A Modular Gigabit Ethernet Backbone for NEPTUNE and Other Ocean Observatories

Andrew MAFFEI [1], John Bailey [1], Albert Bradley[1], Alan Chave[1], Xavier Garcia[1], Haywood Gelman[2], Steven Lerner[1], Frederick Sonnichsen[1]

1) Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA
2) Cisco Systems, Incorporated….

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ABSTRACT

Ethernet is the most popular technology used for Local Area Networks (LANs). Recently, Gigabit Ethernet (GbE) technology has successfully competed with SONET and other legacy alternatives such as ATM and Frame Relay for Metropolitan Area Network (MAN) and Wide Area Network (WAN) implementations. This paper describes a modular ocean observatory node design resulting from design activities of the NEPTUNE observatory data communications team. Internal node modules based on Gigabit Ethernet, point-to-point wave division multiplexing (WDM) and TCP/IP (Internet) protocol technologies are employed to define communications building blocks used in the design of the NEPTUNE regional scale ocean observatory communications system and are also applicable to coastal, buoyed and autonomous observatory nodes.

1. INTRODUCTION

The study of the dynamic, interactive processes that comprise the earth-ocean system requires new approaches that complement the traditional ship-based expeditionary mode that has dominated oceanography for the past century. Long-term access to the ocean is needed to characterize the diverse range of spatial and temporal scales over which natural phenomena occur. This can be facilitated using ocean observatories to provide power and communications for distributed real-time sensor networks covering large areas. Real-time networks also enable an education and public outreach capability that can dramatically impact the public attitude toward the ocean sciences.

The NEPTUNE project (http://www.neptune.washington.edu) is a joint US-Canadian effort to "wire" the Juan de Fuca tectonic plate located off northwestern North America with ~3200 km of dedicated scientific fiber optic cable hosting 26 science nodes spaced up to 170 km apart. Each seafloor science node will provide power at the multiple kW level and two-way communications at a nominal Gb/s rate to many experimental packages. The current system is designed to provide aggregate backbone communications of up to 8 Gb/s. Higher bandwidths can be accommodated for those links that require it. Two shore stations with a total of four backbone fiber pairs provide 32 Gb/s of full-duplex bandwidth between the undersea network and shore-side Internet. Fig. 1 shows the planned layout for NEPTUNE. Installation of NEPTUNE is expected to begin in the 2008 time frame.

NEPTUNE differs from a conventional submarine telecommunications system in two key respects. First, NEPTUNE requires data input and output at many seafloor sites rather than a few land terminuses. This means that transmission lasers and data switches will have to be placed underwater. Second, NEPTUNE has to distribute power at variable and fluctuating rates to many seafloor instruments in addition to energizing its own internal systems. For these and other reasons, the engineering solution for the NEPTUNE power and communications systems differ from those used in commercial telecommunications systems. However, NEPTUNE will take advantage of the submarine fiber optic cable technology used in telecommunications for its backbone, and will be installed using conventional cable laying assets.
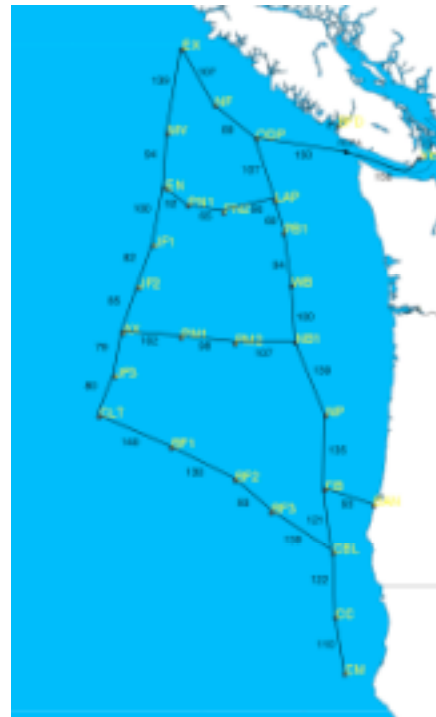
FIGURE 1 - NEPTUNE NETWORK LAYOUT. NODES ARE LABELED WITH YELLOW CODES. DISTANCES BETWEEN NODES SHOWN IN KILOMETERS.

