNE observatory (Fig. 1) will be located on the Juan de Fuca plate off the coasts of Washington, Oregon, and British Columbia. The planned layout consists of approximately 3000 km of cable connecting 30 evenly distributed primary nodes. Most of the cable will be in closed loops with two shore stations to provide high reliability. The shore stations will be located at Nedonna Beach, Oregon and Victoria, British Columbia.

The NEPTUNE study area includes all the major types of oceanic plate boundaries, including the Cascadia subduction zone. NEPTUNE’s capabilities will allow **earthquake** and deformation patterns (Fig. 2) associated with the creation, aging, and destruction of oceanic plates to be examined in a continuous, integrated fashion for decades [4]. A seafloor seismic network will capture the earliest signals from great subduction zone earthquakes and can contribute critical information to tsunami and ground-shaking warning systems.

Ridge-crest **volcanism** is intimately related to the

- Formation of metal deposits,
- Modulation of seawater compositions,
- Local heating of the overlying ocean, and
- Sustaining of a microbial biosphere.

NEPTUNE’s capabilities will help establish the specific nature of links and variations between geological, physical, chemical, and biological processes at active mid-ocean ridges. Seafloor hydrothermal vent fields may be the “tips of icebergs” in total biomass supported by active submarine hydrothermal systems. A significant microbial biosphere apparently thrives within the brittle outer shell of the volcanically active submarine portions of Earth. A crucial use of NEPTUNE will be rapid response to eruptions of submarine volcanoes to sample the exotic microbiological materials released there.

Despite the vigor of ridge-crest activity, it constitutes less than 10% of the total global flux of heat and chemicals from Earth’s interior. Ridge flanks and mid-plate portions of our planet represent the zones of major heat and chemical transfer from Earth’s interior to the hydrosphere and biosphere. Instrumented **boreholes** connected to the infrastructure within the oceanic crust can serve as laboratories for studying the interdependence of tectonics, fluid and thermal flows, and biological activity.

Studies of the volatile fluxes expelled along a subduction zone will allow cross-correlation with major and minor earthquake activity, giving crucial information about potentially major, non-steady-state **carbon** movements. The role of subduction gases and methane hydrates in the dynamics of the continental slope is virtually unknown. Global interest in hydrates reflects their role as a vast potential energy resource and a significant source of greenhouse gases. A classic study site for fluid venting and gas-hydrate formation and breakdown is located within the NEPTUNE study area.

Migration of **fish stocks** and marine mammals along and across the continental shelf can be quantitatively tracked using innovative acoustic techniques. Tying this to small- and large-scale oceanography and the regional carbon budget will be a worthy challenge. The more complete understanding of water-column physics, chemistry, and biology we hope to gain from NEPTUNE will permit researchers to address the links between primary productivity, fisheries, marine mammal migration, and deep-sea ecology [5].



Fig. 1. Location and current layout of the NEPTUNE observatory.

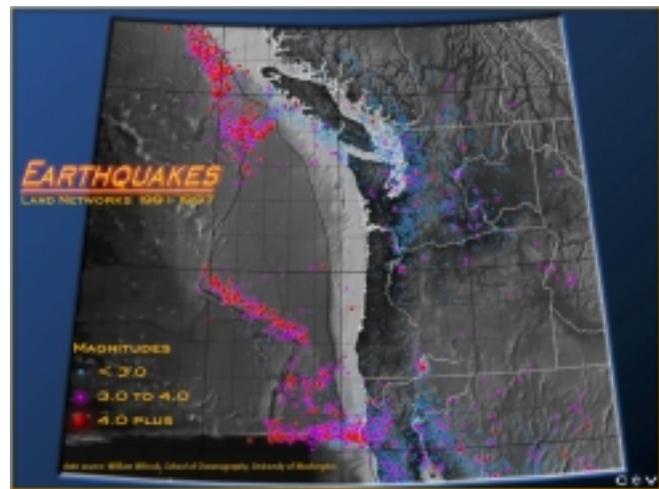


Fig. 2. Earthquakes on the Juan de Fuca Plate.

A fully instrumented suite of **water-column** moorings will allow continuous four-dimensional real-time assessment of the physical, chemical, and biological interactions in a zone of divergence and in coastal upwelling processes. Collecting continuous, long-term data series will improve current physical-chemical-biological models of the representative oceanic processes that occur in the NEPTUNE study area.

**Sediment transport** along and across the continental shelf and into the deep ocean can be quantified. Large fluxes of sediment laden with carbon and anthropogenic chemicals

cross the continental shelf and slope in a highly episodic fashion during major storms, but the mechanisms are unknown. NEPTUNE’s capabilities will permit measuring, sampling, and experimentation during these episodic events.

The deep sea represents two-thirds of our planet, yet in terms of biocomplexity it is virtually unexplored. The NEPTUNE network will provide the capability to develop a functional understanding of the ecology of deep-sea biota, only a small percentage of which have been sampled or identified.

