Regional Scale Nodes
Wet Plant Primary Infrastructure
White Paper

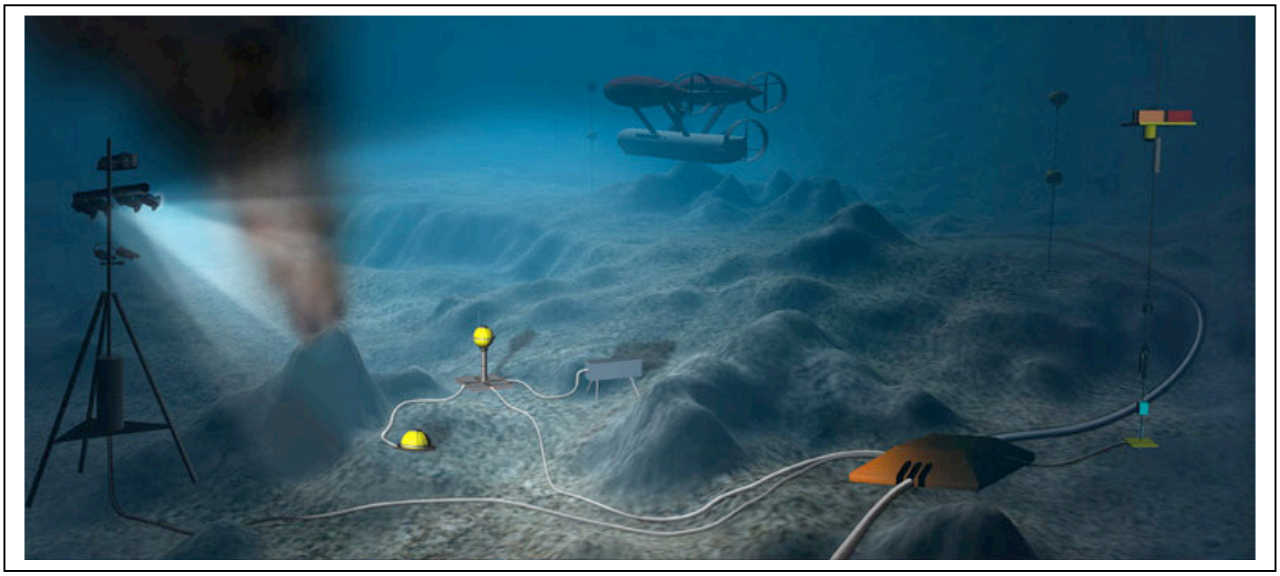

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Table of Contents

	Page
1.0 Introduction	**1**
2.0 Configuration Comparison Approach	**1**
2.1 Methodology and Criteria	**4**
2.2 RSN System Design Options	**5**
3.0 System Maps and Tables	**6**
Initial Design	**7**
Ring Configuration	**9**
Multiple Fiber Ring Configuration	**11**
Star Configuration	**13**
Additional Ring and Star Configurations	**15**
Mid Plate Star	**19**
Canadian Option	**21**
Reduced Coverage Option	**23**
4.0 Analysis and Comparison of Configuration Options	**25**
5.0 Recommendation and Conclusions	**29**

Figures

Figure 1. Conceptual Network Design March 8, 2007 CND	**3**
Figure 2. Initial Design	**7**
Figure 3. Ring Configuration	**9**
Figure 4. Multiple Fiber Ring Configuration	**11**
Figure 5. Star Configuration	**13**
Figure 6. Expanded Star Configuration	**15**
Figure 7. Extended Star Configuration	**17**
Figure 8. Mid Plate Star	**19**
Figure 9 Canadian Option	**21**
Figure 10. Reduced Coverage Option	**23**
Figure B1. Example of Power Requirements for Mooring	**37**

Tables

Table 1. Component Strategy	**25**
Table 2. Risk Summary	**25**
Table 3. Summary of Infrastructure, Bandwidth, and Power, and Science Strengths and Weaknesses for RSN	**26**
Table A1. Risk Factors	**31**
Table A2. Risk Percentage	**31**
Table B1. High Data Rate and High Bandwidth Sensors	**34**

Appendices

Appendix A: Calculating Risk Factors	**30**
Appendix B: Estimate of Power and Bandwidth	**32**

“Dreams and reality

bear fruit in the

hands of engineers”

A White Paper Series

Over the coming months there will be a series of White Papers and Trade-off Studies that deal with components of the Regional Scale (Cabled) Nodes (RSN) of the OOI Network or the Regional Cabled Observatory (RCO) as it is referred to in the NSF-JOI-supported Conceptual Network Design documents that have been generated over the past 3 years within the Ocean Observing Program. The OOI-RSN White Paper documents are being generated by the University of Washington for the JOI division of the Consortium for Ocean Leadership (COL), in part, as preparation for the programmatic Preliminary Design Review (PDR) to be held for the OOI Network in December of 2007 as required by the Major Research Equipment Facilities Construction Fund within NSF. It is our intent that each White Paper will become part of a more comprehensive RSN-oriented set of evaluation documents that will be accessible as the program evolves. Presently planned topical materials include: OOI-RSN WP #1 – The Wet Plant Primary Infrastructure, OOI-RSN WP #2 – The Shore Station Options, and OOI-RSN WP#3 – Wet Plant Secondary Infrastructure. Additional documents will be completed during the year on topics that may include Backhaul, Instrument Availability, Science Requirements, and Engineering Requirements.

1.0 Introduction

The most transformational characteristic of the Ocean Observatories Initiative involves the delivery, throughout the ocean, the seafloor, and the sub-seafloor of unprecedented, sustained levels of electrical power and high bandwidth communications over a volume the size of meso-scale ocean processes, or a tectonic plate (100's of km on a side). Next generation ocean scientists will continue to capitalize on this novel infrastructure to design evolving and innovative sensing modalities, real-time, interactive experiments, and improved approaches to quantifying previously inaccessible processes that unfold rapidly or take decades to occur. Both the ocean and the seafloor are highly dynamic and poorly sampled systems because they are so remote and so difficult to study. The capability envisioned for the RSN components of the OOI Network will allow unprecedented approaches and potentially breakthrough discoveries to take place over temporal and spatial scales that have not been possible using only ships and satellites.

Dependable power, bandwidth and real-time, interactive access to the ocean 24/7/365 for decades will empower ocean scientists in unforeseen ways. Examples of cutting edge scientific investigations that can only be conducted with these new bandwidth and power capabilities include launching clusters of autonomous vehicles to sample and characterize rapidly evolving and energetic events such as turbulent mixing caused by giant storms, erupting underwater volcanoes, major submarine mass wasting events along the continental slope, migratory patterns of marine mammals and fish stocks, assessment of progressive pollution effects, harmful algal blooms and hypoxia, venting associated with subduction zone fault movement and a host of additional processes. At the same time, the evolution of ecogenomic capabilities in the marine environment, the advent of mass spectrometers and gas chromatographs, and the increasingly common use of HDTV to explore and document processes that are otherwise out of reach for humans will be major bandwidth and power consumers.

2.0 Configuration Comparison Approach

This White Paper presents a technical trade-off study of Submarine Cable System configurations for the Regional Scale Cabled Nodes (RSN) of the Ocean Observatories Initiative (OOI) Network, a program overseen by the Joint Oceanographic Institutions, Inc., for the National Science Foundation. These nodes will be installed off the coast of Washington and Oregon at locations spatially coincident with the Juan de Fuca Plate and a suite of meso-scale oceanographic processes that operate in a 300-400-km wide swath that extends from south of Vancouver Island to southern Oregon. The conceptual evolution of this novel ocean research facility over many years has involved numerous scientific reports from community workshops and a number of Conceptual Network Design (CND) efforts. The current Conceptual Network Design is accessible at: http://www.orionprogram.org/PDFs/RevisedOOICND08Mar07.pdf.

The submarine cable system configurations described and compared here could each deliver unprecedented power and bandwidth to a full ocean environment, a capability that is one of the truly transformative components of the OOI. The approach developed over the past ten years of work has been to configure a network of electro-optical cables that will provide multiple Gb/sec bandwidth and considerable, continuous electrical power to the ocean environment in the Northeast Pacific, from boreholes in the seafloor to the air-sea interface.

The purpose of this Study is to evaluate a range of possible configurations for the RSN cable geometry and functionality with the goal of assessing cost, reliability, efficiency and risk. The final decision for the RSN configuration will include factors not taken into account in this study. Those factors may include, but not be limited to, the following: full scientific evaluations involving traceability matrices linking scientific questions posed to measurements empowered by the system design; the location and costs of the shore station(s) required to service the wet plant; the range of secondary infrastructure elements necessary for implementation of the science nodes; the character and style of backhaul; and the costs, timing, scientific and technical requirements of Operations, Administration, and Maintenance (OA&M) for several decades of long-term operations.

Several potential designs are described in this document, but it is important to bear in mind that most of them require some aspect of new technology. Elements of the designs developed for planned systems, such as MARS at MBARI and the Canadian NEPTUNE system, will be explored, as well as variations on the Star geometry developed by the UW RSN Technical Team of P. Barletto, G. Harkins, and M. Kelly. Here we examine nine options from both technical and financial viewpoints, with ramifications for achievable science. It should be noted that a full development of the scientific trade offs for competing node locations is beyond the scope of this White Paper. The required submarine secondary infrastructure will be discussed in a subsequent White Paper

The initial intent of this Study was to evaluate options available to provide for nodes where they were located in the Revised OOI-CND of March 2007, shown in Figure 1. In recent months, however, we were asked by JOI to evaluate two additional options, including 1) a proposal from NEPTUNE Canada to consider a single Canadian landfall for the entire system and which keeps the same primary nodes but cannot accommodate the expansion nodes in the CND, and 2) a recently released recommendation from NSF Program Officers in Ocean Sciences which reduces the cable footprint and changes the locations of the primary and expansion nodes. In this document, our first comparison of alternate geometries is focused on the OOI-CND recommendation, as vetted by the STAC Committee and extensively commented on by the Oceanography Community.

FIG. 1. CONCEPTUAL NETWORK DESIGN OOI REGIONAL SCALE NODES

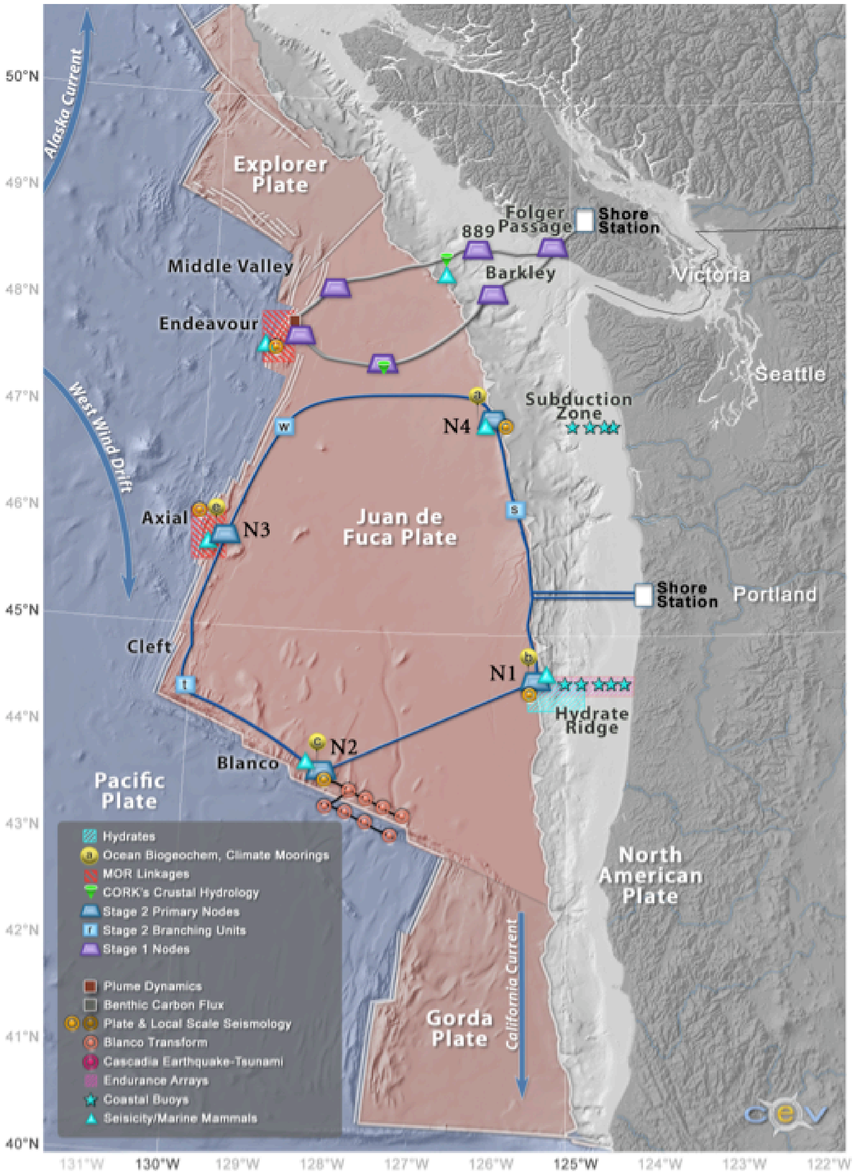


Figure from the March 8, 2007 ORION OOI Conceptual Network Design: A Revised Infrastructure Plan. Regional Cabled Observatory conceptual network design showing Stages I (northern loop, NEPTUNE Canada) and II (OOI Regional Scale Nodes). Stage II includes four primary nodes, three branching units for future expansion, and four cabled full water column moorings with profiling capabilities and a suite of core instruments. Each primary backbone node on Stage II also includes a broadband seismometer, hydrophone, and pressure sensor. Also shown are two coastal sites (blue stars) that are part of the Coastal Scale Observatory's Pacific Northwest Endurance Array. The Coastal Array at Node 1 is connected to the RCO via a cable on the shelf and also includes gliders that will collect measurements across the RCO region; the northern Washington site east of Node 4 includes four stand-alone moorings, two of which are electro-optical (EOM) cabled moorings.

