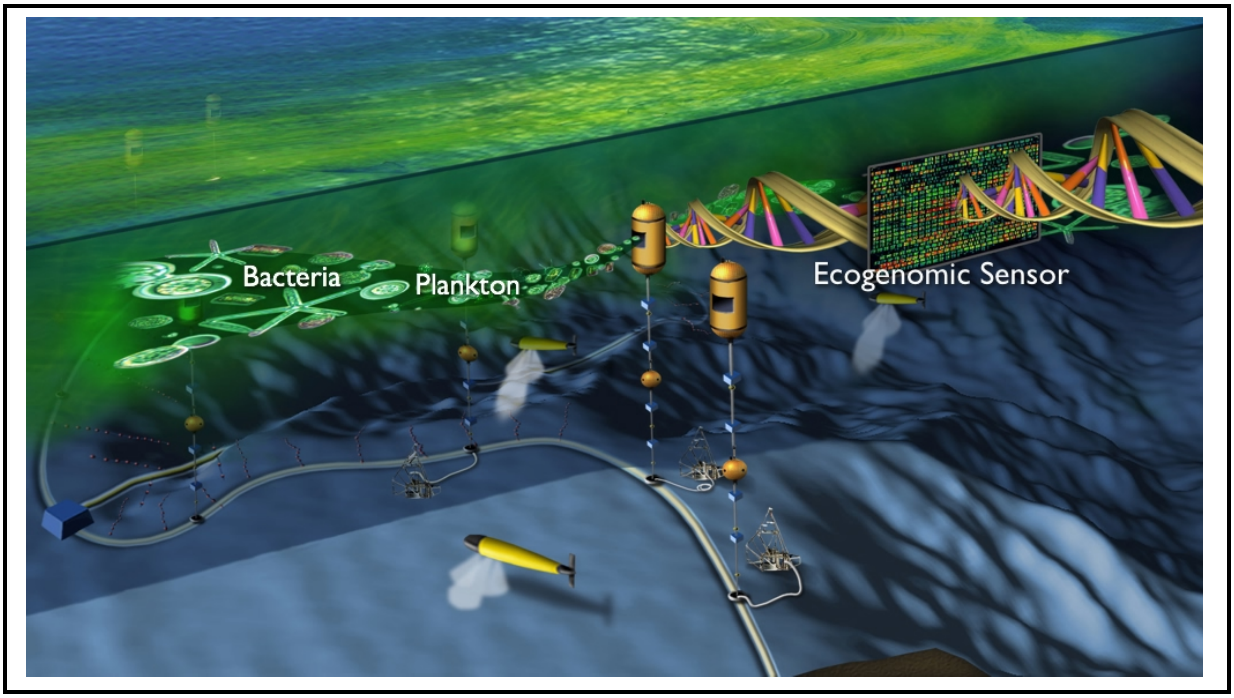
Regional Scale Nodes
Secondary Infrastructure
White Paper



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1.0	July 30, 2007	Initial Release	Harrington, Harkins, Howe, Kelley
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Preliminary Remarks

One of the most transformational characteristics 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 mesoscale ocean processes or a tectonic plate (100s of km on a side). Next-generation ocean scientists will continually capitalize on the existence of 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 Regional Scale Nodes (RSN) system will allow breakthrough discoveries to take place on time and spatial scales that have not been possible. Dependable power, bandwidth and real-time, interactive access to the ocean 24/7/365 for decades will fundamentally revolutionize the ocean sciences.

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1.0 Introduction

The Regional Scale Nodes Secondary Infrastructure White Paper Version 1.0 is a living document that will iteratively evolve through the Ocean Observatories Initiative Preliminary Design Review (PDR) now scheduled for early December 2007. The RSN Infrastructure described in this White Paper encompasses all of the components required to connect the scientific instruments to the Shore Station through various levels of nodes and the underwater backbone cable. The details of the Shore Station and the backbone cable were provided in two previous RSN White Papers, the *Regional Scale Nodes Wet Plant Primary Infrastructure White Paper* and the *Regional Scale Nodes Shore Station Options White Paper*. Block diagrams showing configurations of the RSN were provided in the *Preliminary Design Document* (PDD).

This Secondary Infrastructure White Paper is linked directly with the PDD and provides more detailed information on specific components that make up the RSN system. In the following introductory sections we provide brief definitions of each of the components, followed by more comprehensive descriptions of the components in Sections 2–7. Table 1 and Figure 1 summarize the various levels of nodes and their capabilities.

The terminology used in this White Paper is as follows:

Shore Station: The Shore Station is the cable landing site that houses the Power Feed Equipment and Network Termination Equipment for the backbone cable. The Shore Station provides power to the RSN and is a network gateway between the Nodes and the terrestrial Data Center.