### III. NEPTUNE SCHEDULE

The timeline for NEPTUNE (Fig. 3) is planned as follows:

- Completion of the subsystem and system design: 2001–2003
- Installation and checkout of the test beds and detailed mapping of the area covered in Fig. 1: 2004
- Completion of the network installation: 2006
- Installation of the instruments and initial PI experiments—2006–2007

Further installations of science equipment should continue for the planned 30-year life of the observatory.

The first testbed, Victoria/Vancouver Experimental Network UnderSea (VENUS), will be deployed by the Canadians in the Straits of Georgia and Juan de Fuca located in the coastal waters of British Columbia. The second testbed, Monterey Accelerated Research System (MARS) will be installed in Monterey Canyon, off the coast of California. It is planned to use the MARS testbed to check out the prototype NEPTUNE backbone underwater hardware.

Mapping and cable route surveys are planned in parallel with the testbeds. The mapping of the northern portion of the NEPTUNE area is planned for 2003/2004 and the southern portion sometime thereafter. Following this, the cable route survey is planned for 2005, to be ready for the main installation and commissioning.

To minimize the cost, maximum use will be made of commercial off-the-shelf (COTS) technology. Fabrication of the nodes (junction boxes) and other equipment required for the main installation will be performed in 2005.

Experienced contractors, following generally accepted practices, will carry out the cable installation, which is planned for late 2005 and 2006. Once the cable, nodes, and shore stations have been installed, commissioning can begin. Completion is anticipated by 2007, at which time the installation of the initial community and PI science experiments will take place. We expect that additional instrumentation will be added over the 30-year life of the observatory.

### IV. SYSTEM DESIGN

The prime goal of the NEPTUNE system design is to ensure a capable, reliable, and affordable observatory. Specific goals to enable this are:

- Encompass the Juan de Fuca plate;
- Provide high power, high data rates, accurate timing, and effective control at each node;
- Ensure a 30-year effective life;
- Allow upgrading as technologies change;
- Archive all data in a readily recoverable manner; and
- Ensure that the system will be accessible by PIs and users from their desktops via the Internet.

Proprietary rights and data security are recognized requirements, as is the need to ensure straightforward data mining of the 4D data sets.

These are challenging goals, but the NEPTUNE consortium has the diverse skills and talents necessary to address all the issues and challenges involved. The consortium is led by PI John Delaney (UW) and consists of the University of Washington (UW), the Jet Propulsion Laboratory (JPL), the Monterey Bay Aquarium Research Institute (MBARI), the Woods Hole Oceanographic Institute (WHOI) and Canada’s Institute for Pacific Ocean Science and Technology (IPOST). UW, MBARI, and WHOI each bring extensive oceanographic engineering and science expertise to the project. WHOI has experience and expertise in the development and use of oceanographic equipment, experiments, and Autonomous Underwater Vehicles (AUVs). MBARI has extensive experience in scientific instrumentation, the rapid and consistent deployment of underwater assets, and the routine operation of ROVs. JPL has the demonstrated ability

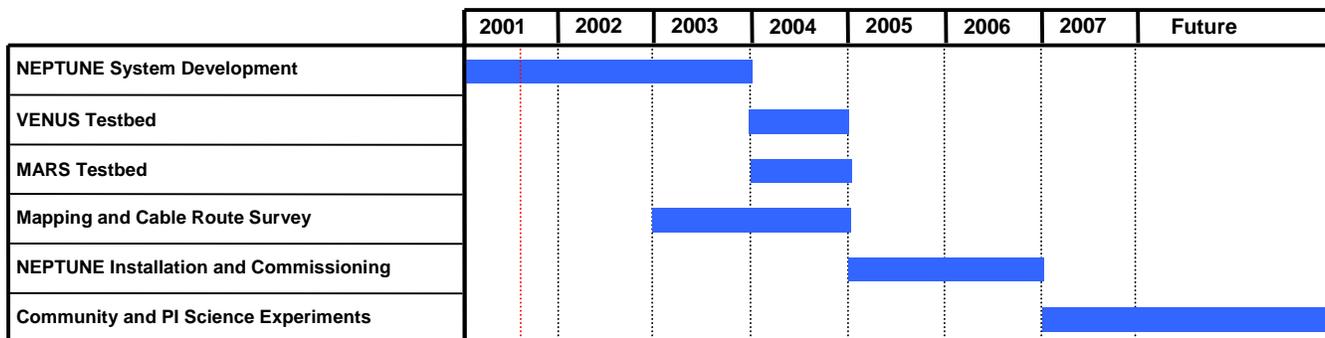


Fig. 3. NEPTUNE Schedule.

to successfully design and manage large novel systems that have proved to be extremely reliable. In addition JPL has oceanographic science expertise that can uniquely provide strong ties to satellite and model-based approaches. The Canadian partners are very strong in the data archiving area and are currently responsible for the non-U.S. Hubble Space Telescope (HST) data archiving and retrieval system. With all these capabilities available, the Consortium is confident in its combined ability to solve the diverse challenges that the observatory development will inevitably pose. At this time we have a baseline system design and funding for the tasks for which COTS technology is inadequate [6].