2 CONSTRAINTS, TECHNOLOGIES, AND TRADEOFFS

2-1.Functional Requirements

The functional design of the NEPTUNE system must be driven by science requirements. For example, the locations of the 26 seafloor nodes in Figure 1 were determined by multi-disciplinary (e.g. geological, biological, chemical, etc.) science needs. Through an assessment of present and projected future ocean instrumentation and experiments, system parameters such as the peak and average data rate, power level, and allowed data latency and jitter (from seafloor instrument to shore) have been defined. Aggregate system capacity of up to 8 Gb/s and delivered power at the 5 kW level per site is sufficient to meet

science goals. The system must also distribute accurate (microsecond level) time information to seafloor instruments. These issues are further discussed in [1].

The infrastructure for NEPTUNE consists of five systems: data communications, power distribution, observatory management, time distribution, and data management and archiving. Each of these components must be designed as end-to-end systems which interface cleanly to the remainder, and must be highly fault tolerant. Physical packaging of the seafloor nodes must be accomplished in a way that facilitates science as well as maintenance. The system engineering for NEPTUNE to accomplish these goals is presently underway [2]. A description of the NEPTUNE power system design can be found in [3]. This paper will focus on the communications architecture, including the requirements and technological alternatives.

2-2. Analysis Criteria

Choosing the best backbone network technology for NEPTUNE is not a simple matter. There are three areas of analysis worth considering:

1. *Business observations*: the selected technology should be close to the commercial Internet mainstream so components can be purchased in the commercial marketplace. Buying into dead-end technology or using a custom approach for a program with a 25-year life cycle can be expensive and limiting. A sense for the wave of the future needs to be part of the analysis.

2. *Technology observations:* different networking technologies offer different capabilities and impose concomitant limitations. Internet technology contains solutions for problems NEPTUNE may or may not have. There is a significant payoff from simplicity, so the technology NEPTUNE chooses to avoid is as important as that which NEPTUNE buys into.

3. Specific NEPTUNE requirements: the two previous items don't have any seafloor-specific flavor; conclusions would probably be similar for a terrestrial network with the same data rate and link span requirements. However, NEPTUNE clearly presents unique issues. For the science nodes, these include packaging to fit into reasonable sized pressure cases, moderate power consumption (both because power is limited and because power represents heat that must be transferred out of a pressure case), high reliability and fault tolerance, ease and effectiveness of network management, the ability to sustain upgrades as the technology evolves, and compatibility with an easily understood science interface. Many of these are difficult to define precisely, but it seems reasonable to limit the "hotel" load for all science node systems to about 500 W, leaving the majority of the available power at a node for science. Pressure case cost and weight rises faster than the square of the inside diameter, so keeping this constrained has a real impact on cost and ease of shipboard handling. The remaining issues have to be examined on a case-by-case basis.

2-3. Data Networking Technologies

NEPTUNE requirements resemble those upon which Internet-like data networks are based. This section examines network technologies available for use in NEPTUNE to determine which are applicable, which are not, and which may become available for NEPTUNE in the near future.

(1) WDM Alternatives

Three optical transmission alternatives are reasonable to consider for the NEPTUNE design. Two of them employ wave division multiplexing (WDM). WDM permits several optical channels to be transmitted over a single fiber using different wavelengths.

1. *Single lambda systems*. These typically operate at 1550 nanometers over a single fiber. The NEPTUNE feasibility study uses extended range, single-lambda Gigabit Ethernet over 10 fiber pairs to span 100-kilometer node separations. Recent advances in optical networking have provided more efficient, lower cost options.

2. *Ultra Long-Haul (ULH) DWDM*. Transmission over several thousand kilometers using many wavelengths and cascaded EDFAs for amplification can be accomplished, as is standard for submarine telecommunication systems. Commercial systems can reach more than 10000 kilometers at 40 Gb/s per lambda using legacy SONET communications technology. Optical add-drop multiplexers (OADMs) can be used to drop wavelengths off at different sites along the fiber path.

It is impractical to install large and power hungry carrier-grade equipment in a NEPTUNE node. It has been suggested that reducing channel count and bit error rate (BER) requirements for the communications channels will allow metro-grade DWDM equipment to be used to build an add/drop optical network. However, this approach is substantially more costly than is advocated here, and preliminary modeling suggests that it offers no reliability advantage.

3. *Metro DWDM and CWDM*. The size of metropolitan DWDM systems has decreased dramatically. Though they are not built to the same tolerances as ultra long-haul seafloor systems, they are capable of transmitting DWDM signals hundreds of kilometers at comparatively low cost.