RSN Wet Plant (includes Primary Nodes): From the Shore Station, main branches of submarine telecommunications cable span long distances at high voltages (10kV) and high data rates (10 GigE) to the Primary Nodes, which are located in areas of high scientific interest on the Juan de Fuca Plate. The Primary Nodes and backbone cable make up the RSN Wet Plant.

In isolation, the RSN Wet Plant is a STAR topology with a direct link between each Primary Node and the Shore Station. Figure 2 shows the STAR configuration. In contrast, the RSN as a whole has a tree-like architecture to distribute the power and to provide the data/control network efficiently.

Primary Nodes convert the high voltage (10kV) from the Shore Station to a more useable lower 400 V level through a Medium Voltage Converter (MVC).

RSN Secondary Infrastructure: The Primary Nodes distribute low voltage (400 V) and data at a lower rate (1 GigE) to a group of Low Voltage Nodes (LVN) clustered geographically around the Primary Node. Primary Nodes also are able to pass the 10kV and 10 GigE signals directly to Secondary Nodes, which in turn have their own MVC and can distribute power and data to LVNs. The LVNs, Secondary Nodes, and the cables that connect them to the Primary Nodes make up the RSN Secondary Infrastructure.

RSN Tertiary Infrastructure: The LVNs are connected to either Medium Power Junction Boxes (MP-JBox) at 400 V and 1 GigE or Low Power Junction Boxes (LP-JBox) at 48V and100BASE-T. The JBoxes provide the correct data and power interface to small groups of scientific instruments. The JBoxes and the sensors make up the RSN Tertiary Infrastructure.

In concert, this infrastructure will support (at least) three general scenarios:

1. Local area networks around a Primary/Secondary node (e.g., Axial Seamount)
2. Water-column moorings at each Primary node site that extend the infrastructure and associated science capabilities from the seafloor to the sea surface; and
3. Extended spatial arrays (e.g., Blanco and Hydrate Ridge/coastal array).

Although this document is entitled the *Secondary Infrastructure White Paper*, for completeness its scope has been expanded to include the Primary Nodes, Secondary Nodes, Low Voltage Nodes, JBoxes, Vertical Moorings, and the connectors and cables needed to interconnect them. For each of these items, this paper provides an overview of the functionality, visualization for possible physical implementation, a block diagram, a summary of technical specifications, and a short description of some of the major system components.

Table 1. Summary of Node Capabilities

	Input Voltage and Power	**Input Data Rate**	**Output Ports**	**Number Ports**	**Output Voltage and Power**	**Data Rate Out**
Primary Infrastructure						
Primary Node	10 kV 40 kW	10 Gb/s	Expansion	2	10kV/40kW*	10 Gb/s
			Science	4	400 V/8kW*	1 Gb/s
Secondary Infrastructure						
Secondary Node	10 kV/ 40kW	10 Gb/s	Expansion	1	10 kV/40 kW*	10 Gb/s
			Science	4	400 V/8 kW*	1 Gb/s
LVN	400 V/ 8kW	1 Gb/s	Expansion	2	400 V/8 kW*	1 Gb/s
			Science	4	48 V/200 W	100 Mb/s
Tertiary Infrastructure						
MP-JBox	400 V/ 1kW	1 Gb/s	Expansion	1	400 V/1 kW	1 Gb/s
			Science	8	Sensor Specific	
LP-JBox	48 V/ 200W	100 Mb/s	Expansion	0	N/A	N/A
			Science	8	Sensor Specific	

*While each port can receive the max power, this is also the total power shared among all the output ports.