2.1 Methodology and Criteria

Nine different configurations were examined including an alternative configuration identified as a Star configuration; this configuration was first suggested by our group of Industry Experts.

Criteria considered include the following:

- Costs: Unit costs for the various components were gathered from reliable sources and based on the quantities required by each configuration (see Table 1 -- Component Summary). The same unit costs were used for each case.

- Risk: Risk was assigned to each option based on the OOI Cost Estimating Plan (CEP), which develops a contingency allocation from consideration of specific technical, schedule, and cost risk levels. This methodology is further described in Appendix A.

- Functionality: Appendix B looks at the suite of scientific sensors that are likely to be deployed in experiments on the RSN. Two important conclusions from this exercise are 1) that bandwidth in excess of 2.5 Gb/s per node is required to support the likely science and 2) that maximum power will be required early in the OOI network's lifetime. Even now peak loads of 20kw can be envisioned for Axial and Hydrate Ridge Nodes.

- Reliability: The reliability of a system has a significant impact on both operational and maintenance costs and on the availability of the system to provide data to scientists. We consider the relative reliability of the options by looking at the likelihood for faults from external aggression (e.g., landslides, earthquakes, or trawlers) and faults from equipment or component failures.

  Although the RSN cable will, by intent, be going into high risk areas, experience has shown that careful route planning can reduce the system's vulnerability. Historical evidence and recent experience following the Taiwanese earthquake show that cables laid parallel to the fault line had multiple kilometers of cable damaged, moved, or buried in areas prone to submarine landslides; this added significant time and cost to the repair operations. In fact some cable owners did not have enough spare cable on hand. In other historical cases, however, cables laid perpendicular to faulted areas (Guam, Hawaii) have rarely sustained damage or, if damaged, the faulted cable length is relatively small and managed normally.

  Equipment and component faults in the telecom industry are generally guaranteed to require less than three ship repairs in a system's 25-year life. While few systems are ever in service that long, the reliability experience has been very good except in a few notable cases. One way of comparing the relative reliability is by looking at the number of components in the network; more components means lower reliability. New technology, especially that which incorporates significant changes, carries higher risk than established designs and technology.

We considered both of these factors in developing our alternative configurations.

- Availability: In addition to being a function of reliability (above), availability is related to what data are lost in a fault condition and to how long it takes to repair a faulted cable. As with reliability, we can estimate the relative availability of the options.

  Telecom systems present a constant DC power load and are operated at a constant current. During the most common types of faults (shunt faults), voltage can usually be balanced to present a zero potential at the fault. This is critical to stabilizing the system and bringing it back into service while repairs are planned. If the voltage is not balanced to zero potential at the fault, fiber damage can occur as a result of galvanic action. In the RSN configurations, the voltage is constant and the power (and therefore the current) is dynamically changing, making the telecom process of balancing the power to the fault not possible. The inability to balance power in these ring configurations will result in reduced network availability during shunt fault conditions.

  While repairs may be theoretically possible on an in-service ring configuration system based on the branching unit's ability to connect any leg to ocean ground, ship captains are extremely reluctant to risk life and limb undertaking repairs without power being removed from the entire cable. Powered branch repairs have been technically possible in the telecom industry for more than ten years; however, given that telecom cables operate at less than 20% of the RSN's current and almost always less than the RSN's voltage, it is extremely likely that the entire RSN would need to be de-powered during repair operations.

2.2 RSN System Design Options

The nine RSN cable system alternatives are briefly described below.

- Initial Design: The Initial Design configuration is the product of NSF-funded feasibility efforts undertaken by the early NEPTUNE Program, a partnership of several institutions led by the University of Washington. This configuration uses custom designed regenerating nodes in place of standard telecom industry repeaters. Each of the nodes is designed to be capable of supporting scientific sensors. In the past, this Initial Design has also been referred to as the Baseline Design.

- Two Ring Options: Two ring configurations that retain the CND nodes are compared in this white paper. The ring footprint is a loop path close to the periphery of the JdF Plate to allow ready access, over the long term, to three plate margins of high interest. The first configuration is the ring with a single fiber pair and the second is the same footprint ring with multiple fiber pairs. Both Ring configurations examined are essentially identical to NEPTUNE Canada except that we have assumed 10Gb/s wavelengths (vice 2.5Gb/s).

- Four Star Options: We compared four variations of a star configuration in which individual cables are run from shore to each of the primary nodes. Cable distances less than 400 kilometers are assumed to be unrepeatered. The first star configuration has four cables going from shore to the four base nodes in the CND; one of the cables is repeatered. The second star configuration, the expanded star, has seven cables going from shore to enable the base nodes and future expansion to the planned nodes in the CND; three of the cables are repeatered. The third star configuration, the extended star, reaches the three planned nodes via extension cables from the base nodes; one cable is repeatered and power and bandwidth will need to be shared between the base and planned nodes. The final star configuration, uses a mid-plate node (similar to those designed for the Initial Configuration) instead of repeaters in the longest cable leg.

- Canadian Option: The NEPTUNE Canada office proposed merging the four base nodes into the NEPTUNE Canada ring, supported by a single cable station at Port Alberni and by the existing NEPTUNE Canada data management system. Please note that the node at Blanco would be reached by using an extension cable from a mid-plate primary node. Once implemented, this configuration would not be capable of expanding to include any of the planned nodes and would initially be limited to a bandwidth of 2.5G.

- NSF Reduced Coverage Option: The NSF Program Directors proposed a reduced footprint as a way of mitigating the high cost of the RSN system. The evaluation of the NSF Reduced Coverage option presented here is conducted primarily on a technical basis, with the recognition that the feasibility of some science experiments may be curtailed and that it discounts numerous planning documents and workshop reports (e.g., NSF Millennium Report, SCOTS, RECONN, NEPTUNE Pacific Northwest Workshop, ORION San Juan Workshop, D&I Workshop) that supported the location of the base nodes. It is not the intention of this white paper to enter a detailed debate on the science benefits of the alternate node locations. Such a debate will be facilitated through the science traceability matrices which are currently in development.

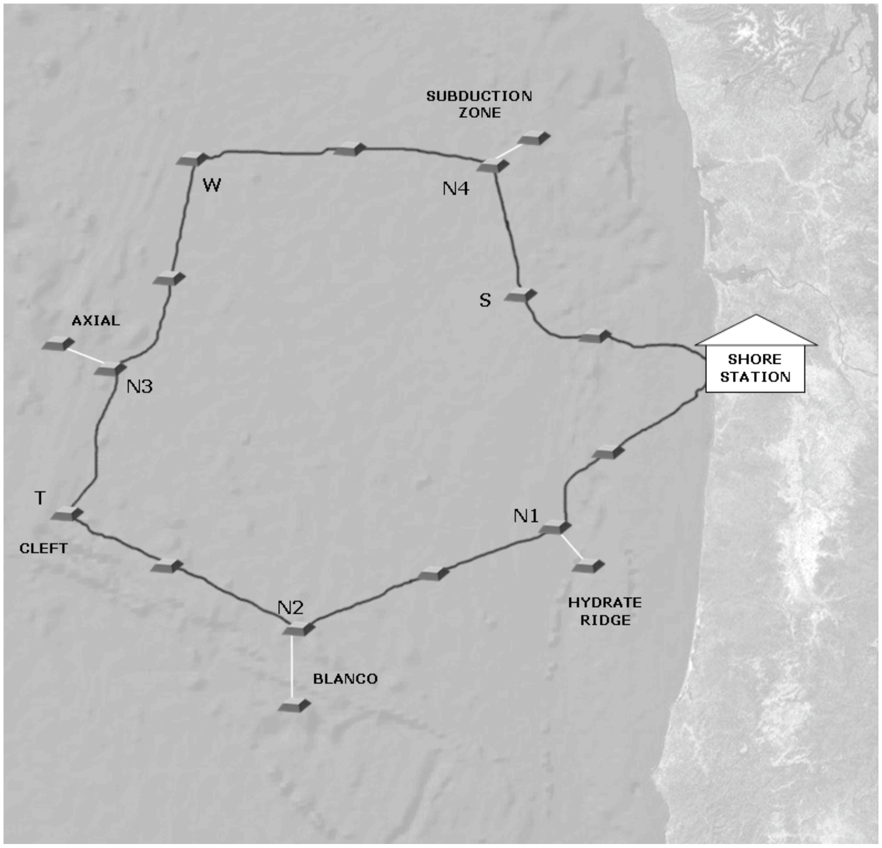
3.0 System Maps and Tables

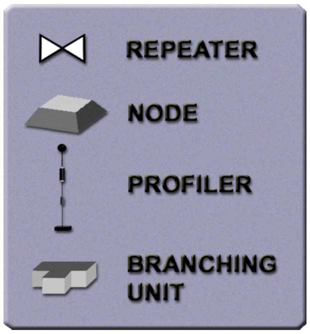
In this section, we present system maps and tables listing positive and negative attributes of each option. In addition, we evaluated the cost, risk factor, budget contingency, and total cost for each configuration. Detailed cost tables are provided for each configuration.

Please note that this document has been modified for public distribution. Cost information is indexed to the single fiber pair ring, which is given a nominal cost of 100% or 100. Cost details have been omitted from the tables, but quantities remain. It is recommended that the reader compare options based upon their risk adjusted cost or total cost along with the other factors.

FIG. 2. INITIAL DESIGN

The Initial Design was a non-telecom non-repeater configuration that relied on nodes located approximately every 100 km. Each node converts the optical backbone signal to an electrical format, filters and routes it to specific sensors and then reconverts it back to optical for transmission to the next node. Power is carried to each of the nodes via a serial DC backbone current.