Coarse Wavelength Division Multiplexing (CWDM) offers an even more cost effective solution for metro and access networks. CWDM uses eight wavelengths, spaced further apart than ITU-standard DWDM. This allows lower cost lasers, filters, multiplexers, and demultiplexers to be used. CWDM systems cannot reach the same distances as metro DWDM, but they may be appropriate for shorter haul coastal observatories.

(2) Optical IP Alternatives

Both the science user interface and shore station Internet interface will utilize Internet Protocols (IP), which have clearly emerged as the dominant networking protocol. There are a few non-IP solutions, such as switched ATM to the end user, but none are available in the marketplace in a practical sense, and will not be considered further. All of the pertinent technologies now work over DWDM. There are currently about five ways to design an IP infrastructure for NEPTUNE:

1. *IP/ATM/SONET/DWDM*. IP can be transmitted over some switched technology such as frame relay or asynchronous transfer mode (ATM). On a fiber optic backbone cable, these switched technologies can in turn ride over a multiplexing technology such as synchronous optical network (SONET)/synchronous digital hierarchy (SDH). The purported attraction of this approach is the promise of switched virtual circuits connecting science users at the seafloor and on land. However, with ATM, these quality of service characteristics stop at the router, so there is limited practical payoff. Full-fledged SONET equipment is quite large and requires a lot of power. Such systems are impractical for placement in a NEPTUNE node.

2. *IP/SONET/DWDM*. This is sometimes called packet-over-SONET, and eliminates the complexity of ATM/frame relay. This approach was used by large ISPs a few years ago since the available highest capacity optical links were larger than router capacity. As router capacity has increased with the advent of layer 3 switches that work at line speed using routing fabrics, this approach is declining in popularity. IP over SONET is likely to become a legacy technology. Also, although packet-over-SONET equipment is available, it is sold in larger router packages that are not appropriate for NEPTUNE node housings.

3. *IP/RPR/Ethernet-PHY/DWDM*. Resilient Packet Ring (RPR) is an emerging IEEE standard (802.17) that mixes the transport efficiencies, quality of service and reliability characteristics of Ethernet and SONET. The physical layer can be either SONET framing or Ethernet-like line coding. RPR can be designed to operated in an inter-linked, counter-rotating ring. Spatial reuse is employed for improved throughput and a 50 ms. failover time is built into the current requirements. RPR is not yet a

standard, and products based on this technology are currently too large. This may change soon if RPR is successful.

4. *IP/Ethernet/SONET-Frames/DWDM*. Ethernet (actually GbE) over SONET framing is a recent alternative introduced with the emergence of Next-Generation SONET products that have been developed to compete with less expensive GbE over fiber products. Chips exist which allow two GbE channels to be carried over a single SONET-framed OC-48 channel. Much of the overhead associated with the SONET/SDH protocols is avoided. Smaller scale metro-Ethernet systems are available that would fit in NEPTUNE nodes.

5. *IP/Ethernet/DWDM* This is a rapidly growing technology as the capabilities of "campus area networks" have been radically increasing. Conceptually, what started out as a single segment of LAN has undergone mitosis and gained a vertebrae. Gigabit Ethernet (GbE) and 10GbE are commonly used as backbones with a desktop Ethernet (10/100 Mb/s) fan out at the user (access) end. The fiercely competitive Ethernet market is driving technology forward, reliability up, and prices down. Further, a great deal of development effort is being focused on making these LAN technologies work over long (100+ km) physical distances using DWDM.

(3) Topology and Repeating Alternatives

1. *Star Topology with in-line repeaters.* As an alternative for NEPTUNE, it would be possible to utilize a star topology in which a single pair of optical fibers (or more likely a pair of wavelengths on a WDM system) are assigned to each node and then linked directly to a shore station hub. In a DWDM-based system, individual wavelengths would be dropped at each node with the use of an OADM.

Expensive ($500k-$1M) in-line submarine EDFAs is required. Submarine quality repeaters would be installed in the cableplant itself so that the optical signal generated by transmission lasers can be amplified and carried all the way from hub-to/from-spoke without the need for regeneration. Spacing between in-line repeaters depends on the number of wavelengths, speed of transmission, power of the transmission lasers, and fiber dispersion characteristics, but is typically 60-80 km.