The expected needs of each observatory node (assuming a total of 30 nodes distributed as shown in Fig. 2) have been analyzed at UW; the results are shown in Table 1. The current system design meets the requirements by providing a high-power, fast, standardized connection to the science instruments at each node.

To ensure reliability the observatory has been interconnected so that failure of one node or a single cable break will not preclude operation of the remaining elements. Dual shore stations are included for the same reason.

The basic cable and the shore landings will use standard communication cable technology, because it is well known and has high, proven reliability.

Conventional sub-sea communication system approaches for data communications, power, and timing are, however, inadequate to meet the NEPTUNE system requirements. NEPTUNE-unique approaches are, therefore, being designed to meet these specific needs. The following Integrated Product Development Teams (IPDTs) have been set up to accomplish the new designs: System Design, Communication System, Power System, and Data Archiving and Distribution. These systems are distributed throughout all the physical elements of the NEPTUNE observatory—nodes, cables, shore stations, data archive, control center, etc. Significant coordination is required to ensure that a contractor (or contractors) can satisfactorily fabricate the physically discrete elements of the system.

David H Rodgers (JPL) and Alan D. Chave (WHOI) jointly lead the System Design team, which is responsible for overseeing the activities of the other teams to ensure compatible solutions.

#### A. Communication

WHOI leads the Communication System design effort and is presenting a companion paper at this conference. The team’s approach is to use the architecture that has proven successful for the Internet and adapt it to NEPTUNE. Fig. 4 is an overview of the NEPTUNE communication system. Fig. 5 schematically shows the planned configuration of this system.

With this approach, the system user, in particular the PI in his home institute, can access any of his instruments as if they were an extension of the Internet. Each instrument will have an IP address. Firewalls will be necessary and will be configured to protect against intrusion.

Although the NEPTUNE communication fabric will use a conventional sub-sea telecommunication cable, it will differ from a trans-oceanic scheme, in that it will not be point-to-point. While the cable topology is a ring with a couple of chords, the fiber topology inside the cable will be much more complicated. In the Internet, the options for controlling communications in this kind of structure are changing as the technology develops [7]. However, they are implemented, the functions are essentially the same. Fig. 6 shows the functions required.

Block ISP is an Internet Service Provider, acting as interface to the Internet. Blocks ADM are add/drop multiplexers, though in practice the necessary switching can be accomplished via electrical switching, optical switching, or wavelength filters, and there are several options for implementation. Blocks C represent the signal and protocol conversions needed to interface the science instruments to the backbone. It is likely that a “Science Instrument Interface Module” (SIIM) currently under development at MBARI will play a role here.

TABLE 1  
EXPECTED NEEDS OF AN OBSERVATORY NODE

	Number	Average Power (W)	Peak Power (W)	Average Data Rate (Mb/s)	Peak Data Rate (Mb/s)
Mooring A	12	58	58	0.03	0.03
Mooring B	4	220	510	0.4	0.7
ADCP	6	7.2	72	0.001	0.01
OBOS	16	73	80	13.8	13.9
In situ Chem./Bio	6	58	58	0.002	0.002
Seafloor Monitors	4	48	48	0.001	0.001
Acoustic Ranging	8	0.4	19	0	0
AUV	3	400	1188	7.2	24
Video Camera	3	182	1821	1.1	11
Digital Still Camera	6	2.3	230	1.4	144
<b>TOTALS</b>	<b>68</b>	<b>1047</b>	<b>4085</b>	<b>24</b>	<b>194</b>

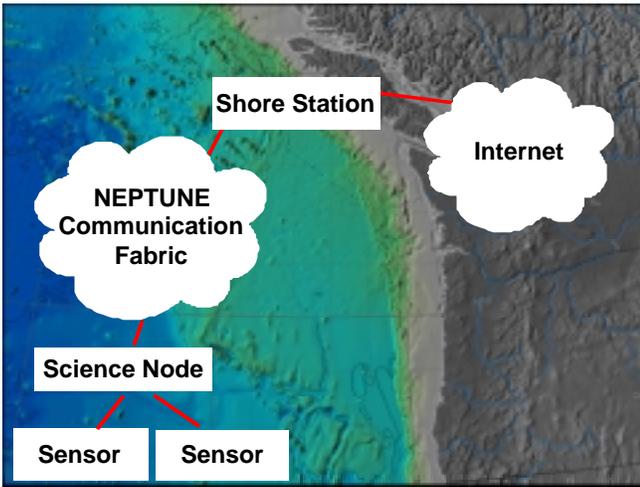


Fig. 4. Overview of NEPTUNE communication system.