Legend for all White Paper maps

INITIAL DESIGN	
POSITIVE ATTRIBUTES	**NEGATIVE ATTRIBUTES**
No External Repeaters	Limited Future Bandwidth Expansion beyond 2.5 Gb/s per Node
No External Branching Units	Large DC Current in Ring
Can Accommodate up to 14 Nodes	New & Unique Node Design
Redundant Data Paths	No Proven Reliability Record
Potentially Less Expensive to Build	

INDEXED COST	RISK FACTOR	CONTINGENCY	TOTAL COST
101.25	36%	36.45	137.71

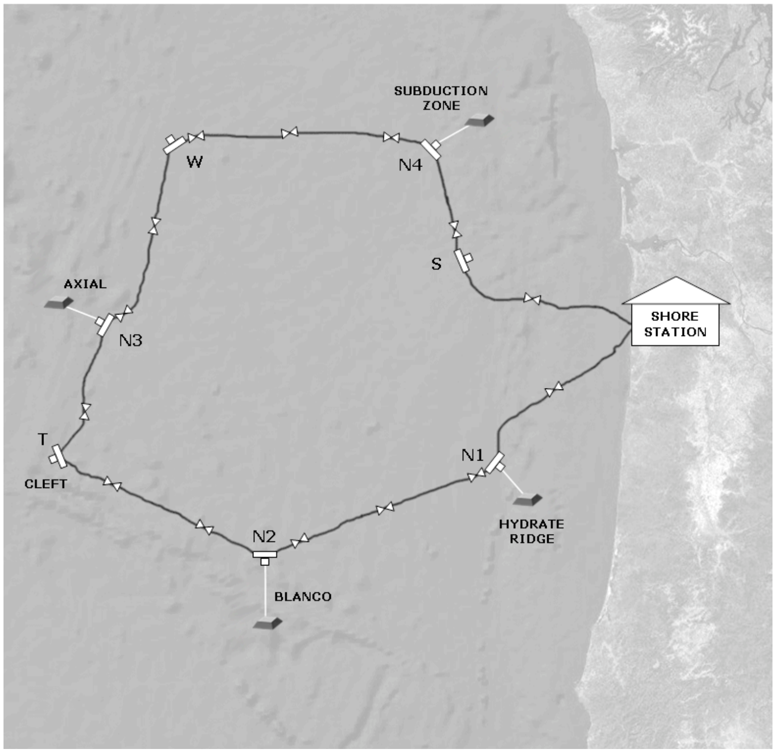
Details on file with JOI

Initial Design

	Unit		Unit Price	Full Price
Equipment Cost				
Landings	2	ea		
Nodes	4	ea		
repeater	10	ea		
Repeaters	0	ea		
BU	0	ea		
Cable	1432	km		
DA	114	km		
SA	0	km		
LWA	136	km		
SPA	405	km		
LW	777	km		
Installation Cost				
Landings	2	ea		
bore pipe	2	ea		
Nodes	13	ea		
Plowing	250	km		
ship	12	days		
tool	250	km		
Surface	1,182	km		
ship	9	days		
Mob/Demob	1	ea		

Assumption: Includes all cable and installation seaward of beach manhole.
Does not include route survey or post lay inspection/burial

FIG. 3. RING CONFIGURATION



The Ring Configuration is the same basic infrastructure as the one chosen for NEPTUNE Canada. It uses standard telecom cable, repeaters and modified branching units to deliver power and optical bandwidth to a set of primary nodes. The Ring system requires optical repeaters approximately every 60 km. The system uses multiple wavelengths carried on a single pair of optical fibers. An OADM drops single wavelengths to each Node. WDM equipment is used to handle optical wave management. Power is carried to each of the nodes via a serial DC backbone current.

RING CONFIGURATION	
POSITIVE ATTRIBUTES	**NEGATIVE ATTRIBUTES**
Redundant Data Paths	No Backup Fiber in Cable
Standard Telecom Cable	Large Non-Standard DC Cable Current
Standard Telecom Repeaters	WDM Equipment Required
Bandwidth Available @ 10 Gb/s per Node	OADMs Required in Node
	Bandwidth Limited w/o Major Modification
	Repair may affect all Nodes

INDEXED COST	**RISK FACTOR**	**CONTINGENCY**	**TOTAL COST**
100	**27%**	**27**	**127**

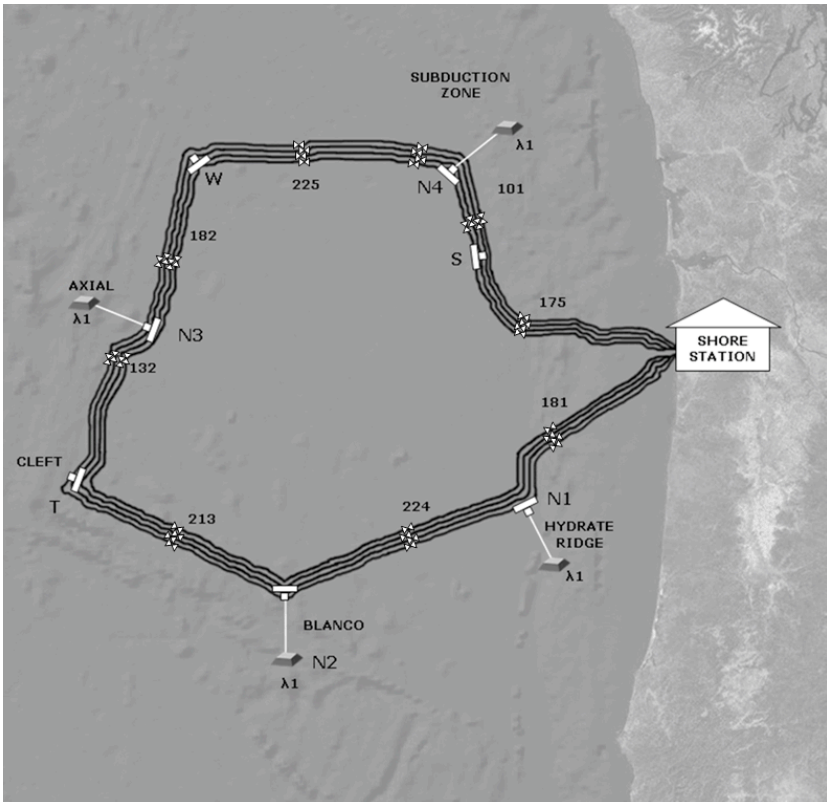
Details on file with JOI

Ring Configuration

		Unit		Unit Price	Full Price
Equipment Cost					
Landings		2	ea		
Nodes		4	ea		
Repeaters		24	ea		
BU		7	ea		
Cable		1432	km		
	DA	114	km		
	SA	0	km		
	LWA	136	km		
	SPA	405	km		
	LW	777	km		
Installation Cost					
Landings		2	ea		
	bore pipe	2	ea		
Nodes		4	ea		
Plowing		250	km		
	ship	12	days		
	tool	250	km		
Surface		1,182	km		
	ship	9	days		
Mob/Demob		1	ea		

Assumption: Includes all cable and installation seaward of beach manhole. Does not include route survey or post lay inspection/burial

FIG. 4. MULTIPLE FIBER RING CONFIGURATION



The Multiple Fiber Ring Configuration uses individual fiber pairs to connect to each of the primary nodes. The topology uses standard telecom cable, repeaters and branching units to deliver power and optical bandwidth to these nodes. The system requires optical repeaters approximately every 60 km. The design is built upon each fiber pair carrying a single optical wavelength to the attached node. WDM and OADM equipment are not required. The three future node locations will require bandwidth sharing with the original 4 nodes. Power is carried to each of the nodes via a serial DC backbone current.

MULTIPLE FIBER RING CONFIGURATION	
POSITIVE ATTRIBUTES	**NEGATIVE ATTRIBUTES**
Redundant Data Paths	Large Non-Standard DC Cable Current
Standard Telecom Cable	Bandwidth Limited w/o Major Modification
Standard Telecom Repeaters	Repeaters Require Multiple Amplifiers
No WDM Equipment Required	Expansion could require System Modification to wet plant – BU-OADM and Nodes
Bandwidth Available @ 10 Gb/s per Node	Repair may affect all Nodes

COST	RISK FACTOR	CONTINGENCY	TOTAL COST
128.94	**27%**	**34.81**	**163.76**

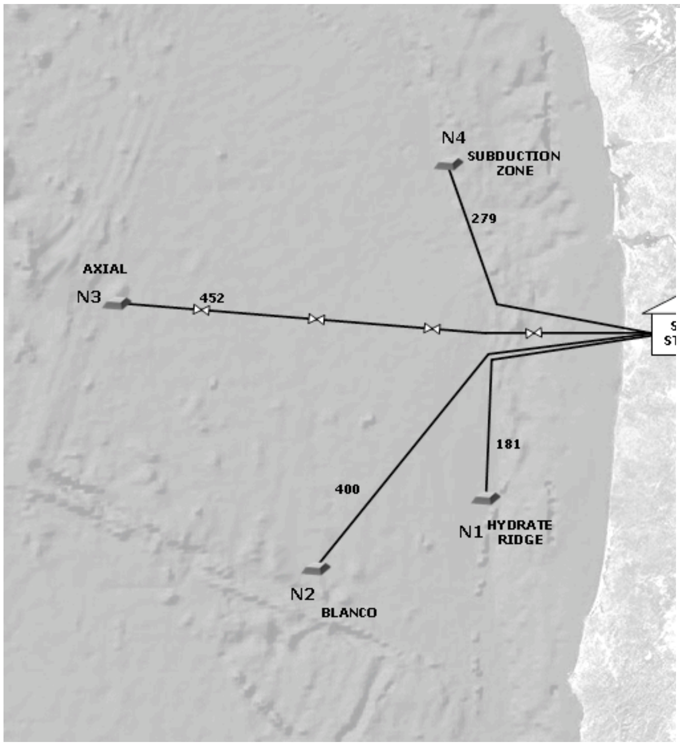
Details on file with JOI

Ring Multi Fiber Configuration

		Unit		Unit Price	Full Price
Equipment Cost					
Landings		2	ea		
Nodes		4	ea		
Repeaters		24	ea		
BU		7	ea		
Cable		1432	km		
	DA	114	km		
	SA	0	km		
	LWA	136	km		
	SPA	405	km		
	LW	777	km		
Installation Cost					
Landings		2	ea		
	bore pipe	2	ea		
Nodes		4	ea		
Plowing		250	km		
	ship	12	days		
	tool	250	km		
Surface		1,182	km		
	ship	9	days		
Mob/Demob		1	ea		

Assumption: Includes all cable and installation seaward of beach manhole. Does not include route survey or post lay inspection/burial

FIG. 5. STAR CONFIGURATION



The Star Configuration utilizes individual cables running from the shore station to each of the four required nodes. A single wavelength is carried to each node. All cable lengths 400 km or less utilize repeaterless technology. The nodes are connected directly to the end of the cable segments.

STAR CONFIGURATION	
POSITIVE ATTRIBUTES	**NEGATIVE ATTRIBUTES**
Small Number of Telecom Repeaters	No Data Path Redundancy
No Telecom Branching Units	Multiple Shore Cable Landings
No OADM’s	No Coverage of Future Nodes
No WDM Equipment	Covers More Fishing Grounds
No Large DC Ring Current	Potential Permit Issues
Lower FIT Rates – Higher Availability	

INDEXED COST	RISK FACTOR	CONTINGENCY	TOTAL COST
89.06	**23%**	**20.48**	**109.54**

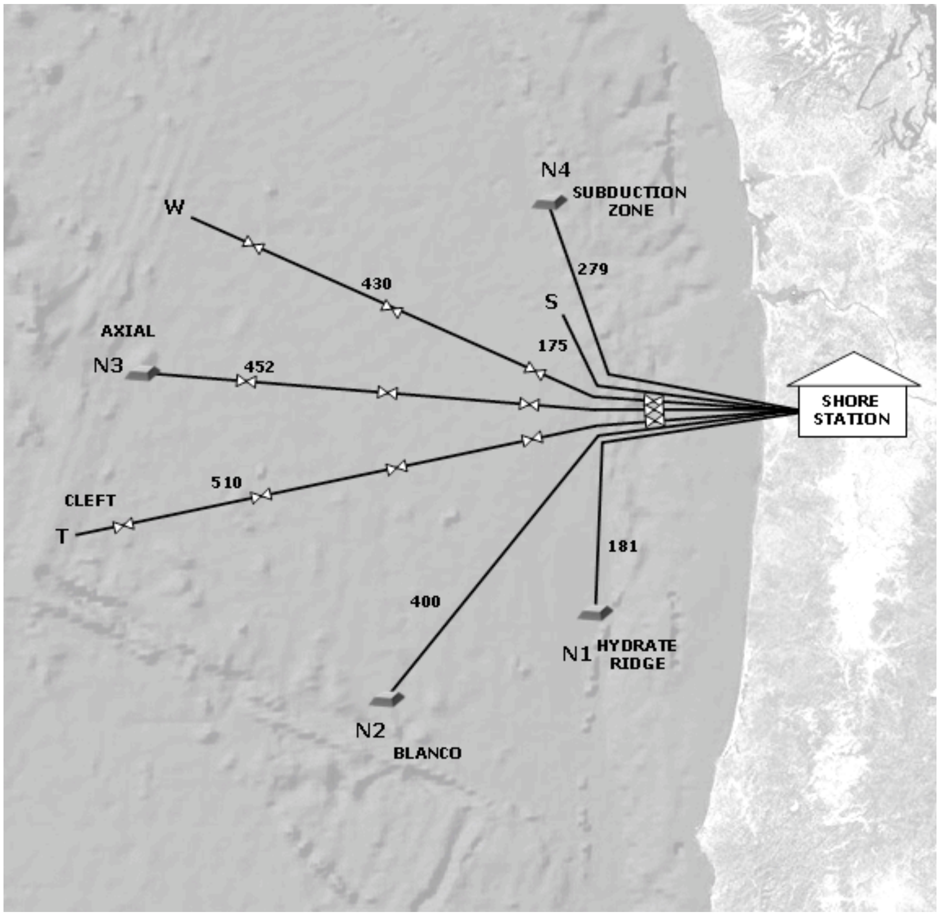
Details on file with JOI

Star Configuration

		Unit		Unit Price	Full Price
Equipment Cost					
Landings		4	ea		
Nodes		5	ea		
Repeaters		0	ea		
BU		0	ea		
Cable		1312	km		
	DA	228	km		
	SA	0	km		
	LWA	272	km		
	SPA	405	km		
	LW	407	km		
Installation Cost					
Landings		4	ea		
	bore pipe	4	ea		
Nodes		4	ea		
Plowing		500	km		
	ship	23	days		
	tool	500	km		
Surface		812	km		
	ship	6	days		
Mob/Demob		1	ea		