2. *Mesh topology with in-node repeaters*. Terrestrial data networks usually utilize a mesh network architecture to provide redundant paths and ensure rapid restoration in the even of a fault. The mesh is established by creating point-to-point connections between switches. More connections between nodes produce a denser mesh. In a DWDM system the separate optical channels are used for bandwidth aggregation. Instead of allocating a single wavelength from shore hub to node, multiple wavelengths (eight or more) are operated between each node pair. There is no need for OADM technology.

If distances between nodes are kept to less than 170 kilometers, then there is no need for in-line repeaters. In-node pre and post amplifiers can be used instead. Nodes are designed to be repairable and the mesh network is capable of self-healing during component failure. Therefore, the reliability requirements for EDFAs decrease. Since the distance between OEO signal regeneration is short, dispersion compensation requirements are minimal and the quality of the signal and the BER supports high-speed network applications.

2-5 Cross Comparisons of Viable Alternatives

(1) WDM Analysis

One of the constraints on a system built with ultra long-haul DWDM is the lack of flexibility of the cableplant infrastructure. The physical locations of OADMs, EDFAs, and dispersion compensation components are fixed at installation time and it is very difficult (if not impossible) to expand the system.

Ultra long-haul DWDM also requires the use of expensive submarine-quality in-line EDFA repeaters. These repeaters, though ultra-reliable, can significantly increase the cost of a system. If another system design can be made *reliable enough*

without the use of these repeaters, then significant cost benefits may be realized.

There is some question as to whether the longer optical paths used in the long-haul DWDM systems can support the BER required (~10^{-12}) by high-speed networking applications. Forward error correction (FEC) and other advanced technologies are not generally available in metro quality components, and a high BER would significantly reduce node throughput by requiring frequent packet re-transmission at the TCP layer.

The metro-DWDM and CWDM technologies both look promising for NEPTUNE as long as distances between nodes is kept short enough. Recently, vendors have announced the availability of DWDM GBICs (GigaBit Ethernet Interface Converters) that slip into Layer 2/3 GbE switches. Other vendors provide compact DWDM subsystems that support a multitude of communications interfaces.

(2) Optical IP Analysis

SONET/SDH and ATM solutions are designed to grow an essentially voice network to increasingly large communications pipes while accommodating IP data on the side. Further, SONET is a virtual circuit, time domain multiplex approach to implementing a physical layer, while IP data is bursty, which makes SONET comparatively bandwidth inefficient. As a result of a predominantly telephone orientation, SONET/SDH is also designed to provide nearly instantaneous restoration in the event of a fault at the cost of tying up most of a fiber in standby mode. As a result, these technologies offer many features that NEPTUNE does not require, but which increase switch and multiplexer complexity, size, and cost. Other discussions about the inappropriateness of IP/ATM/SONET/DWDM can be found in [4].

IP/SONET/DWDM (packet over SONET) implementations are becoming scarce in the metro-realm becoming as IP/Ethernet/DWDM emerges. Packet over SONET requires large, power-hungry routers while IP/Ethernet/DWDM architectures can be accomplished with the switching fabrics of smaller, less power-hungry Layer 2/3 switches.

IP/RPR/Ethernet-PHY is an emerging standard. It is not clear whether the technology will become commercial before other GbE-based efforts adopt some of the same features. The commercial success of RPR is still in question and it is too early to choose IP/RPR/Ethernet-PHY/DWDM as a viable option for NEPTUNE, although it should be watched carefully

The last two alternatives, IP/Ethernet/SONET-Frames/DWDM and IP/Ethernet/DWDM, are similar. COTS products have recently become available for the first. It salvages SONET framing, but eschews all the rest of an essentially legacy telephone technology. Though it maintains the simplicity of using Ethernet to carry IP frames, there is some added complexity in using both SONET and Ethernet framing. This is done for two reasons. First, it allows two GbE channels to be inserted into a single OC48 (2.5Gbps) optical channel. Second, it maintains compatibility with existing long-haul SONET systems.

The IP/Ethernet/DWDM approach is the simplest. It uses, of course, Ethernet framing. The key technology used is Gigabit Ethernet (GbE), which is the highest speed version of the most widely used (more than 80% of the market) data networking technology in the world. GbE routing and switching hardware is readily available from many vendors, and several are also marketing integrated Gigabit Interface Converters (GBICs) which are available in single lambda, CWDM, and (soon) DWDM optical transport technologies.