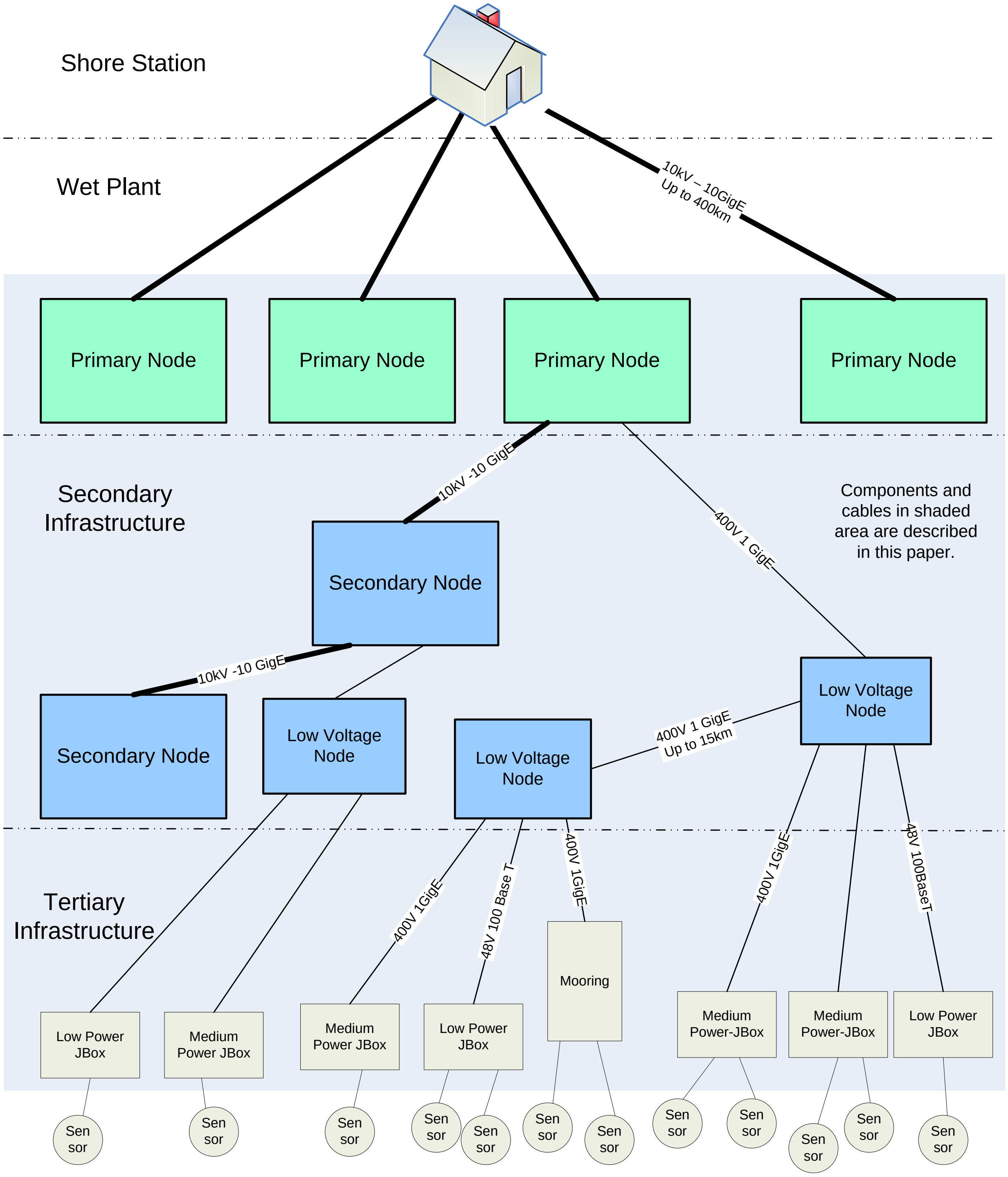


Figure 1. Tree-like topology for the Regional Scale Nodes

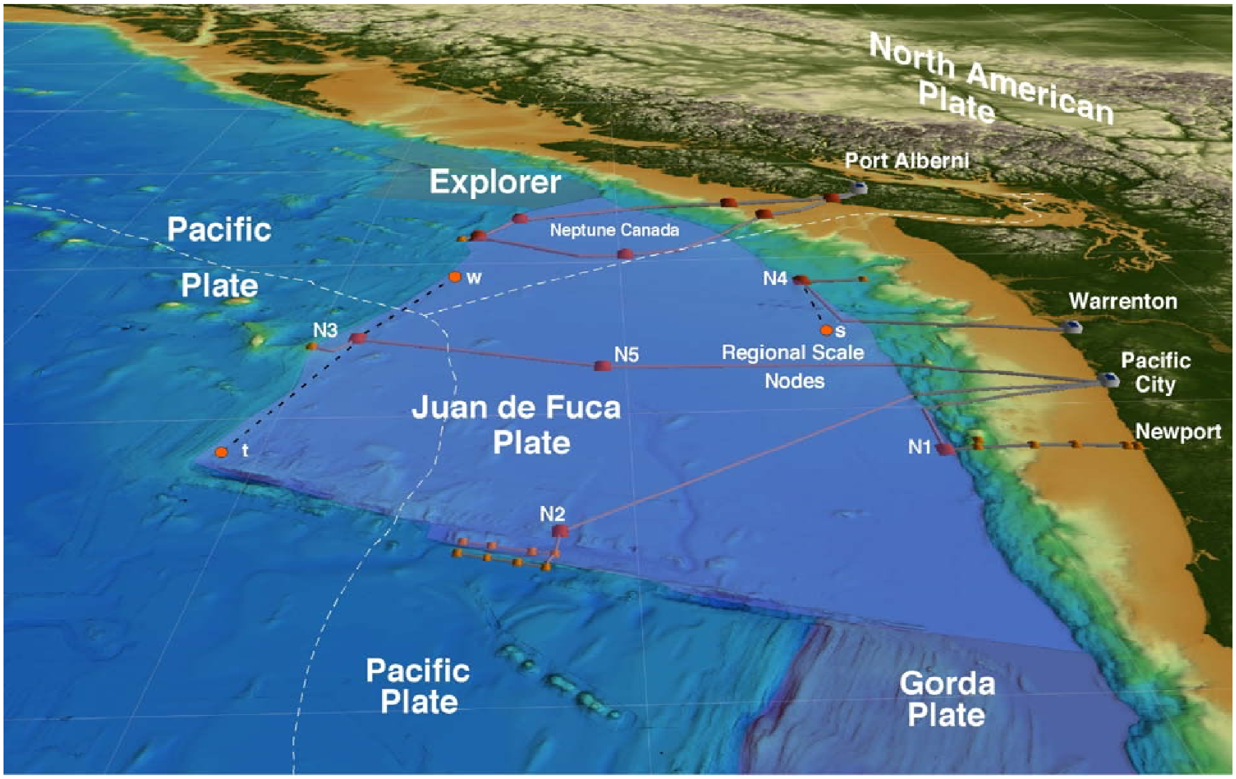


Figure 2. Cable configuration and location of five nodes and two shore stations for the Regional Scale Nodes component of the OOI.

2.0 Primary and Secondary Nodes

The Primary and Secondary Nodes function as gateways between the backbone cable, which operates at 10 kV and 10 GigE over very long distances, and the Secondary Infrastructure, which operates at 400 V and 1 GigE over shorter distances. Node specifications are shown in Table 2. The mechanical design for the Primary and Secondary Nodes for the RSN system is similar to the MARS (www.mbari.org/mars) and NEPTUNE Canada systems (www.neptunecanada.ca) (Figure 3). A trawl-resistant frame (TRF) protects the electronic equipment from fishing activities. Installation can be phased such that the TRF can be installed first using the cable ship, with follow-on installation of the electronics module using a Remotely Operated Vehicle (ROV). The electronics module has two independent pressure cases. One case houses a Medium Voltage Converter that converts the 10 kV to 400 V for infrastructure and science loads. The other case houses the power monitoring and control subsystem components and the network communications electronics to pass the data between the Secondary Infrastructure and the Shore Station.

The Primary and Secondary Nodes have expansion ports that pass the 10 kV and 10 GigE link to other Secondary Nodes. The power and bandwidth are shared equally between the Primary Node and all Secondary Nodes. This allows one backbone cable to the Shore Station to be expanded geographically beyond a single Primary Node location. Figure 4 provides a block diagram of a Primary Node.