Assumption: Includes all cable and installation seaward of beach manhole. Does not include route survey or post lay inspection/burial

FIG. 6. EXPANDED STAR CONFIGURATION



The Expanded Star Configuration uses individual cables running from the shore station to each of the required nodes as well as the three future nodes. Single wavelengths are carried to each node. All cable lengths 400 km or less use repeaterless technology. The nodes are connected directly to the end of the cable segments.

EXPANDED STAR CONFIGURATION	
POSITIVE ATTRIBUTES	**NEGATIVE ATTRIBUTES**
Small Number of Telecom Repeaters	No Data Path Redundancy
No Telecom Branching Units	Multiple Shore Cable Landings
No OADMs	Large Amount of Cable Required
No WDM Equipment	No Back-up Fibers in Cable
No Large DC Ring Current	
Lower FIT Rates – Higher Availability	
Bandwidth Available @ 10 Gb/s per Node	

INDEXED COST	RISK FACTOR	CONTINGENCY	TOTAL COST
154.23	**23%**	**35.47**	**189.70**

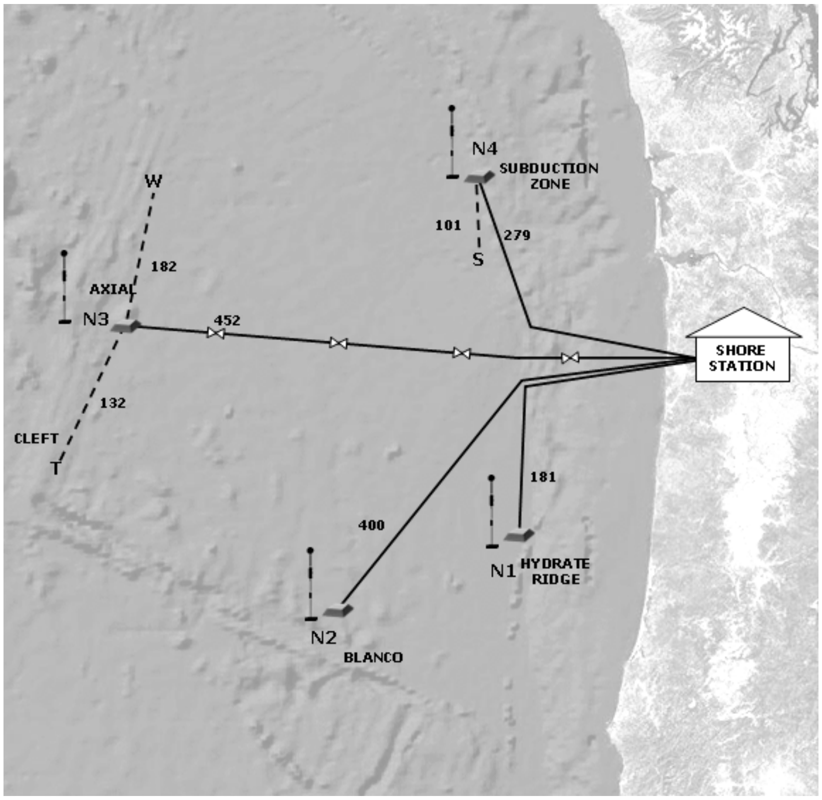
Details on file with JOI

Expanded Star Configuration

		Unit		Unit Price	Full Price
Equipment Cost					
Landings		7	ea		
Nodes		4	ea		
Repeaters		24	ea		
BU		0	ea		
Cable		2427	km		
	DA	415	km		
	SA	0	km		
	LWA	460	km		
	SPA	505	km		
	LW	1047	km		
Installation Cost					
Landings		7	ea		
	bore pipe	7	ea		
Nodes		4	ea		
Plowing		875	km		
	ship	41	days		
	tool	875	km		
Surface		1,552	km		
	ship	12	days		
Mob/Demob		1	ea		

Assumption: Includes all cable and installation seaward of beach manhole. Does not include route survey or post lay inspection/burial

FIG. 7. EXTENDED STAR CONFIGURATION



The Extended Star Configuration is designed to extend the Star to the four required nodes as well as to the three future node locations. This configuration uses individual cables running from the shore station to each of the required nodes. The three future nodes are then reached by using extension cables from one of the primary nodes. All cable lengths of 400 km or less use repeaterless technology.

EXTENDED STAR CONFIGURATION	
POSITIVE ATTRIBUTES	**NEGATIVE ATTRIBUTES**
Small Number of Telecom Repeaters	No Data Path Redundancy
No Telecom Branching Units	Multiple Shore Cable Landings
No OADMs	Large Amount of Cable Required
No WDM Equipment	Bandwidth and Power To Extended Nodes Must be Shared with Primary Node
No Large DC Ring Current	No Back-up Fiber in Cable
Lower FIT Rates – Higher Availability	
Bandwidth Available @ 10 Gb/s per Node	

INDEXED COST	RISK FACTOR	CONTINGENCY	TOTAL COST
98.91	**23%**	**22.75**	**121.65**

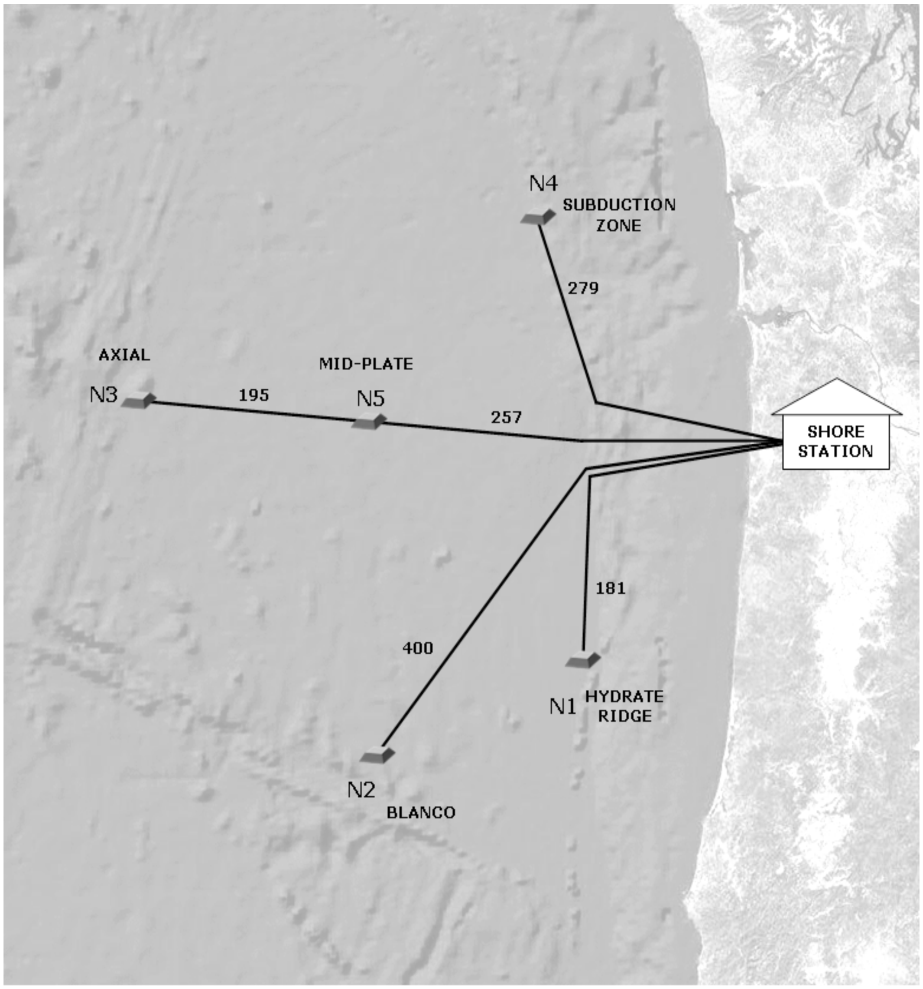
Details on file with JOI

Extended Star Configuration

		Unit		Unit Price	Full Price
Equipment Cost					
Landings		4	ea		
Nodes		4	ea		
Repeaters		8	ea		
BU		0	ea		
Cable		1727	km		
	DA	228	km		
	SA	0	km		
	LWA	272	km		
	SPA	405	km		
	LW	822	km		
Installation Cost					
Landings		4	ea		
	bore pipe	4	ea		
Nodes		4	ea		
Plowing		500	km		
	ship	23	days		
	tool	500	km		
Surface		1,227	km		
	ship	9	days		
Mob/Demob		1	ea		

Assumption: Includes all cable and installation seaward of beach manhole. Does not include route survey or post lay inspection/burial

FIG. 8. MP STAR CONFIGURATION



The Star Configuration uses individual cables running from the shore station to each of the four required nodes as outlined in the CND. A single wavelength is carried to each node. The addition of a mid-plate node means that all cable lengths are possible without telecom repeaters. All nodes, except N5 are connected directly to the end of the cable segments. The addition of N5 is comparable in cost to that of four repeaters (which would be required if N5 was not included) and allows high priority science at mid-plate to be addressed.