(3) Topology and Repeating Analysis

One problem with the star topology is that the distance a non-regenerated lambda has to travel is much greater than with the mesh topology. This raises dispersion compensation issues. It is questionable whether metro-grade DWDM equipment that can fit in a node can provide an adequate bit-error-rate (BER) to

maintain Gb/s packet transmission. The star topology also has a fixed number of fibers/wavelengths, which limits future extendibility and flexibility.

One advantage claimed by proponents of a star topology is that packet switching need not be done at the IP (layer-3) level. Instead, it can be done at the Ethernet (layer-2) level. However, deficiencies in the layer-3 spanning tree algorithm suggest that layer-3 switches will still be necessary.

If, somehow, simpler layer-2 switches could be used, then slightly lower latency will be achieved for node-to-shore communications. However, node-to-node communications must all pass through a shore station, substantially increasing overall latency

The mesh topology, established with point-to-point links between nodes and combined with layer-3 switching provides a more robust fabric of paths between nodes and shore. Indeed, this is the principal on which the Internet delivers 99.999% transmission reliability.

The ability to reconstitute the network in the event of component failure or a cable break is a clear NEPTUNE requirement. This can be achieved in a variety of ways. Since the major loop of NEPTUNE has two shore termini, each of the seafloor routers would have an adjacent router as well as any redundant routers per science node in their reachability tables. A failure in either direction would cause routers to automatically redirect all traffic in the opposite direction or simply to the second router in the node. This mechanism operates against both component failures and cable breaks.

2-6. Choice of Gigabit Ethernet for NEPTUNE

Based on the arguments given above, the current NEPTUNE baseline data communications system (DCS) design is based on a DWDM optical system that employs multiple optical channels between adjacent nodes. Point-to-point connections between layer-3 switches in each node use IP/GbE/DWDM to deliver IP packets between nodes. These layer-3 switches are configured in a mesh topology in order to create the robustness required to meet network availability requirements for the system. No expensive in-line submarine repeaters are necessary. Instead, less expensive, field-replaceable pre- and post-optical amplifiers are installed inside the nodes if necessary to meet distance requirements.

This solution fits the NEPTUNE requirements best. The NEPTUNE application has a diverse set of pure data applications, no voice applications, and video applications that can easily be handled as "video over IP". Indeed, most video applications that one can imagine for NEPTUNE would not be highly interactive, so there is less motivation to precisely control jitter and latency which are the most common video shortcomings in an IP world that is either low capacity or highly congested. An IP-only solution is the best mix between simplicity of the plumbing and applications available to the users.

2-7. Future Network Technologies

The NEPTUNE network will probably not be deployed until 2008. Given the quick-paced progress of the optical networking field, it is unlikely that the communications design specified today will be the final design. Emerging technologies such as RPR may prove successful and emerge as viable options. Higher speed Ethernet alternatives such as 10GbE and 40GbE are being developed. Valuable optical devices will likely be developed over the coming years that meet the node space, power, and other requirements.

Smaller, higher speed; less expensive, more innovative optical components have been announced regularly in the recent past. New optical switches, amplifiers, passive wavelength translators, electrical repeaters, optical cross connects, etc. may be available in future COTS network components. Although recent news is that this industry is slowing down, the NEPTUNE project must keep an eye out for products that can meet NEPTUNE's size, power, reliability, and economic constraints. These options could also be considered for the NEPTUNE design as long as NEPTUNE's funding profile provides time for them to be engineered and qualified.

3. OBSERVATORY NODE CONCEPTUAL DESIGN

Even though the deployment of NEPTUNE is several years off, it makes sense to proceed with the development and testing of a modular data communications system design for NEPTUNE and other observatory nodes. Such a design makes it more likely that NEPTUNE observatory nodes can be adapted to operate in regional scale, coastal, buoyed, and even autonomous ocean observatories.

3-1. NEPTUNE Data Communications System

The NEPTUNE Data Communications System currently consists of five subsystems. The first two are the undersea distribution network (providing inter-node communications) and the science instrument access network. Components of these subsystems are primarily located in NEPTUNE observatory nodes. The second two subsystems are the shore station local area network and the Internet portal subsystems. The fifth subsystem is the network management subsystem, components of which are distributed throughout all of the other subsystems.