ROV wet-mateable connectors (WMCs) are used to interconnect the Primary and Secondary Nodes to the backbone cable from the Shore Station, to each other, and to associated Low Voltage Nodes. This enables the entire electronics module to be removed for maintenance and repair.

The only difference between the Primary and Secondary Nodes is that the Primary Node has a Long Range Optical Amplifier for the fiber-optic link to the Shore Station and two expansion ports to Secondary Nodes. The Secondary Node only has one expansion port at 10 kV. Command and control communications are available between Shore Station and Primary Nodes via separate wavelengths in order to preserve the maximum data capacity of the Node. Out-of-Band (OOB) control is available only in the Primary Node.

Table 2. Primary and Secondary Node Specifications

Item	Specification
Connection to Shore Station through Backbone Cable	
Power	10 kV - 4 A = 40 kW, total power used by this node and all attached equipment including Secondary Nodes 8kW, total power capacity of each primary or secondary node
Data/Command Communication	One pair Single Mode Fiber 10 GigE
Maximum Distance to Shore Station	400 km
Connections to Secondary Nodes	
Number of Secondary Connections	Primary Node – 2 Secondary Node – 1
Power	10 kV - 4 A = 40 kW total max power passed to all attached Secondary Nodes 8kW, total power capacity of each primary or secondary node
Data/Command Communication	One pair Single Mode Fiber 10 GigE
Maximum Distance to Secondary Node	160 km
Connections to Science Ports (Low Voltage Nodes)	
Number of Connections	4
Power	400 V - 20 A (8 kW) **combined** power to all 4 ports. Each port can receive full power
Data	Electrical 1 GigE. Will be converted to fiber outside of Node in cable
Maximum Distance to Science Node	15 km
Data Switch	
Number of 10 GigE Ports	3
Number of 1 GigE Ports	5
Other Parameters	Commercial - Layer 2
Medium Voltage Power Converter	
Input Voltage	10 kV (+20/-40%)
Output Voltage	400 V
Total Output Power	8 kW