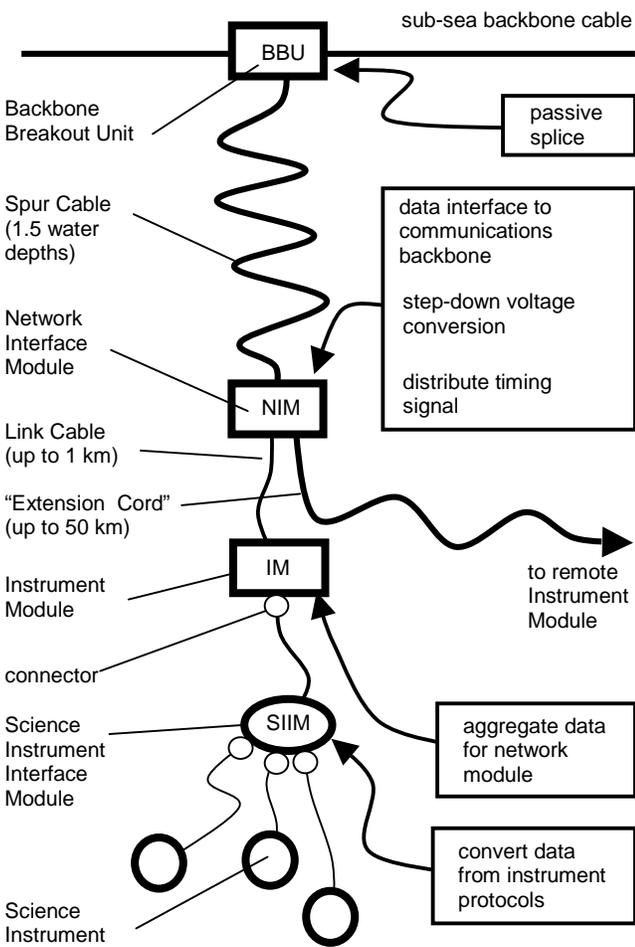


Fig. 5. Schematic of the planned system configuration.

The ADM function at the node is needed to allow retrieval of data from the science nodes and the ability to transmit commands to instruments located there. It is also used as a repeater for data “passing through” the node site. An interesting implementation challenge is the variety of

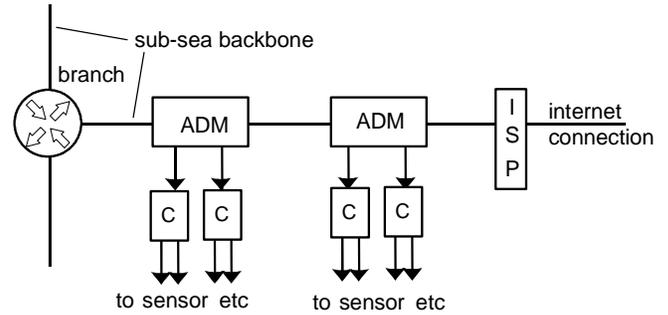


Fig. 6. Functions required to implement NEPTUNE communication system.

data that must be handled: from low-speed measurements, such as temperature; to the equivalent of audio with hydrophone data; to video (or HDTV) for direct, real-time observation.

The implementation details for these functions, using COTS router technology, are discussed in a companion paper being presented at this conference [8].

### B. Power

If the communication system extends the Internet, then the power system extends the utility power network. Conceptually, a version of Fig. 4 can be applied. Essentially, the same problems addressed by the communication system have to be addressed by the power delivery network: how to deliver the power throughout the network, how to step down from a high-power backbone system to a low-power user, and how to effect a branch. Fig. 7 shows the required functions.

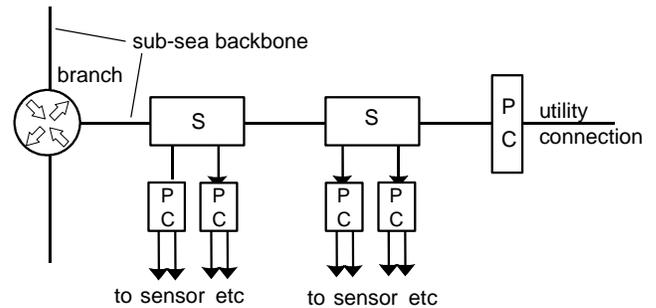


Fig. 7. Functions required to implement NEPTUNE power system.

Here, block PC contains power conversion equipment. Blocks S are for sectionalizing the line, isolating faulted segments.

A major point of difference between the communication system and the power system is that the power system topology is forced to be the same as the cable topology. There is only one power conductor in the cable, whereas there are many fibers. This makes the power network far less flexible and reduces the level of redundancy.

The NEPTUNE power delivery system has relatively little in common with its land-based equivalent, and little

COTS equipment is available to meet the requirements. Harold Kirkham (JPL) and Bruce Howe (UW/APL) lead the power system team. Working with UW's APL and Electrical Engineering Department, as well as JPL's Avionic Systems and Technology Division, the team is designing a direct current delivery scheme based on a backbone at approximately 10 kV. Unlike conventional sub-sea (telecomm) systems, the NEPTUNE scheme will use a parallel network. The power system is described in greater detail in a companion paper at this conference [9].

An item that is of key interest is the use of a parallel power system is its stability under load. Fig. 8 shows the successful simulation results, which are discussed in more detail in a companion paper by Harold Kirkham that is being presented at this conference [10, 11, 12].