STAR CONFIGURATION	
POSITIVE ATTRIBUTES	**NEGATIVE ATTRIBUTES**
No Telecom Repeaters	No Data Path Redundancy
No Telecom Branching Units	Multiple Shore Cable Landings
No OADMs	No Coverage of Future Nodes
No WDM Equipment	No Back-up Fibers in Cable
No Large DC Ring Current	
Lower FIT Rates – Higher Availability	
Bandwidth Available @ 10 Gb/s per Node	
Addition of a Fifth Node at Mid-Plate	

INDEXED COST	RISK FACTOR	CONTINGENCY	TOTAL COST
89.40	**23%**	**20.56**	**109.97**

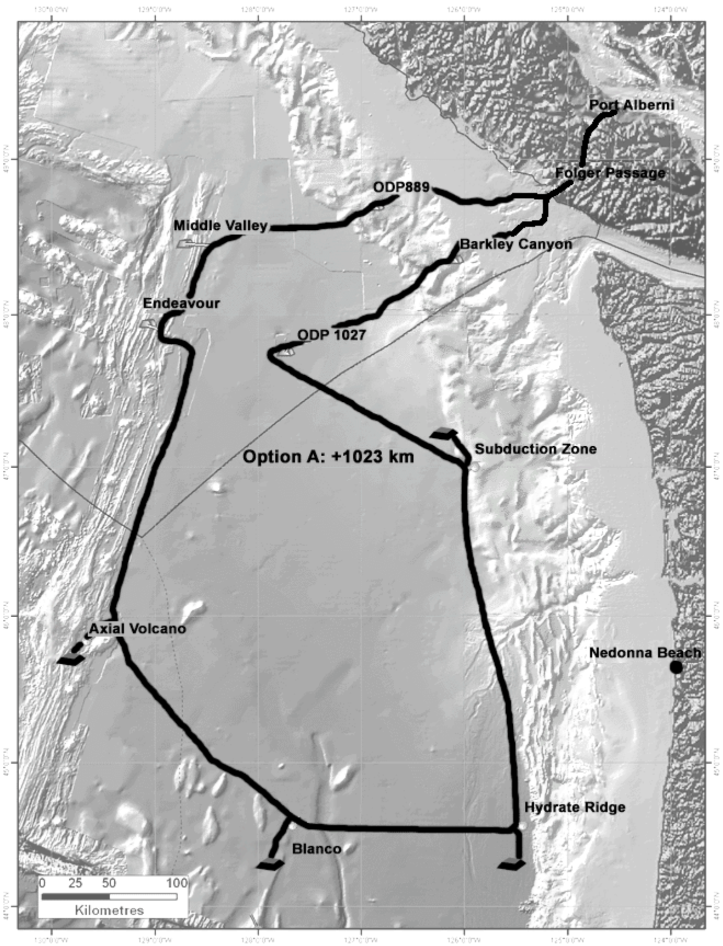
Details on file with JOI

Star Configuration

		Unit		Unit Price	Full Price
Equipment Cost					
Landings		4	ea		
Nodes		5	ea		
Repeaters		0	ea		
BU		0	ea		
Cable		1312	km		
	DA	228	km		
	SA	0	km		
	LWA	272	km		
	SPA	405	km		
	LW	407	km		
Installation Cost					
Landings		4	ea		
	bore pipe	4	ea		
Nodes		5	ea		
Plowing		500	km		
	ship	23	days		
	tool	500	km		
Surface		812	km		
	ship	6	days		
Mob/Demob		1	ea		

Assumption: Includes all cable and installation seaward of beach manhole. Does not include route survey or post lay inspection/burial

FIG. 9. CANADIAN OPTION



The Canadian Option eliminates the RSN shore station and cable landing by extending the NEPTUNE Canada system to include all of the base nodes of the RSN. An ~ 90 km extension cable would need to be run from the mid-plate to the Blanco Fracture Zone in this configuration.

POSITIVE ATTRIBUTES	NEGATIVE ATTRIBUTES
No New Shore Station	No further expansion possible beyond 10 nodes and 8 amperes of power
No New Cable Landings	No Possible Coverage For 3 Future Nodes
Standard Telecom Cable	Cable Length At Upper Bounds of Capability
Standard Telecom Repeaters	Repair may affect all Nodes
	2.5 Gb/s per Node & Limited Future Bandwidth Capability
	Does not extend to Blanco Fracture Zone

INDEXED COST*	RISK FACTOR	CONTINGENCY	TOTAL COST
58.42	**27%**	**15.77**	**74.199**

* Includes some, but not all, savings resulting from a single shore station.

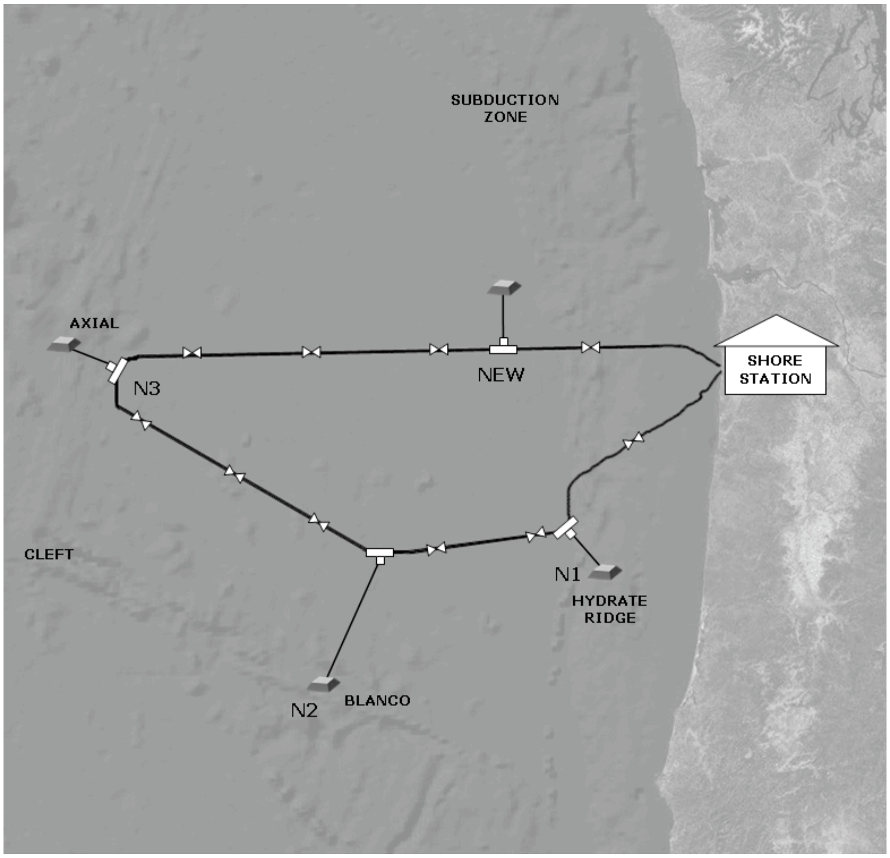
Details on file with JOI

Canadian Option

	Unit		Unit Price	Full Price
Equipment Cost				
Landings	0	ea		
Nodes	4	ea		
Repeaters	10	ea		
BU	7	ea		
Cable	1023	km		
DA	0	km		
SA	0	km		
LWA	0	km		
SPA	247	km		
LW	776	km		
Installation Cost				
Landings	0	ea		
bore pipe	0	ea		
Nodes	4	ea		
Plowing	0	km		
ship	0	days		
tool	0	km		
Surface	1,023	km		
ship	8	days		
Mob/Demob	1	ea		

Assumption: Includes all cable and installation seaward of beach manhole.
Does not include route survey or post lay inspection/burial

FIG. 10. REDUCED COVERAGE OPTION



The Reduced Coverage Option is a reduced-size Ring topology that requires the most northern node to be moved to the south, removing a connection to the CSN Washington array. In addition the connectivity to Blanco is reduced to an extension cable. This option is designed to reduce the total required cable length.

REDUCED COVERAGE OPTION	
POSITIVE ATTRIBUTES	**NEGATIVE ATTRIBUTES**
Reduced Cable Length	No Coverage of Washington Coastal Array
Standard Telecom Cable	Does not extend to Blanco Fracture Zone
Standard Telecom Repeaters	No Backup Fiber in Cable
Bandwidth Available @ 10 Gb/s per Node	Large Non-Standard DC Cable Current
	WDM Equipment Required
	OADM Required in Node
	Bandwidth Limited w/o Major Modification
	No Coverage of Three Planned Expansion Nodes
	Repair may affect all Nodes

INDEXED COST	RISK FACTOR	CONTINGENCY	TOTAL COST
82.41	**27%**	**22.25**	**104.66**

Details on file with JOI

Reduced Coverage Configuration

		Unit		Unit Price	Full Price
Equipment Cost					
Landings		2	ea		
Nodes		4	ea		
Repeaters		17	ea		
BU		4	ea		
Cable		1010	km		
	DA	114	km		
	SA	0	km		
	LWA	136	km		
	SPA	305	km		
	LW	455	km		
Installation Cost					
Landings		2	ea		
	bore pipe	2	ea		
Nodes		4	ea		
Plowing		250	km		
	ship	12	days		
	tool	250	km		
Surface		760	km		
	ship	6	days		
Mob/Demob		1	ea		

Assumption: Includes all cable and installation seaward of beach manhole. Does not include route survey or post lay inspection/burial

4.0 Analysis and Comparison of Configuration Options

Table 1 summarizes the main components required for each of the submarine cable system configurations. The table does not distinguish differences in types of cables or nodes but does attempt to show the reader quantities of each type of item that the different options will require. As discussed earlier, in general, the more components in an option, the lower the reliability. Hence this chart gives us a means of assessing the relative reliability of each option.

Table 1. COMPONENT SUMMARY

SYSTEM	CABLE	REPEATERS	BRU	PRIMARY NODES	SECONDARY NODES	CABLES TO SHORE
PRELIMINARY DESIGN	1432	0	0	14	4	2
RING CONFIGURATION	1432	24	7	4	4	2
MULTIPLE FIBER RING	1432	24	7	4	4	2
STAR CONFIGURATION	1312	4	4	5	4	4
EXPANDED STAR	2427	24	0	4	4	7
EXTENDED STAR	1727	8	0	4	4	4
MID PLATE STAR	1312	0	0	5	4	4
REDUCED COVERAGE	1010	17	4	4	4	2
CANADIAN OPTION	1023	10	7	4	4	0

Table 2 shows the risk level and percentages used to calculate the risk factor for each configuration. Appendix A describes the methodology for the assignment of risk levels. Table 2 allows us to assess the relative risk associated with each option.

Table 2. RISK SUMMARY

SYSTEM	TECHNICAL	COST	SCHEDULE	RISK
PRELIMINARY DESIGN	10*2%	8*1%	8*1%	36%
RING CONFIGURATION	8*2%	3*1%	8*1%	27%
MULTIPLE FIBER RING	8*2%	3*1%	8*1%	27%
STAR CONFIGURATION	6*2%	3*1%	8*1%	23%
EXPANDED STAR	6*2%	3*1%	8*1%	23%
EXTENDED STAR	6*2%	3*1%	8*1%	23%
MID PLATE STAR	6*2%	3*1%	8*1%	23%
REDUCED COVERAGE	8*2%	3*1%	8*1%	27%
CANADIAN OPTION	8*2%	3*1%	8*1%	27%

Table 3 provides a summary overview of many of the factors discussed in this document.

Table 3. Summary of Topologies, Infrastructure and Science Strengths and Weaknesses for the Regional Scale Nodes