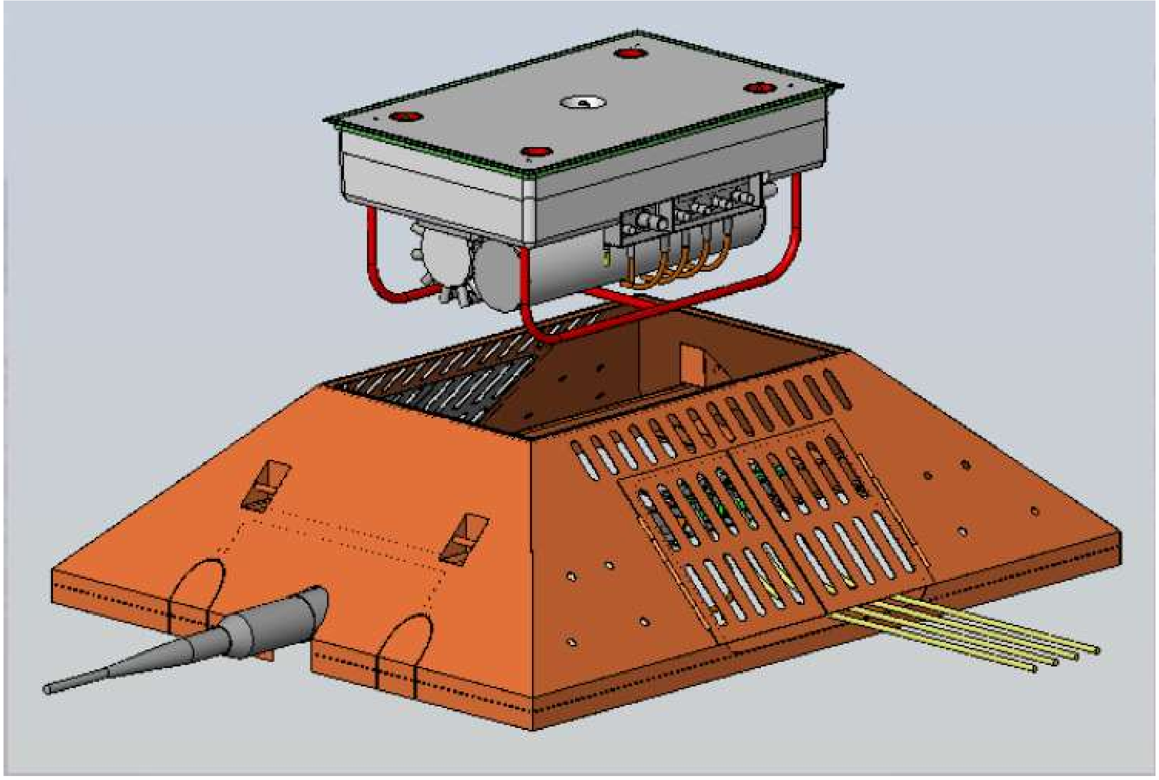


Figure 3. A trawl-resistant frame (TRF) and electronics module for MARS.