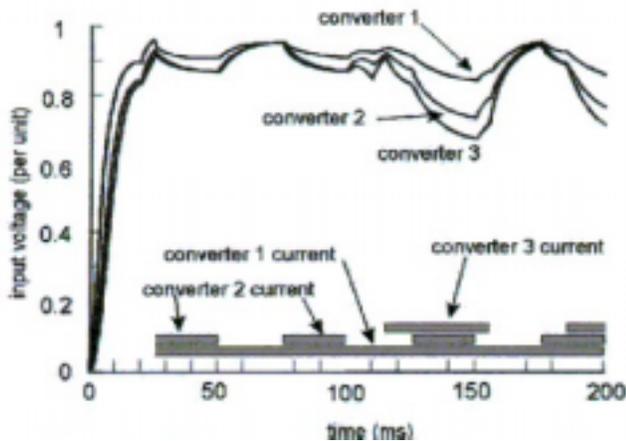


Fig. 8. Results of a pSpice simulation with 3 nodes.

### C. Fault Tolerant Design

A key question regarding fault tolerance is how the communication fabric and the power network will respond to failures in a node or in the cable. In terms of the communication system, NEPTUNE is somewhat different from the land-based Internet. On land, packets are routed via different paths to readily bypass a failed node. This may mean adding only one hop to the route taken by a packet. The same geographical diversity does not exist throughout the NEPTUNE system. In fact, for 28 out of 33 nodes failure of one node (or cable) would block the shortest cable path between neighboring nodes, leaving a very much longer alternate route. However, because there are multiple fibers in the cable, it will still be possible to find an alternate route. This and other aspects of the design are dealt with in the companion paper from WHOI.

For the power system, the failure of a node would mean that all functions of the node were unavailable, both science and communications. Because the power system is so crucial to the node operation, and because there is only one power conductor in each cable, the team is taking a conservative, fault-tolerant design approach. The most basic node function, the DC/DC converter, will be built from a large number of redundant subsystems. The network switching arrangements will also be made redundant.

### D. Interactions

Without a power system, nothing under the sea will work. Once the power system has started up (which it must do autonomously), it will be dependent on the communication system for its operation. The two subsystems are interdependent. While the power system will employ a protection scheme that can act on only local information at a node, its first line of defense will be based on the availability, via the communication system, of information about other parts of the network.

Similarly, there are failure modes in the communication scheme that will require external intervention, e.g., a “babbling” node could conceivably require a reset initiated by turning off the power input from the adjacent nodes for a few seconds.

It is clear that the design of the power and communication systems must be coordinated. This coordination function comes about through the system engineering process and the data it generates. The interface matrix shown in Fig. 9 gives an idea of the pervasiveness of these interactions. It identifies the physically separate elements of the system and relates them to the various subsystems that support the observatory. Understanding and controlling the interactions between the physical elements and the subsystems is crucial to the system design effort. At a minimum, the hardware and software interfaces must be specified in a rational and consistent manner to enable the physical hardware, and the software it hosts, to be built and tested. At a higher level, the degree of complexity in the underwater hardware elements should be minimized to ensure high reliability and adequate quality of service. The matrix can, and is, being used as a starting point for examining these issues and ensuring the completeness of the system specifications.

### E. Data Archiving and Distribution

Séverin Gaudet [Canadian National Research Council (CNRC), Canada] leads the Data Archiving and Distribution system team. The design is shown in Fig. 10. The architecture is based on the successful approach taken by HIA for HST data archiving [13], but also reflects the work done to date in support of the NEPTUNE activities. A significant challenge for the archiving system is the very large volume of data that will be collected and the long duration over which the observatory is planned to work. Assuming the data requirements given in Table 1, the data collected per year will be approximately  $24 \text{ Mbit/sec} \times 30 \text{ nodes} \times 3.15 \times 10^7 = 2.26 \times 10^{16}$  bits. Over 30 years this could increase by two orders of magnitude. This very large database must be preserved as new storage technologies are developed. Over the past two decades four improvements have occurred in storage media—from magnetic tapes to disk to optical disks (CDs), and recently DVD. Each technology development has provided increased density but also has required that archived data be moved to the new storage media to prevent obsolescence.

Given this, over the life of the NEPTUNE Observatory we should expect to relocate the data about every eight

years. This is a sizeable undertaking that must be planned into the basic approach. For safety's sake, the archive also needs to be redundant to guard against damage from natural or man-made causes. The NEPTUNE archive is being designed to meet these requirements.

*F. Shore Station*

The shore station (Fig. 11) will house the land-based components of the communication, power, and timing and control systems and will be the “front end” of the archiving system. The required technologies are straightforward, even if the power system will be perhaps two orders of magnitude larger than the conventional series-fed communication cable, probably about 300 kW

Provision may be made for an uninterruptible power source, which could be hybrid. Battery or capacitor banks may be used for short-term support; a diesel electric generator will be needed to cope with prolonged outages. Local data storage must also be provided because the backhaul Internet connection could be subject to interruptions. One trade-off still under consideration is whether to archive at the shore station, thus minimizing backhaul costs, or negotiate “off-peak” rates and site the archives in Seattle and Victoria

*G. Time Distribution System*

The Time Distribution System provides the accurate and precise time almost universally necessary for science experiments. This requires a reference standard and the distribution of a time signal across the seafloor network. In the U.S. the National Institute for Standards (NIST) performs the reference function, which provides standard time distributed through a series of radio stations, such as