The remainder of this paper focuses on the design of a variety of optical transport options to be considered as part of the undersea distribution subsystem components in NEPTUNE observatory nodes.

3-2. Overall Observatory Node Communications Design

Figure 2 depicts a generalized communications design for the data communications modules included in NEPTUNE observatory nodes. The details of the node power module have been omitted from this figure, but can be found in [3]. The NEPTUNE power distribution subsystem delivers up to 2 kilowatts of power at both 48VDC (used by communications subsystem components) and also 400VDC to each node.

NEPTUNE observatory nodes are to be dispersed around a topology as shown in Figure 1. Though not shown here, a 3-way version of the observatory node is also possible with a third fiber pair entering the NBU from a 3rd node. Additional optical transport and switching equipment is added to a 3-way node so that it can accommodate the additional ports.
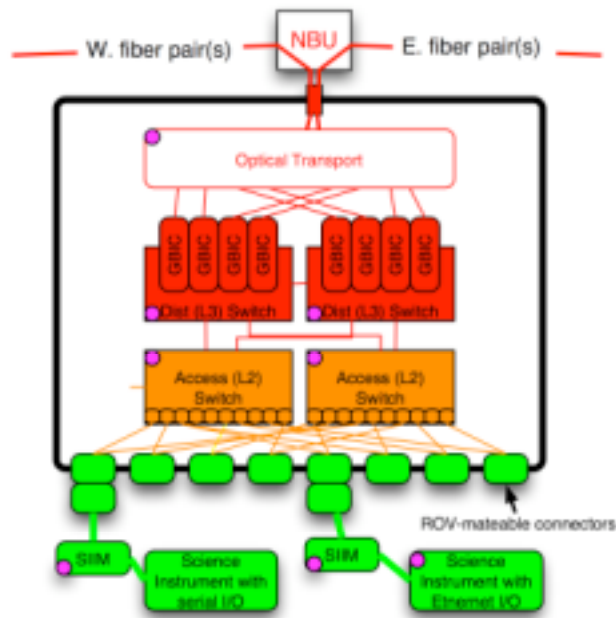

FIGURE 2 - NEPTUNE OBSERVATORY NODE COMMUNICATIONS MODULES

A single fiber pair from each of two adjacent NEPTUNE nodes (one fiber pair indicated as east, the other as west) enters the NBU (Node Branching Unit). The NBU simply provides a splice point at which the two (or 3 in the case of a 3-way node) fiber pairs can be connected to a spur cable. The spur cable runs from the NBU to the observatory node and is one and a half water depths long. This allows the housing, and the electronics enclosed within it, to be regularly maintained by a UNOLS vessel.

An empty box, indicating the optical transport module is shown. It is responsible for converting wavelengths on the inter-node cable into Gigabit Ethernet channels that are input to layer-3 (L3) GbE switches via GBICs.

The redundant L3 switches shown in the figure perform two primary functions. Their first function is to act as OEO repeaters for GbE channels operating over the mesh backbone. Their second function is to connect the science instruments, via the intermediate L2 switches with access to the undersea distribution network and on to the shore stations. Note that the shore stations have equipment similar to that shown in the nodes that connects the undersea distribution network to the shore station LAN.

Note that the L2 switches are also redundant. Only one of the two 10/100BaseT Ethernet connections leading from the L2 switches to the ROV-mateable connectors is active at a time. If an L2 switch port fails, then the port on the other L2 switch can be activated from shore.

A new NEPTUNE team effort is currently underway to define the full functionality of the Scientific Instrument Interface Modules (SIIMs) that are depicted in Figure 2. At a minimum, these devices provide the conversion of serial signals to/from Ethernet. Such devices are common on factory floors today. The SIIM will also include features such as metadata storage, ground-fault monitoring and other instrument-related functions.

The small circles shown in various modules shown in Figure 2 indicate the Simple Network Management Protocol (SNMP) agents that will be used to monitor and control the network elements with an off-the-shelf Network Management Station (NMS).

3-3. Optical Transport for NEPTUNE Observatory Node

Note that in the following and previous figure, for simplicity's sake, only four channels per adjacent node are shown. The NEPTUNE observatory node includes eight channels per adjacent node.

The optical transport module used for the current baseline data communications system in a NEPTUNE node is shown in Figure 3. The receive fiber from each adjacent node enters a DWDM optical demux where the ITU-based DWDM lambda (15XX nm) is delivered to the DWDM transponder that translates it to 1310nm, compatible with the receiver in one of the GBICs in an L3 switch.