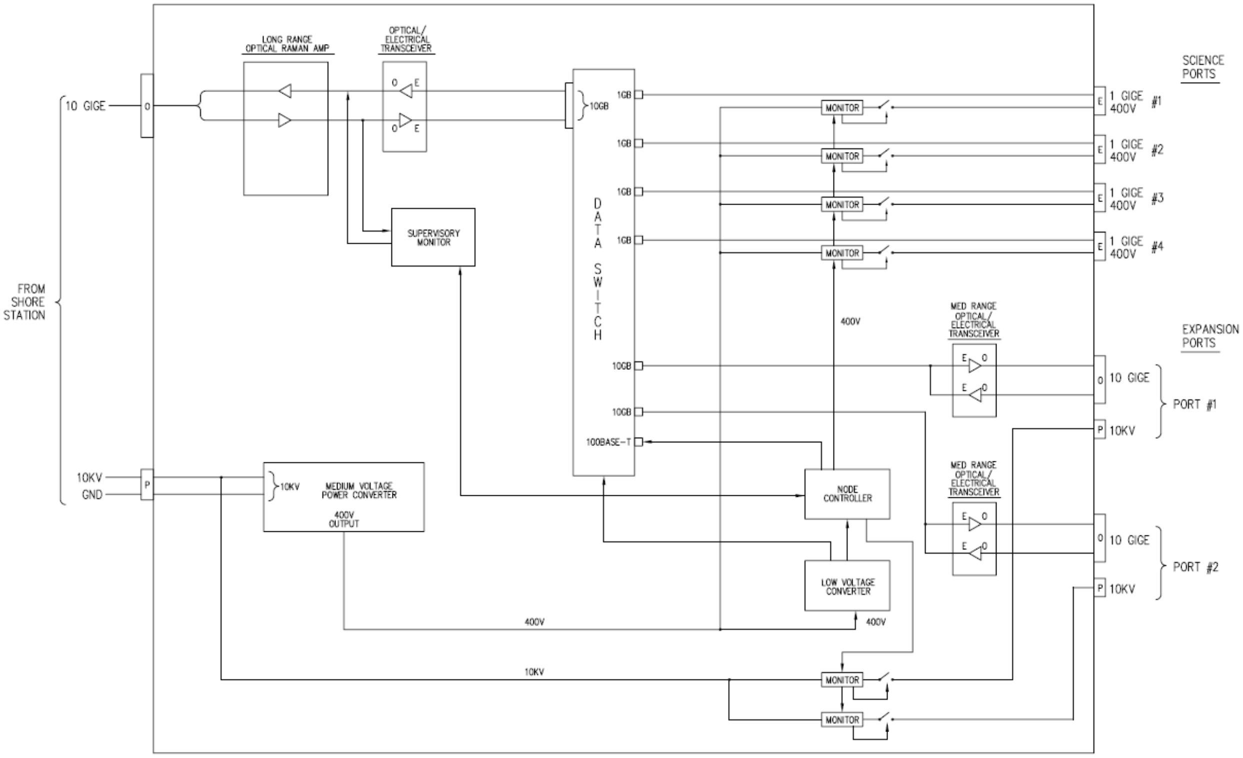


Figure 4. Primary Node Block Diagram

2.1. Data Switch

Within the Primary and Secondary Nodes, the Data Switch aggregates the communication links to and from Secondary Infrastructure for transmission to the Data Center. This switch will be able to communicate to the Shore Station and any attached Secondary Nodes at 10 GigE. All other network links will be at 1 GigE. The Data Switch will be a commercial switch, customized for this application, with redundant DC power supplies, additional heat sinking, sealed optics or electrical interfaces, possible conformal coating of the boards, and ruggedized connectors. Front panel indicators, switches, and displays may be removed.

2.2. Long Range Optical Amplifier

The Long Range Optical Amplifier is required in the Primary Node to enable long distance, repeaterless connection to the Shore Station at 10 GigE (Table 3). This type of amplifier is used for unrepeatered long-haul telecommunications applications with shore station equipment at both ends of the cable (e.g., in festoon systems). The commercial amplifier will require customization to fit our application because one end is submerged. In the case of the connection between the N5 and N3, both ends of the link will be submerged. These amplifiers are not used in the Secondary Nodes.

Table 3. Distances between the Shore Station and Nodes

Link	Distance
Shore Station – Hydrate Ridge	173 km
Shore Station – Blanco	347 km
Mid-Plate – Axial	184 km
Shore Station – Subduction Zone	210 km
Shore Station – Mid Plate	270 km

2.3. Medium Voltage Converter

The Medium Voltage Converter (MVC) converts 10kV power to 400 V for use by the Primary Node and Secondary Infrastructure. The MVC has challenging requirements that are unique to large underwater observatories.

Terrestrial high-power systems can use AC to transmit high power over long distances. This allows simple transformers to step the voltages down to useable voltage levels for electronic systems. In the case of the RSN, however, DC power must be used for power transmission. Because of the high capacitance/reactance of the submarine cable, prohibitively large reactive components would be needed to permit the use of AC. The use of DC requires a step-down converter based on switching electronics.

Development of a MVC for MARS has been funded by NSF in anticipation of the RSN. This work has been further developed by NEPTUNE Canada and Alcatel and a similar MVC is being used by the Neutrino Mediterranean Observatory (NEMO; http://nemoweb.lns.infn.it). We will evaluate these MVCs and, depending on the outcome, we may use one of these MVCs with or without modifications.

2.4. Node Controller

The Node Controller is a processor for monitoring status and for controlling functionality of the Primary and Secondary Nodes. The Node Controller is connected to a network port in the data switch and also to the Out-of-Band Communication link in the Primary Node. The Node Controller is responsible for collecting health and status information such as temperature, voltages, and current from the components in the Node. It also controls electronic and mechanical switches that determine which ports are active and which ports should be isolated from the system. The Node Controller allows re-configurations during the life of the system and isolation of faulty Secondary Infrastructure, so that the unfaulted infrastructure can continue to function until a repair can be made.

2.5. Power Monitor and Switching

One of the Primary Node’s main functions is to distribute power to downstream Infrastructure including any Secondary Nodes. The power monitor and switching function allows 1) the Primary Node to dynamically turn power on and off to any of these ports, and 2) to monitor current used in order to evaluate the health of the attached Secondary Infrastructure and to balance the load on the whole system. Power Monitoring and Switching will use both fast-acting electronic switches as well as mechanical deadface switches to provide galvanic isolation. Ground fault isolation circuits will provide detection of high- and low-resistance shorts to ground so that corrective action can be taken.