WWV. The global positioning system (GPS) is based on time and frequency references provided by the United States Naval Observatory, with traceability after the fact to NIST. For NEPTUNE, one option for high accuracy time from the GPS system will be to use low-level control fibers and an addition to the Serial ASCII Instrumentation Loop (SAIL) protocol used in ocean engineering. Additionally, the use of InterRange Instrumentation Group (IRIG) time codes, which are used in other systems, can be implemented. The requirement is a high accuracy time to be transferred from the shore station to the nodes (including correction for propagation delays on the backbone cable and providing synoptic time ticks everywhere on NEPTUNE). The accuracy goal is 1µS. For science users who do not require time at this accuracy, standard IP protocols are available for clock synchronization. The most widely used of these is network time protocol (NTP). Operating as a client in seafloor nodes and instruments, NTP is capable of clock synchronization with a few milliseconds accuracy across the NEPTUNE network, including correction for propagation delays.

Fig. 12, a block diagram of the network module components, shows how the elements of each subsystem are interconnected in the node to provide the necessary functionality. All components in this unit, with the exception of the pressure case itself, are redundant to meet the long-term reliability requirements and to ensure that a high level of service is provided to the science user.

	Subsystems							
	Power	Communi- cation	Data Mgmt.	Timing Distribution	System Control	Mech. & Thermal	Operations	Reliability/ Quality of Service
<b>Physical Hardware</b>								
PI on Internet			I/F		I/F		I/F	I/F
Data Archive			SW	SW	I/F	HW	SW	I/F
Control Center	SW	SW	H&S	H&S	H&S	HW	H&S	H&S
Backhaul Cable	I/F	I/F	I/F	I/F	I/F	HW	I/F	I/F
Shore Station	H&S	H&S	SW	H&S	HW	H&S	H&S	H&S
Cable	HW	HW	I/F	I/F	I/F	HW&O	H&O	H&O
Break-out Box	HW &/or S	HW				HW&O	H&O	H&O
Spur Cable	HW	HW				HW&O	H&O	H&O
Network Module	H&S	H&S	I/F	H&S	H&S	HW&O	H&S&O	H&S&O
Instrument Module	H&S	H&S	I/F	H&S	H&S	HW&O	H&S&O	H&S&O
SIIM	H&S	H&S	H&S	H&S	H&S	O	O	H&S&O
Instruments	I/F	I/F	SW	I/F	I/F		I/F	I/F

Fig. 9. Interface Matrix—Physical Hardware [I/F=interface definition only; SW=software; HW=hardware; O=ocean engineering; H&S=hardware & software; blank=no interaction].