Configuration	Infrastructure	Backbone Nodes	Expansion Nodes	Power Node	Bandwidth Node	Engineering Positive Attributes	Engineering Negative Attributes	Science Strengths	Science Weaknesses	Indexed Cost	Risk Factor	Grand Total
Ring Preliminary Design† March 8, 2007	Non-telecom, non repeater configuration, nodes ~ 100 km-optical backbone to electrical, *BU's connect primary nodes to backbone; primary nodes branch off of backbone	Hydrate Ridge, Blanco, Axial, Subduction Zone	T(Cleft-West Blanco); W(Cobb Segment); S(Central Subduction)		2.5 Gb/s	•No External Repeaters •No External BU's •Very Easy Node Expansion •Redundant Data Paths •Potentially less expensive to build	•Limited future bandwidth expansion •Large DC current in ring •New & unique design •No proven reliability record	Allows all 10 of the regional plate scale science drivers to be addressed and allows future expansion to sites outlined as high priority in the RFA process (e.g. Cleft and Western Blanco).	The footprint of secondary infrastructure is substantially reduced from that of the June 19th, CND. This results in a significant loss in water column science and access to other high priority interdisciplinary areas of interest (see Recommendation for Changes STAC document 12-01-06).	101.25	36%	137.71
Ring¥	Same configuration as NEPTUNE Canada, standard telecom cable, repeaters and modified BU's, optical to primary nodes, optical repeaters ~ 100 km, single pair optical fibers, serial DC backbone current; 2.5 Gb/s with some expansion capabilities	Hydrate Ridge, Blanco, Axial, Subduction Zone	T(Cleft-West Blanco); W(Cobb Segment); S(Central Subduction)	: 8- 10 kw Not upgradeable	: 10Gb/s May be upgradeable (Analysis of initial repeater spacing and optical loss budgets required. Upgrade costs could range between ~$10m and $50M)	•Redundant data paths •Standard telecom cable •Standard telecom repeaters	•No backup fiber in cable •Large 8 ampere non-standard DC cable current •WDM equipment required •OADM's required in BU and node •Bandwidth limited w/o major modification •Repair activity may affect all nodes	Allows all 10 of the regional plate scale science drivers to be addressed and allows future expansion to sites outlined as high priority (e.g. Cleft and Western Blanco).	The possible restriction in power to each node may mean a limitation to the number and types of sensors that could be on the cable in the 5-year time range. Limited power will likely be restrictive: Raman, cytometers, , mass spec systems use 500-1 kw ea at up to ~0.5 Gb/s.	100	27%	127
Multiple Fiber Ring	Four individual fiber pairs; standard telecom configuration, Each fiber pair carries a single optical wave length to node	Hydrate Ridge, Blanco, Axial, Subduction Zone	T(Cleft-West Blanco); W(Cobb Segment); S(Central Subduction)	8-10kw	10Gb/s May be upgradeable, either with 40Gb/s wavelengths or WDM. Analysis of optical loss required. Costs could be $10M and up.	•Redundant data paths •Standard telecom cable •Standard telecom repeaters No WDM equipment required	•Large 8 ampere non-standard DC cable current •Bandwidth limited w/o major modification •More expensive cable •Repeaters require multiple amplifiers •Expansion requires system modification •Repair activity may impact all nodes	Allows all 10 of the regional plate scale science drivers to be addressed and allows future expansion to sites outlined as high (e.g. Cleft and Western Blanco). Increased fiber pairs provide significant bandwidth for data intensive, high resolution sensors such as HD video, mass specs, gas chromatographs, ADCPs, hydrophones etc.	The possible restriction in power to each node may mean a limitation to the number and types of sensors that could be on the cable in the 5 year time range.	128.94	27%	163.76
Basic Star††	Four individual cables from shore station to each node, single wavelength to each node, all but one cables repeaterless, nodes connected directly to cable terminus	Hydrate Ridge, Blanco, Axial, Subduction Zone	**Either Extended or Expanded version (below)**	10kw expandable to 80kw per segment	10 X Gig E Upgradeable at a cost of ~ $1M/node as needed.	•Small number telecom repeaters •No telecom BU's •No OADM's •No WDM equipment •No large DC ring current •Lower FIT rates, higher availability	•No data path redundancy •Multiple shore cable landings Future Nodes require cable extensions	Provides maximum current to ea. node; bandwidth is not shared with other nodes. These two attributes will allow data and power intensive experiments to be conducted that include HD transmission, multiple acoustic experiments**, event response capabilities, mass specs, gas chromatographs, ADCPs, hydrophones, extensive experiments on moorings.	Future expansion to Nodes T, W, and S would require a topology similar to the *extended star* configuration (see below).	89.06	23%	109.54
Mid-Plate Star††	Four individual cables from shore station to each node, single wavelength to each node, all cables repeaterless, nodes connected directly to cable terminus with exception of mid-plate node	Hydrate Ridge, Blanco, Axial, Subduction Zone	**Either Extended or Expanded version (below)**	10kw expandable to 80kw per segment	10 X Gig E Upgradeable at a cost of ~ $1M/node as needed.	•No telecom repeaters •No telecom BU's •No OADM's •No WDM equipment •No large DC ring current •Lower FIT rates, higher availability	•No data path redundancy •Multiple shore cable landings Future Nodes require cable extensions	Provides maximum current to ea. node; bandwidth is not shared with other nodes. These two attributes will allow data and power intensive experiments to be conducted that include HD transmission, multiple acoustic experiments**, event response capabilities, mass specs, gas chromatographs, ADCPs, hydrophones, extensive experiments on moorings.	Future expansion to Nodes T, W, and S would require a topology similar to the *extended star* configuration (see below).	89.40	23%	109.96
Expanded Star	Same as Star but includes the addition of three other cables that run fro the Shore station to BU;s T, W, S	Hydrate Ridge, Blanco, Axial, Subduction Zone	T(Cleft-West Blanco); W(Cobb Segment); S(Central Subduction)	10kw expandable to 80kw per segment	10 X Gig E Upgradeable at a cost of ~ $1M/node as needed	•Small # of telecom repeaters •No telecom BU's •No OADM's •No WDM equipment •No large DC ring current •Lower FIT rates, higher availability	•No data path redundancy •Multiple shore cable landings •Larger amount of cable required	Reaches many sites outlined as high priority (Juan de Fuca Ridge, accretionary margin). Provides maximum current to each node; bandwidth is not shared among other nodes. In concert these two attributes will allow data and power intensive experiments to be conducted that include HD transmission, multiple acoustic experiments**, event response capabilities, mass specs, gas chromatographs, ADCPs, hydrophones, extensive experiments on moorings.	To reach western Blanco would require an extension cable from Cleft. Note: this configuration includes cable to S, T and W but not primary nodes.	154.23	23%	189.70
Extended Star	Utilizes *Star* configuration but includes expansion cables from the four primary nodes to the three BU's	Hydrate Ridge, Blanco, Axial, Subduction Zone	T(Cleft-West Blanco); W(Cobb Segment); S(Central Subduction)	10kw expandable to 80kw per segment	10 X Gig E Upgradeable at a cost of ~ $1M/node as needed	•Small # of telecom repeaters •No telecom BU's •No OADM's •No WDM equipment •No large DC ring current •Lower FIT rates, higher availability	•No data path redundancy •Multiple shore cable landings •Large amount of cable required •Bandwidth and power to extended nodes is shared with primary node	Allows nearly all 10 of the regional plate scale science drivers to be addressed with accesses to expansion sites outlined as high priority. Provides maximum current to each node; bandwidth is not shared among other nodes. These two attributes will allow data and power intensive experiments to be conducted that include HD transmission, multiple acoustic experiments**, event response capabilities, mass specs, gas chromatographs, ADCPs, hydrophones, extensive experiments on moorings.	To reach western Blanco would require an extension cable from Cleft.	98.91	23%	121.65
Canadian Option	Expanded *Ring* topology that connects NEPTUNE Canada system to four primary nodes on US portion of the system	Hydrate Ridge, Blanco, Axial, Subduction Zone, Endeavour, ODP 1027, 889, Folgers Passage, Barkley Canyon	--------	8 – 10kw Not upgradeable	2 X Gig E May be upgradeable (Same as Ring above)	•No new shore station •No new cable landings •Standard telecom cable •Standard telecom repeaters	•Four required nodes maximizes system •No possible expansion to 3 Nodes •Cable length at upper bounds •Limited number of future Secondary nodes •Limited future bandwidth capability •No shore station redundancy •Higher probability of double faults •Repair activity may affect all nodes •Significant extension cable to Blanco (90 km ~$2M) & MVBN ($1.5M)	Allows all 10 of the regional plate scale science drivers to be addressed. Topology allows some science at each of the Canada NEPTUNE nodes and Regional Scale Nodes; maintains concept of "plate scale experiment".	Serial current to each node on ring and loss in long cable runs means each node would likely supply ~ < 10 kw. There may not be enough power to drive moorings and other sensors nor allow event response capabilities. Backbone does not reach Blanco and would require additional infrastructure to reach it. Unclear if there is enough power to reach Blanco, which maybe why the ring passes through the mid plate node. System is maximized - future science expansion for power is not possible & bandwidth is expensive	58.42	27%	74.20
NSF Reduced Coverage with Four Water Column Moorings	Ring topology with reduced footprint, connectivity to Blanco is an extension cable	Hydrate Ridge, Blanco, Axial, Mid-Plate Node	--------	8-10kw	10Gb/s May be Upgradeable	•Reduced cable length •Standard telecom cable •Standard telecom repeaters	•No coverage to Washington CSN •No redundancy of Blanco extension •No backup fiber in cable •Large non-standard DC cable current • WDM equipment required •OADM's required in node •Bandwidth limited w/o major modification •No coverage of T,W,S Node's •Repair activity may affect all nodes	Topology allows high priority science at Hydrate, Mid-Plate, Axial and Blanco.	No deepwater & offshore connection to the WA coastal array and loss of instrumentation at gravity low for investigation of earthquake propagation. Possible restriction in power to each node may mean a limitation to the number and types of sensors that could be on the cable in the 5 year time range. Limited bandwidth may also be restrictive.	82.41	27%	104.66

**BU = branching units; WDM= wave division multiplexing is a technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths (colors) of laser light to carry different signals; OADM = is an optical add/drop multiplexer. This is a device used in wavelength-division multiplexing systems for multiplexing and routing different channels of light into or out of a single mode fiber (SMF). This is a type of optical node, which is generally used for the construction of a ring-based optical telecommunications network); FIT rates = failure in time; MVBN = medium voltage benthic node*

†Final OOI Conceptual Design Review Report September8, 2006 (page 39) notes "that the present conceptual design is currently the minimum required to satisfy the ten regional plate scale science drivers"

*¥Ring Topology: Alcatel system's requirement was to supply 10 kw to each of the nodes starting with 10 kv at the shore station. A serial current will then flow around the Ring supplying power to each node. Submarine telecom systems normally only carry 0.5-1.0 amps through their repeaters to power the electronics. To run a much higher current through the ring is a new scenario and there is a worry about how high that serial current can go without damaging the repeaters. Alcatel is hoping to run 8-10 amps through the ring without hurting the system. With a maximum of 10 amps split between 10 nodes that leaves total possible power to each node at 1 amp * 10 kv or 10 kW per node-voltage drop in the cable so each node would supply something less then 10 kw to the sensor string attached to it.*

††Star Topology: The maximum current restriction for the Star topology is unknown. The only limitation to the amount of power at a node is that the voltage applied to the node be at least 5 kv. This is the minimum voltage that the power converter is designed to handle. The longest cable run proposed is ~500 km. With a nominal impedance of 1 ohm/km and a starting source voltage of 10 kv, 10 amps could be carried on each of the cables with a loss of only 5kv in cable drop. This would provide each node with 10 amps at 5 kv (10kv-5kv = 5kv) or 50 kw at each node = five times what a node on the ring could produce.

***A single acoustic sensor now in operation has 100 elements and each element samples at ~100 khz with a 16 bit converter. This would produce a bandwidth of 160 Mbits/Sec. For a 1 GBit data path composed of asynchronous sources, it should be anticipated that a realistic useable bandwidth is 600-700 Mbits/Sec. Thus, this one acoustic sensor could take up 20-25% of the channel. It is anticipated that both Axial and Hydrate Ridge will have high definition (HD) video and digital still cameras. Current HD cameras transmit at 1.5 Gb/s and digital images are saved at 75 Mb each. HD cameras record at 30 frames/sec. When these cameras are in operation, data rates for most other components on the network will need to be reduced. There will also be a need for HD stereo (3 Gb/s) for biological and measurement of temporal evolution of vent structures. HD stereo will allow microbathymetric analyses to be completed at the sub centimeter scale; compression of HD will result in a loss of resolution.*

Discussion of Configurations

Initial Design: The Initial Design Configuration uses the same amount of cable as the Ring Configurations, but introduces the need for a node design that also serves as a repeater in the backbone. This eliminates the need for branching units and ultimately will allow the "repeater nodes" to become science nodes. The uniqueness of this approach does not allow reliance on proven submarine cable technology with its known reliability experience. Its high cost does not make this an attractive option when only the CND base nodes are being used.

Ring and Star Discussion: Both the Ring and the Star Configurations have the capability of handling the current bandwidth and power requirements for the RSN Nodes. In addition, the proposed implementation for the Star Configuration will add a mid-plate science node with minimal cost impact.

The basic Star Configuration requires less cable than the Ring configurations. However, the reduction in cable quantity is offset by the need for more armored cable and installation time for the additional shore landings. However, the Star configuration's direct link to each node results in far fewer expensive components (repeaters, BUs, and OADMs). The cost of these additional components in the Ring overshadows the additional cost for armored cable and cable landings. The base cost for the single fiber pair Ring structure comes in slightly higher than the base cost of the simple Star structure. The Star configuration may also offer a potential commercial advantage in that a greater number of bidders would be able to offer existing standard products to fulfill the requirements.

This additional cost for the mid-plate node which will provide signal regeneration is mostly covered in lieu of four telecom repeaters that would be required to reach Axial Seamount. (Telecom repeaters amplify the signal rather than regenerating the signal; this requires more repeaters (shorter repeater spacing) offset by less expensive repeaters. Our science nodes will convert signals from optical to electrical anyway, so the mid-plate node can provide the regenerative function and additional science in a synergistic way.)