The switching of the 10 kV presents a technical challenge. The switches required for opening and closing the circuits would be carrying current that could be large enough to arc and damage or weld the contacts. One option is to do the switching at a lower voltage during system startup as designed in the NEPTUNE Power project. This would require specialized PFE equipment in the Shore Station and would require powering the system down anytime that switching was required. A second option is to hardwire the connection to the Secondary Nodes, as in NEPTUNE Canada. In this case a fault could de-power the entire infrastructure connected to that cable segment.

2.6. Out of Band Communication

The Out of Band (OOB) Communication link, shown as the Supervisory Monitor in Figure 4, is a secondary path between the Shore Station and the Node Controller over the fiber optic cable. It will allow the Shore Station to diagnose problems with the system in the event that the shore station is not able to communicate with the Node Controller through the Data Switch. This link will either be a different wavelength or an amplitude modulation of the main wavelength.

2.7. Precise Time Distribution

One requirement of the RSN is for precise and accurate timing (i.e., synchronized with GPS time to better than 10 microseconds) of the measurements made by the sensors throughout the system. One solution is to implement the PTP 1588 standard (http://ieee1588.nist.gov/) over the IP network like NEPTUNE Canada.

In the NEPTUNE Canada case the Shore Station will have a GPS referenced master clock. Other 1588-enabled network equipment can synchronize with the master clock and provide a local clock reference. If all of the network switches between these clocks are 1588 enabled then very accurate measurements are possible (100s of nanoseconds). If they do not implement the hardware time-stamping mechanism of the 1588 standard then extra jitter is introduced as the packet is passed through the switch. Unfortunately 1588 is not currently available in 10 GigE or 1 GigE switching hardware, but, depending on how the switches are configured and on system loading, it may still be possible to achieve the necessary accuracy.

3.0 Low Voltage Node

The Low Voltage Nodes (LVNs) interconnect sensors, their associated Junction Boxes, and Primary and Secondary Nodes. Connections to a LVN are made using ROV wet-mateable connectors so that the LVN can be brought to the surface for maintenance and repair without having to recover the cables or other attached infrastructure.

The input voltage to the LVN is 400 V and the input data link is 1 GigE. There are two expansion ports that pass on the 400 V and have a 1 GigE data link. These ports can either be connected to another LVN for expansion, to a Medium Power JBox, or to other specialized equipment that requires higher power or bandwidth, e.g., inductive power coupler systems in docking stations for charging batteries in mobile platforms, or high-definition cameras. In addition, the LVN has four science ports that provide 48 V and has 10/100BASE-T data links, which provide connections to Low Power JBoxes. Node specifications are summarized in Table 4.

The LVN will include a pressure housing attached to a frame (trawl resistant if required) that will sit on the seafloor. The ROV wet-mateable connectors will be on the outside of the frame for access by an ROV. Depending on what will be connected to a specific LVN and node location, not all of the possible ROV wet-mateable connectors may be populated. Because of the high cost of the optical WMCs the LVNs will be equipped only with electrical-only connectors. When distance requires optical transmission, electrical to optical conversion in the cable system will be used. Figure 5 shows one possible configuration being used as the seafloor LVN for the ALOHA-MARS mooring system. Figure 6 is a block diagram of a LVN.

Table 4. Low Voltage Node Specifications

Item	Specification
Connection to Primary or Secondary Node or other LVN	
Power	400 V – 20 A (8 kW) total power used by this node and all attached equipment
Data/Command Communication	Electrical 1 GigE. Will be converted to fiber outside of LVN in cable
Max Distance to Primary Node or LVN	15 km
Expansion Ports to LVN or MP JBox	
Number Ports	2
Power	400 V –20 A (8 kW) **combined** power to both ports. Each port can receive full power
Data/Command Communication	Electrical 1 GigE. Will be converted to fiber outside of LVN in cable
Maximum Distance to attached LVN or MP JBox	15 km
Connections to Science Ports	
Number of Connections	4
Power	48 V – 4.2 A (200 W) power used by port.
Data	Electrical 10/100BASE-T
Maximum Distance to LP-JBox	100 m
Data Switch	
Number of 1 GigE/ 10/100BASE-T Ports	8
Other Parameters:	Commercial - –Layer 2