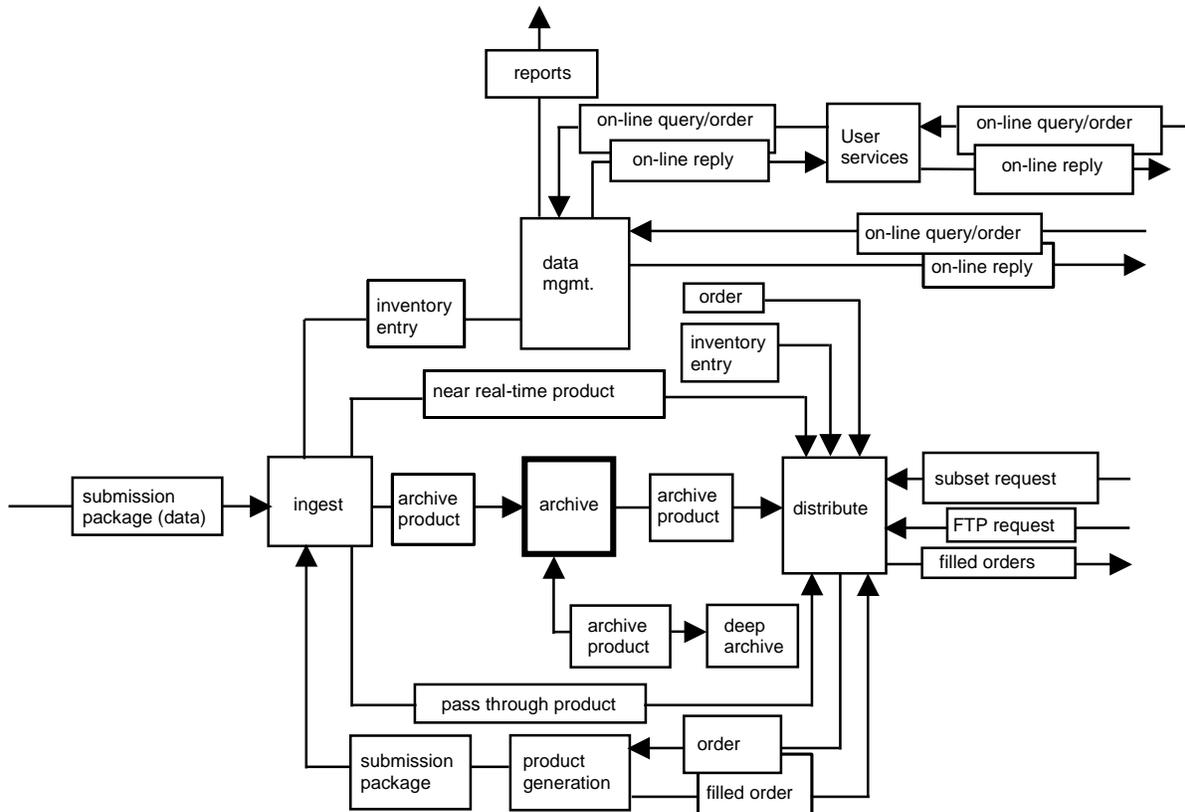


Fig. 10. Data Archiving and Distribution System.

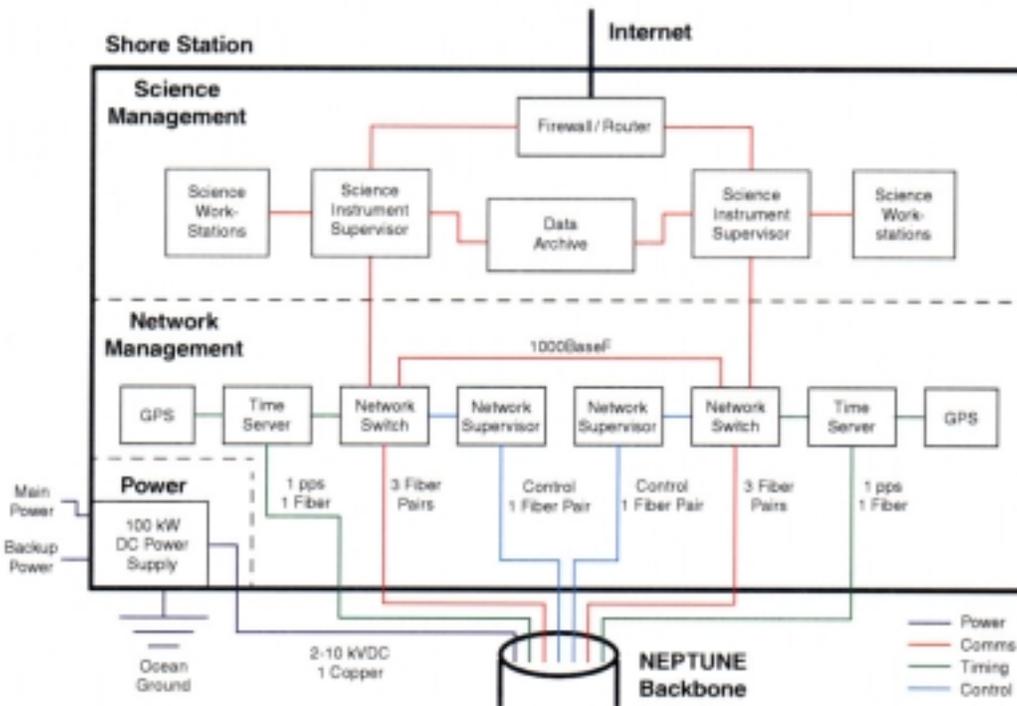


Fig. 11. Block diagram of a conceptual NEPTUNE shore station separated into power, network, and science instrument management components. The major links are color coded into power (blue), timing (green), communications (red), and monitoring and control (cyan) components.

*H. Science Interface*

The science interface provides the connection between the NEPTUNE system and the remote scientific sensors and instruments. It is planned that sensor metadata will be provided, in addition to the raw science measurements, so that all data needed by the archive system is present in the data stream. This data will identify the sensor and provide calibration data and any other information pertinent to subsequent data retrieval and processing. Some instruments will be developed with this capability included, some will not. For those instruments that do not have a metadata capability a Science Instrument Interface Module (SIIM) will be provided to establish the interface between the network and the sensor. MBARI has been developing such a unit, and it will be deployed in the test sites to obtain early validation in a system environment. The power to operate the instruments is another capability that must be provided.

The basic output of the DC/DC converters in the NEPTUNE node will be in the 400V range, which needs to be translated to voltages used by the sensors. The NEPTUNE design currently assumes that these conversions will be accomplished in the PI-provided instruments. An alternative that could be considered would be to provide this as a function of the SIIM. Data communication to the SIIM will be standard 10/100 base T duplex Ethernet. The SIIM will support RS 232/422 on the input side, as well as Ethernet. Additionally, the connection between NEPTUNE and the sensors will use extension cables that may be from a few meters to 100 km in length. These cables are expected to be multi-conductor copper cables up to 100 m and standard communication electro-optical cables for the longer lengths.