The transmit laser in the same GBIC delivers a 1310nm signal to another transponder that converts it to a 15XX nm lambda and delivers it to a DWDM mux. The signal from the mux passes through an EDFA that boosts the power of all wavelengths by 23dB, providing for a maximum of 170km between nodes.

3-3. Additional NEPTUNE Observatory Node Types

Although IP/GbE/DWDM is the chosen technology for the current baseline NEPTUNE observatory communications system design, there are other optical transport module designs that can support other types of observatory nodes. Four example optical transport options are described.

Figure 4 depicts a slight modification of the NEPTUNE observatory node DWDM-based transport. In this design, a subset of the DWDM channels bypass the L3 switch and are regenerated only by the DWDM transponders. This design protects some of the channels from the possibility of L3 switch

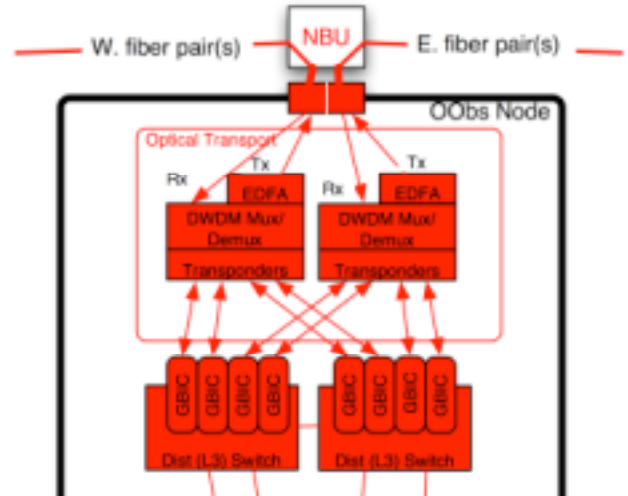failure, providing a direct OEO regeneration of a GbE signal.

FIGURE 3 - NEPTUNE OBSERVATORY NODE DWDM-BASED OPTICAL TRANSPORT

It is also possible to create a node that OEO repeats all DWDM signals by sending all DWDM channels through OEO transponders (not shown), eliminating the need for an L3 switch, but lacking support for science instrumentation to be attached. Such a node can be useful in the case where a GbE channel must extend beyond distances that the optical budget will allow.
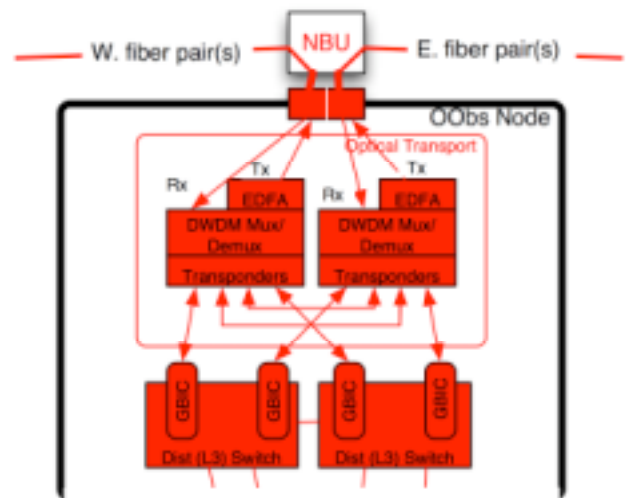

FIGURE 4 - MULTICHANNEL DWDM WITH BYPASS

Another alternative for extending the distance between active science nodes is to build a simpler submarine repeater (optical amplifier) as shown in Figure 5.

Unlike expensive ($500K - $1M) submarine amplifiers that are normally placed every 50-100 km. apart in submarine telecommunications systems, these nodes could be repaired using oceanographic UNOLS vessels. When a node fails, the robust mesh of the distribution network provides alternative paths for packets until the amplifier can be repaired. FIT rates on commercially available EDFAs are quite low (<100 FITS), so repairs would not be expected very often.
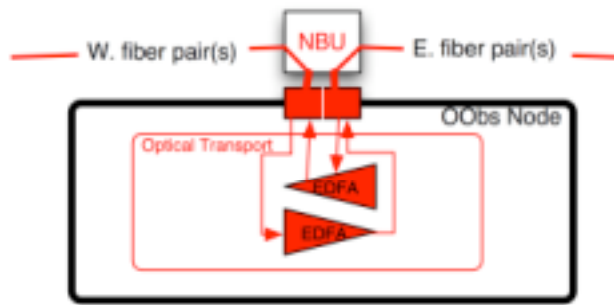
FIGURE 5 - MAINTAINABLE SUBMARINE REPEATER

The choice as to whether OEO or OO repeaters are used in a design depends on the optical signal-to-noise (OSNR) of the GbE channels as they proceed through the optical network. Anecdotal evidence is that GbE channels can survive five or six OO amplifications before they must be electronically regenerated, but this must be further researched.