When contrasted to the Ring configuration, the Star geometry may appear less expandable from a geographic point of view. This is mostly true. However, the Star configuration offers two opportunities for geographic expansion. The more robust approach, shown as the Expanded Star Configuration, would bring three additional cables from shore to the three planned expansion nodes. As shown, two of these three cables are repeatered, but the repeaters could be replaced by additional mid-plate nodes if desired. The Expanded Star approach would increase initial costs because we would want to lay all seven shore ends at the same time. However, the Extended Star Configuration erases this concern by reaching the three planned expansion nodes via extension cables from the primary nodes. Although the Extended Star configuration would have to share power and bandwidth with the associated base node, its total cost compares favorably with the Ring.

In addition to geographical expansion, bandwidth capacity expansion at each node is desirable. Both a single fiber pair Ring configuration and a four fiber pair Ring configuration were considered. The single fiber pair expansion approach is hampered by inefficient bandwidth utilization due to the Optical Add Drop Multiplexers (OADM's) at the node. The multi-fiber ring offers advantages with regard to bandwidth capacity expansion because each node is supported by a single fiber and wavelength, but carries a significant cost penalty. The Star configuration offers the single fiber and wavelength advantage of the Multi-pair Ring, but without the cost penalty.

The Star Configuration has a simpler DC power scheme than the Ring configurations because each cable segment is independently powered. Therefore, the power capability is more flexible and expandable. Conversely, the power configuration in the Ring configurations are (unlike standard Telecom) complex series-parallel networks and present dynamically changing loads that are a stressor to active components, making the Ring configurations less reliable.

The Ring configurations have a natural built-in redundancy. If a cable break occurs, data will still reach the shore via the other half of the ring. It should be noted that the Ring may be more likely to experience a double fault scenario, in which case multiple nodes might be isolated. Double (or simultaneous) faults are rare in telecom configurations, but the probability in the Juan de Fuca environment would be higher based on higher FIT (failure) rates for non-standard equipment, stresses related to the unique powering arrangements (particularly during a fault), and cables located in areas of high seafloor deformation and induced submarine mass wasting (or landslide). For the Star Configuration there is no built-in redundancy. In the event of a fault, the node(s) attached to that cable would be disconnected from the network.

Availability during repair activities is higher for more of the nodes in the Star configuration. In single fault scenarios, the Star would isolate a single node. Dependent upon the fault location, the Ring Configuration may or may not isolate a single node; if isolated, the powering arrangement will be complex. Moreover, due to the common power path inherent in the Ring Configuration and based on common industry safety practices, repair activities would escalate the out of service condition to all Ring nodes.

Overall, we would judge that Star Configurations offer significant advantages over the Ring architecture.

NEPTUNE Canada: The NEPTUNE Canada (NC) proposal was received by JOI in January and was analyzed by the program office staff. Although the proposal was deemed to be technically feasible and attractive from a cost standpoint, we would need to address numerous and onerous political, financial, ownership, sovereignty, and governance issues.

The NC proposal does not allow implementation of a full primary node at Blanco because of the length of cable involved. Instead, it suggests a mid-plate node with an extension cable to Blanco. Therefore, it does not fully implement all the base nodes shown in the CND.

The NC system is a Ring Configuration and therefore has the characteristics of the Ring configurations described above. As constructed, the system is less capable than we plan to implement in our system; NC will provide a little less than 2.5 G per node for sensors. We are concerned that this option would require us to make a direct award to Alcatel-Lucent because considerable risk would result in using a different supplier than had been contracted by NC. This could result in higher costs than anticipated.

Our analysis of the NC option includes the cost reduction resulting from no shore landings or armored cable. However, the cost of cable station space is not included, but we estimate that NC's leasing charges will be comparable to what we will pay in Oregon.

NSF Reduced Footprint: At the request of JOI, we included the reduced footprint option advocated by the NSF Program Directors. The evaluation of the NSF Reduced Coverage option presented here is conducted primarily on a technical and cost basis with the understanding that the scientific implications of the loss of nodes from the CND locations will be vetted by the scientifically-focused, advisory Tiger Teams at JOI. The NSF Footprint is a Ring Configuration and therefore has the characteristics of the Ring configurations described above. We would propose to consider Star Configurations for this option if we are directed to maintain these node sites for the Preliminary Design.

5.0 Recommendations and Conclusions

Our conclusion--that we favor the newly conceived Star Configuration--is our best effort at recommending an affordable solution to developing an RSN system that first and foremost satisfies the primary science goals. The Star Configuration offers a cost-effective means of delivering the required power and bandwidth to each node and it is expandable in geographic coverage, bandwidth, and power. Most importantly, its simplicity and reliance on existing technology offer what we believe to be the highest level of reliability and availability. Finally, it offers a means of easily including a mid-plate node in addition to the well-vetted science nodes of the Conceptual Network Design.

We recommend that we continue with this approach in to the Preliminary Design phase.

APPENDIX A: CALCULATING RISK FACTORS

Risk calculations were based on the Ocean Observatories Initiative (OOI) Cost Estimating Plan (CEP) Revision 1: April 13, 2007. The section below summarizes the process and includes the Risk Factors (Table A1) and Risk Percentage (Table A2) used for comparison of the submarine cable system configuration costs.

Risk Analysis (From CEP pages 7-9)

A risk analysis is used to calculate contingency. The method is based on estimator evaluation of the technical, cost, and schedule risk for every activity. Technical, cost, and schedule risk factors are input fields on the forms used to enter data into the database. Standard ranges for these parameters are 1 to 15 for technical and cost risk and 2 to 8 for schedule risk.

Risk Assessment Methodology

Risk Factors are assigned as described in Table A1. For technical risk, a value of 1 implies "normal industry supplied off the shelf items" and 15 is reserved for components significantly "beyond the current state-of-the-art." For cost risk, a value of 1 is used to indicate "vendor quote or catalog price for a specific item" and 15 is used for estimates where no data are available. Schedule risk factors range from 2 to 8.

The technical risk factor is multiplied by the risk percentage, which is categorized in Table A2. The applied risk percentage depends on two factors. The first is whether the risk is associated with technical, cost, or schedule concerns. The second is whether these concerns relate to design, manufacturing, materials cost, or labor rate uncertainties. Acceptable values in the range of 1 percent to 4 percent are defined in Table 2 on page 7. These percentages are multiplied by the corresponding risk factor to determine the contingency to be applied. The resulting percentages are added together to establish the total contingency for the activity. The minimum contingency percentage using this approach is five percent and the maximum is 98 percent. There may be special cases where the parameter limitations defined above are not appropriate. Some high-risk elements may deserve contingencies greater than 98 percent. In these cases, at the discretion of the estimator and Project Management, higher values may be used. Written justification must be provided in the supporting documentation and with the cost book.
Risk analyses shall be performed at the activity level. Results of this analysis will be summed to compute the contingency that will be reported at each level of the WBS.

While contingencies will be estimated at the same level as the bottom-up cost estimate, during execution of the project contingency will be held at the top level by the JOI Project Office and allocated as needed to address problems and items or activities that have been overlooked during the estimating process. A formal change control process will be used to allocate contingency to specific activities.

Table A1: Risk Factors

Risk Factor	Technical	Cost	Schedule
1	Existing design and off-the-shelf hardware	Off the shelf or catalog item	Not used
2	Minor modifications to an existing design	Vendor quote from established drawings	No schedule impact on any other item
3	Extensive modifications to an existing design	Vendor quote with some design sketches	Not used
4	New design within established product line	In-house estimate for item within current production line	Delays completion of noncritical path subsystem item
6	New design different from established product line. Existing technology	In-house estimate for item with minimal company experience but related to existing capabilities	Not used
8	New design. Requires some R&D development but does not advance the state-of-the-art	In-house estimate for item with minimal company experience and minimal in-house capability	Delays completion of critical path subsystem item
10	New design. Development of new technology which advances the state-of-the-art	Top down estimate from analogous programs	Not used
15	New design far beyond the current state-of-the-art	Engineering judgment	Not used

Table A2: Risk Percentage

	Condition	Risk Percentage
Technical	Design or manufacturing concerns only	2%
	Design and manufacturing concerns	4%
Cost	Material cost or labor rate concern	1%
	Material and labor rate concern	2%
Schedule		1%

APPENDIX B – ESTIMATE OF POWER AND BANDWIDTH

Example Instruments, Power Requirements, and Data Rates

Major power consumers for the cabled system will include those instruments and devices that require the following (see Table B1 for examples of high power and high bandwidth sensors):

- Motion (tethered, swimming, and bottom roving vehicles, active acoustics, pumping of fluids, etc)
- Heat transfer (freezers to preserve specimens and to cool electronics, heaters for chemistry experiments)
- Light (video imagery and lasers)
- Electronics (transducers, computers, and communications)

A typical power requirement for any single item in the first three categories might be between 100 and 1000 W. Electronics can typically draw milliwatts to order 100 W. Energy storage may be involved with any of these. At highly interdisciplinary nodes such as Axial Seamount and Hydrate Ridge, where it is anticipated that a large number of instruments will be concentrated, a peak load could be as much as 20 kW. Given that most sensors will have duty cycles less than unity and that there will be a mix of instruments at the different nodes, an average load might be 2-5 kW at each science node. During responses to events (earthquakes, eruptions, storms etc), it is likely that both power and bandwidth will be pushed to the maximum, such that it will be necessary to mediate these events. A system such as the NEPTUNE Canada one, in which the system is already nearly maximized, will not easily accommodate event response capabilities event even though scientifically they are one of the most important aspects of the observatory.

Imagery

A major bandwidth and power user for the cabled system will be video and digital still images. Initially, it is likely that at least one high definition (HD) camera will be at Axial and another at Hydrate to capture animals, fluid perturbations, and bubble formation. Lower resolution cameras as well as digital still cameras are likely to be initially installed as well. Images from such systems are valuable to science and are likely to be some of the most successful components in terms of capturing the public's interest.

High Definition Imagery

The present standard for uncompressed HDTV for a single HD video stream (1920x1080 resolution) is 1.5 Gb/s. While compression could be considered an option, recent analyses of all of the HD codecs available show that the high frequencies are lost during this process. It is the high frequencies that provide the details. If a decision is made record 4:4:4 images (RGB capture so as not to reduce the color space) then the data rate for a single HD stream would be 3Gb/s alone. These cameras take 30 frames a second. There is growing interest in using HD in stereo because, for example, it allows calculation of bathymetry at sub-centimeter resolution. These systems have now been used on submersibles and it is extremely likely that within the first five years of operation that stereo HD will be used at least one of the sites (e.g. the Ashes vent field on Axial Seamount). This would mean that there will be periods of time where at least 6 Gb/s will be required for a single instrument cluster. It should also be noted that the industry is moving to even higher resolution HD cameras, which will require even more bandwidth.

Standard Definition

Standard definition (uncompressed 4:2:2) occupies 270 mb/s, and RGB upwards of 450 mb/s, or ~0.5 Gb/s. For serious image capturing required for analyses of organisms, fluid flow, bubble formation it is important not to use current forms of video compression such as MPEG2, MPEG4 (AVC), VC-1, DV, etc). There are likely to be numerous cameras and light systems of this type at all active seafloor sites, as well as on moorings.

Still Image Capture

Using an RGB camera with 3 12 mega pixel chips - uncompressed – cameras are now delivering individual still images that are 75 megabytes. For a raw image - uncompressed - captured in RGB with either a Foveon imaging chip (no Bayer filtering), or some RGB array that increases the color space, this camera would spit out ~ 0.5 gigabyte files. It is likely that at sites such as Hydrate Ridge and Axial, there will be several of these cameras taking pictures.

Chemical Sensors

One of the most transformational aspects of the cabled system is its ability to provide continuous power and bandwidth to the seafloor. This will allow oceanographers in all disciplines to develop in situ instruments that previously were only accessible in shore-based laboratories. Therefore, a goal of many analytical researchers now is to take high power, high resolution and sensitivity bench top instruments and modify them for long-term ocean deployment. Prior to the development/concept of cabled observatories, a major requirement for submarine sensors was that they were low power and had modest data accumulation rates because of battery limitations and limited disk space. Although the explosion in storage capacity has eased the data storage problem, power derived from batteries alone is still a significant limitation. Therefore, stand-alone marine sensors were previously designed for low sensitivities (at least 3 times less than laboratory instruments), resolution and pump rates.