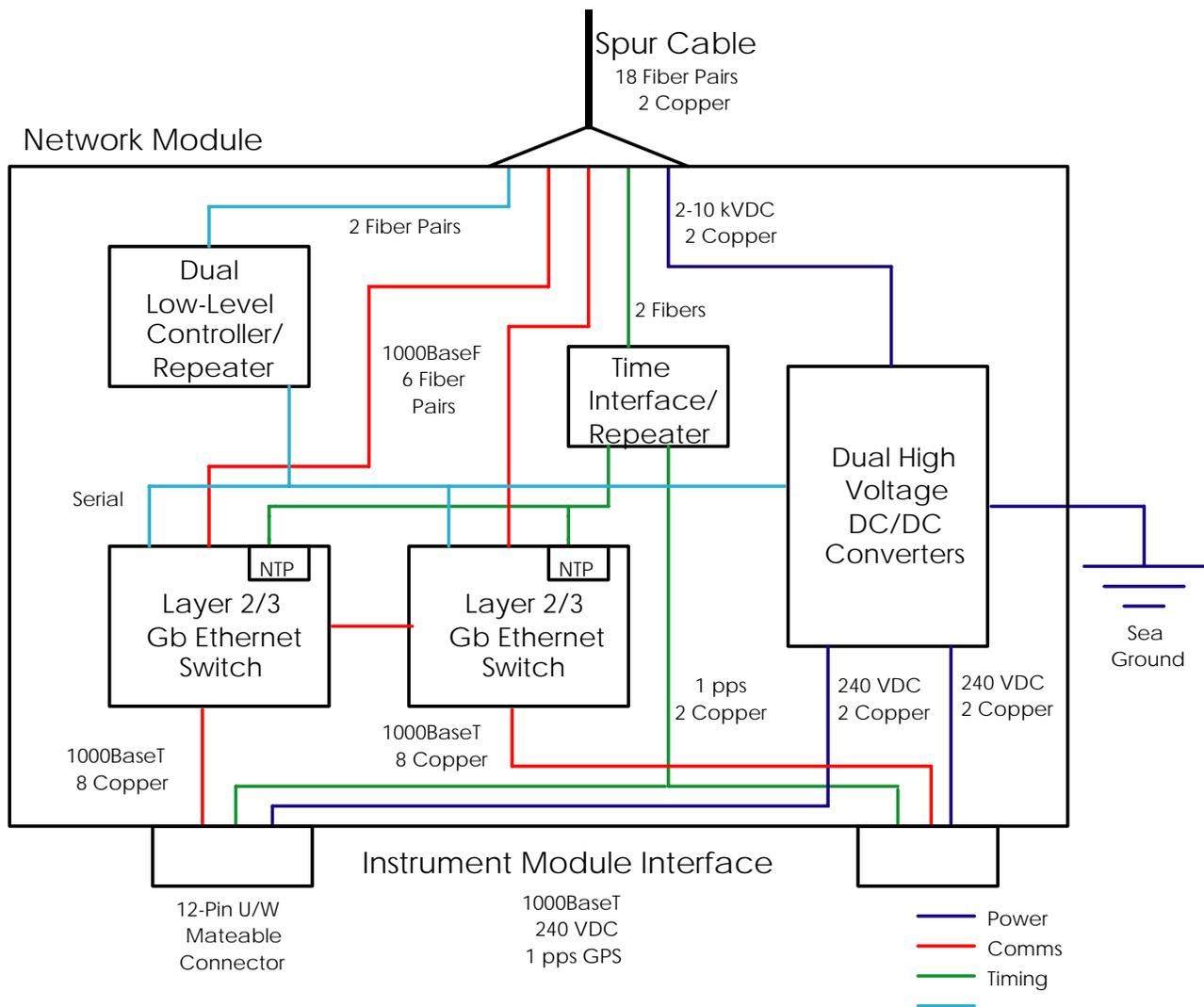


Fig. 12. Block diagram showing the network module components: a pair of gigabit Ethernet 2/3 switches, high-voltage DC/DC converters, control system elements, and a time interface.

## V. SUMMARY

The feasibility of the NEPTUNE Observatory was addressed in detail in the NEPTUNE Feasibility Study (<http://www.neptune.washington.edu/>) [3]. That report conclusively showed that NEPTUNE is feasible and affordable. In the past year the team has actively addressed the areas, identified in the earlier report, where COTS hardware/software will not meet the requirements. Funding has been obtained for both the communication elements, being addressed at WHOI, and the power system, where the responsibility lies with JPL and the UW. These activities will culminate in designs for viable subsystems ready to be incorporated into the final system design by the end of 2002. The system reliability is under study and preliminary results look promising with availability over a 30-year period of approximately 90%. The timing approach appears viable and straightforward and can be readily incorporated into the NEPTUNE design. Additionally, test systems VENUS and MARS have been identified that will provide the necessary "in water" demonstration of the Observatory.

Given this situation, the system design activity is changing from synthesis to design oversight, to ensuring that the individual developments proceed in a compatible fashion rather than identifying new items to consider. The focus for this next year is, therefore, oriented to completing the design to the point that it can be documented and implemented. The team will also address providing costing at a greater level of detail than has been previously accomplished and opening discussions with industry.

We look forward to the time when an operational NEPTUNE observatory can make great contributions to complement the other ways in which the oceans are explored.

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Reference herein to any specific commercial product, process or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government or the Jet Propulsion Laboratory, California Institute of Technology.

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