Figure 6 shows another optical transport alternative using coarse wavelength division multiplexing (CWDM). Although the range on these systems (~70 km.) is less than a post-amplified DWDM system such as that shown in Figure 3, CWDM components are about half the price. Another distinct advantage is the simplification of the node design because of the recent availability of CWDM GBICs, which also play the role of transponder. One vendor has recently announced DWDM GBICs. When available, this promises a simpler future version of the optical transport system shown in Figure 3.
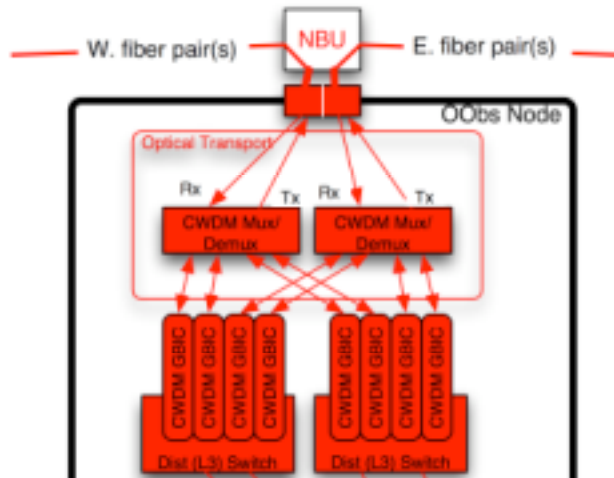

FIGURE 6 - MULTICHANNEL CWDM GBIC OPTICAL TRANSPORT

A final optical transport alternative to be considered is a simpler observatory node comms system for use in coastal applications or for node extensions that have linear topologies. GBICs of several different types (short range, long range, and extended range) are available for the node comms design shown in Figure 7. A ZX (extended range) GBIC is capable of transmitting up to 100 km. An optical transport system similar to this, using short-range (SX) GBICs, has been operating flawlessly on the Martha's Vineyard Coastal Observatory (MVCO) for the past two years.

4. Next Steps

We have first described the optical transport alternatives considered for the NEPTUNE observatory design. We have proceeded to describe a conceptual design for an IP/GbE/DWDM based system for which parts are commercially available today.
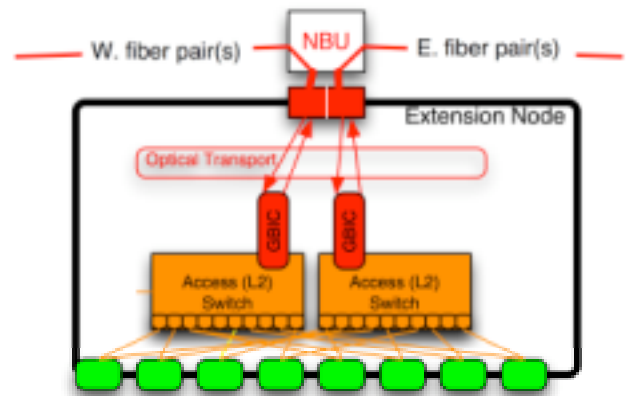
FIGURE 7 - EXTENSION NODE OPTICAL TRANSPORT

Recognizing that the installation of the NEPTUNE observatory infrastructure is some time off, we have proceeded to describe a number of different node types based on alternative optical transport designs that are worthy of consideration for existing or near-future observatory designs.

Our next step is to build prototypes of the described nodes and to model their characteristics. Existing products will be evaluated in terms of size, power requirements, heat dissipation, and other criteria. Recognizing that a new suite of more advanced optical transport hardware will be available a nominal year from now, we will purchase equipment so that our laboratory test bed can be upgraded such that the various configurations can be built and tested inside pressure housings.

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