Examples of chemical sensors that were previously bench top instruments and have now been transitioned to underwater in situ sensors include: mass spectrometers, flow cytometers, and laser raman systems. All three of these instruments have been deployed in marine environments and will be invaluable on the cable to evaluate fluid and gas composition of seawater, seeps, and hydrothermal fluids and biological communities in the water column and in vent fluids. These instruments, as well as many of the high end sensors, have the common feature that they typically require 500 to 1000 kw of power, and that they each produce at least 0.5 Gb/s data streams. A mass spec, currently being tested for deployments in 4000 m water requires ~ 100 watts. At a cost of ~ $15K, it is anticipated that at least 10 of these sensors will be deployed on the cable early in the program, requiring 1 kw total power; they would use 10% of the bandwidth at 2.5 Gb/s.

Table B1. High data rate and high power instrumentation for RSN

Reference	Sensor	Description	duty cycle fraction	peak power W	average power W	channels	bits/ sample	samples/ second	peak data rate bit/s	average data rate bit/s
Daly; ALOHA-MARS Mooring eHyd	single broadband hydrophone	for all signals and ambient sound	1.000	2.5	2.5	1	16	768,000	12,288,000	12,288,000
Daly	4 element 3-d array of broadband hydrophones	for all signals and ambient sound - determine direction, on subsurface float (e.g., toothed marine mammals)	1.000	10	10	4	16	768,000	49,152,000	49,152,000
Daly	4 element vertical hydrophone array	tomography, all signals, ambient sound (lower frequency)	1.000	5	5	4	24	125,000	12,000,000	12,000,000
Daly	Marine fish echosounder	simrad es60: 1280x1024 once per second, 24 bit	1.000	100	100	1	24	1,310,720	31,457,280	31,457,280
	Flow cytometer	from Jurgis	1	500	500	1	1	500,000,000	500,000,000	500,000,000
Jones	fish sonar	128 element circumferential recevier array with a 10 element vertical transmit array (guesses here)	0.050	200	10	128	16	40,000	81,920,000	4,096,000
Harkins	acoustic lens	100 element	1.000	500	500	100	16	100,000	160,000,000	160,000,000
SoundMetrics	Didson acoustic lens	96 beams, 50 kbytes/frame, 30 frames/s	1.000	30	30	1	400000	30	12,000,000	12,000,000
AMM mooring	total system	The ALOHA-MARS Mooring system as presently configured with MMP/inductive power transfer; see web page and attached spreadsheets	1.000	675	350	1	1	89,000,000	89,000,000	89,000,000
AMM Mooring	video camera	DeepSea Power and Light model 2065 with video server, 400 kBytes/s??? 11-30V, camera 200 mA, LEDs 0-250 mA; assume 12 V, 2.5W and 3W respectively add 6 W for video server for total of 12 W	1.000	12	12	1	2564712	30	76,941,360	76,941,360
	SDTV	704 x 480 pixels (16:9), 30 frames a second, 24 bit/pixel	1.000			1	8110080	30	243,302,400	243,302,400
	HDTV	1920 × 1080 pixels, 30 frames a second, 24 bit/pixel = 1.5 Gb/s Kongsberg oe14-500 - 1A at 16-30V = 30W	1.000	30	30	1	49766400	30	1,492,992,000	1,492,992,000
	HDTV HDCAM compressed	HDCAM compressed 200 Mb/s - factor 7.5	1.000			1	6635520	30	199,065,600	199,065,600
	HDTV MPEG-2 compressed	MPEG-2 compressed 40 Mb/s - factor 37.5	1.000			1	1327104	30	39,813,120	39,813,120

Table B1. High data rate and high power instrumentation for RSN (*cont.*)

Reference	Sensor	Description	duty cycle fraction	peak power W	average power W	channels	bits/ sample	samples/ second	peak data rate bit/s	average data rate bit/s
	HDTV broadcast	19.2 Mbit/s - factor 80	1.000			1	622080	30	18,662,400	18,662,400
	UHDTV	Super Hi-Vision's main specifications: * Resolution: 7,680 × 4,320 pixels (16:9) (approximately 33 megapixels); Frame rate: 60 frame/s; Audio: 22.2 channels; Bandwidth: ~6600 Mbit/s bandwidth' 1 minute - 194 Gbytes = 26 Gb/s, implies 13 bit/pixel	1.000			1	433333333.3	60	26,000,000,000	26,000,000,000
	HMI light	DSP&L SeaArc2	1.000	400	400	1	100	1	100	100
	ROPOS lights	Lights: 3 x 250W HID, 4 x 250W Quartz	1.000	1750	1750	1	100	1	100	100
	Bremen Quest ROV	2 x 400W HMI Daylight 4 x 500W Halogen 5 x 150W Halogen dimmbar 5 x 10 W HID 2 x 532nm Laser 5mW (green) 2 x Blitzlicht "Insite Scorpio Strobe"	1.000	2000	2000	1	100	1	100	100
WHOI web pabge	ABE charger	Autonomous benthic Explorer (ABE), example of AUV, from web page total power about 300 W (presently does not dock, but it or similar is a likely candidate). Guess leave in dock 24 hours for charging and then use 24 hours. and assume fills one 500 GB disc in 24 hrs. assume 80% efficiency for battery charging	0.500	375	187.5	1	1	46,296,296	46,296,296	23,148,148
http://www.hydroidinc.com/6000spec.html	AUV charger	remus 6000 (6000 m), 11 kWhr battery, 8 hour recharge for 22 hour mission, assume 50% efficiency. There is not a dock yet for this vehicle. Assume 80% efficiency for battery charging	0.733	625	458.33	1	1	50,505,051	50,505,051	37,037,037
MBARI	AUV charger	dorado, 6 kWh, 8 hr mission, assume 8 hour to recharge, assume 200 GB disc	0.500	312.5	156.25	1	1	55,555,556	55,555,556	27,777,778
Smith RFA	Benthic rover charger	Smith	0.330	300	99	1	1	22,222,222	22,222,222	7,333,333
http://www.mbari.org/mars/pdfs/Paull.pdf	Borehole pumping	pump fluids between two nearby boreholes. Desire as much power as possible	1.000	5000	5000	1	1	1,000,000	1,000,000	1,000,000

Autonomous Underwater Vehicles (AUVs)

A major consideration for AUVs with docking capabilities would the data volume associated with cameras, followed by multibeam sonar. For example, the camera on the Autonomous Underwater Explorer (ABE) currently stores about 1.5 gigabytes/hour, with multibeam storage of about half of that. Newer multibeam systems will store up to a few 100 gigabytes/dive the raw data are recorded (rare). To offload the data, a full recharge cycle would need to be completed (100 gigabytes over 10 hours, which equates to 2.8 megabytes/second). However, a more significant driver would be the ability to transmit video. An optical modem is being designed that will support very high data rates (100 mbit/sec) over short ranges (100 m). Looking towards the near future, a major application would be a battery powered vehicle that makes repeated (daily?) surveys of vent fields. In this scenario, the 100 megabit link would seriously eat into the capacity of the 2.5 gigabit link; many vehicles could eventually be operated on the system synchronously.

Moorings

Full water column moorings with high bandwidth and power capabilities include arrays of sensors that will include some of the sensors described above (e.g., cameras, hydrophones, cytometers)(See Table B1), but they also include moving platforms such as profilers and winches. Total power for these systems could reach > 2 kW, and require very high bandwidth (Gb/s) for transmission of data associated with cameras, ADCPs, phytoplankton, zooplankton and fish and mammal observations, tomography, and high resolution and high sensitivity chemical measurements. An example of such a mooring is shown in Figure B1.

Example Profiling Mooring Electrical Power Budget

DRAFT - still changing from AMM/MARS - Sensors are still "old"
Minimum voltage for Vicor converters is 250 V
Top float node voltage must be maintained >300V.
Assumes major charging (or winch or profiler or tomog) going on at same time on top and mid nodes

RSN Node Voltage	375	vdc
RSN Node Power	2000	watts
Cable Current	5.33	amps
Cable wire gauge	14	AWG
Cable Length	1.7	km
Conductors in leg 1	6	
Conductors in leg 2	6	#
Resistance per conductor	9	ohms/km
Total Cable Resistance	5.1	ohms
Voltage Drop	27	vdc
Cable Power Loss	145	watts
Extension Cable Efficiency	93%	%
Anchor Node Voltage	348	vdc
Power to Anchor Node	1855	watts
Power to for Anchor Sensors	34.9	watts
Power to Hotel Load	35.4	watts
Power to Guest Instruments	150	
Power from Anchor Node	1580	watts
Anchor Node Voltage	348	
Mooring Cable wire gauge	14	AWG
Mooring Cable Length	1.9	km
Conductors in leg 1	6	
Conductors in leg 2	6	#
Resistance per conductor	9	ohms/km
Total Riser1 Cable Resistance	6	ohms
Riser1 Cable Voltage Drop	26	vdc
Riser1 Cable Power Loss	118	watts
Riser1 Cable Current	4.54	amps
Riser1 Cable Efficiency	93%	%
Mid-water Voltage	322	vdc
Power to mid-water node	1462	watts
Power to mid-water charging/tomog	321	watts
Power to mid-Hotel Load	23.7	
Power to mid-water Sensors	46.9	
Power available for mid Guest Instrument	150	watts
Power from mid Node	785	watts
Mid-water Voltage	322	
Mooring Cable wire gauge	14	AWG
Mooring Cable Length	0.45	km
Conductors in leg 1	6	
Conductors in leg 2	6	#
Resistance per conductor	9	ohms/km
Total Riser Cable Resistance	1	ohms
Riser2 Cable Voltage Drop	3	vdc
Riser2 Cable Power Loss	8	watts
Riser2 Cable Current	2.44	amps
Riser2 Cable Efficiency	99%	%
top-float Voltage	319	vdc
Power to top-Float	776	watts
Power to charging/winch	321	watts
Power to top-Hotel Load	23.7	
Power to top Float Sensors	46.9	
Power available for top Guest Instruments	229	watts
Total Power (check)	2000	watts
Converter Efficiency	80%	%
Power to Loads	1383	watts
Conversion and Transmission Loss	617	watts
Total Power (check)	2000	watts
Overall efficiency (user load/total)	69%	

RSN Node Power ◀ 2000 W
RSN Node Voltage 375 V

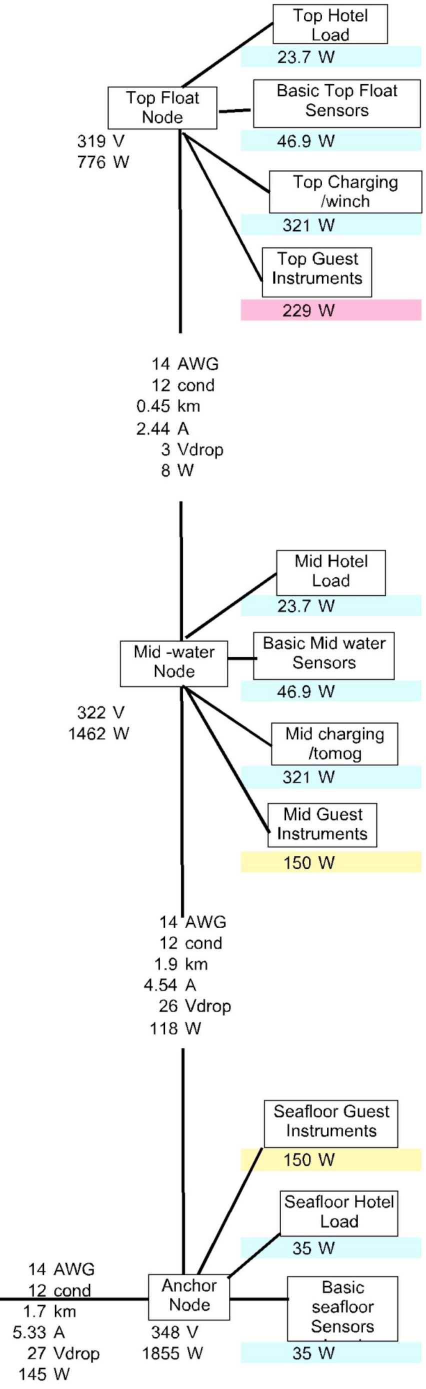


Figure B1. An example of a power budget for a full water column mooring with capabilities similar to that high-lighted in the RSN Request for Assistance proposal "An interdisciplinary Ocean Observatory Linking Ocean Dynamics, Climate and Ecosystem Response from Basin to Regional Scales".