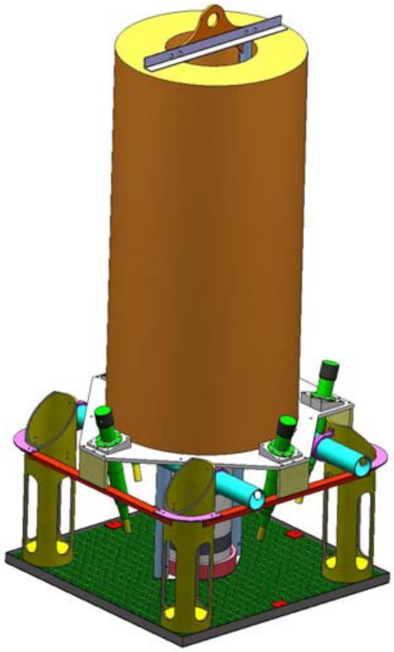


Figure 5. ALOHA Low Voltage Node

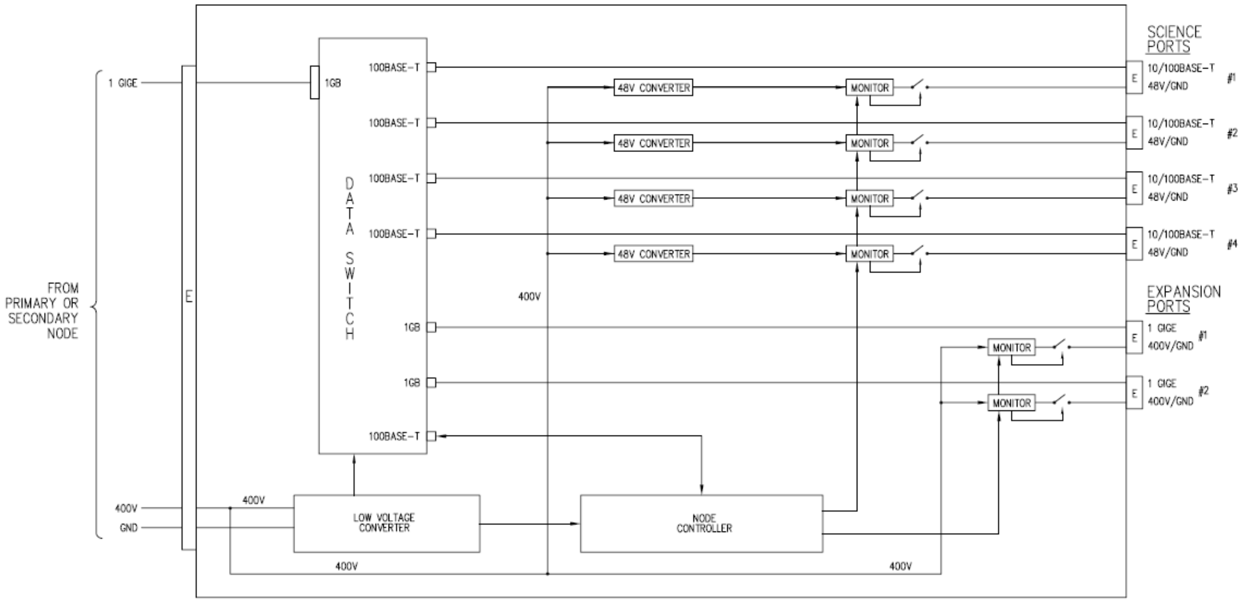


Figure 6. Low Voltage Node Block Diagram

Within the Low Voltage Nodes, the Data Switch aggregates the communication links to and from Secondary Infrastructure for transmission to the Data Center. The Data Switch will be managed through the network link back to the Shore Station. The Switch will always return to a state such that it can be accessed by the Data Center after the Switch is powered on. The Switch will automatically configure its ports to the correct data rate depending on the rate of the device to which it is connected.

3.1. Node Controller

The Node Controller for the LVN is a very simple processor with a network interface. Similar to the controller in the Primary and Secondary Nodes, the node controller is responsible for measuring system status parameters like internal temperature. It is also responsible for turning on and off power to connected components and for monitoring and reporting the power usage of those components. The Data Center can set the LVN configuration and retrieve system information through the Network Interface connection to the Node Controller.

3.2. Low Voltage Converter

The Low Voltage Converter converts the input 400 V into voltages needed by the Data Switch, the Node Controller, and other internal electronics. This will be a commercial off the shelf low-power device on the order of 10 Watts.

3.3. Power Monitor and Switching

The Node Controller can turn power on and off to the individual port through the switches and monitors attached to each port. There will be both software-controlled (slow) electronic switches and mechanical deadface switches to provide galvanic isolation. There will be ground fault isolation circuits to detect high- and low-resistance shorts to ground, so that corrective action can be taken.

4.0 JBox

The ultimate connection to the sensors is through a Junction Box (JBox). The JBox has specific power and protocol converters for each sensor type that will be attached to it. Typically the JBox will be configured for a cluster of sensors that are mechanically attached together and will be deployed at the same time. One ROV WMC connector can be used to plug the entire sensor cluster into the system at one time. Our JBox has similar functions as the VENUS (/www.venus.uvic.ca/) instrument platform shown in Figure 7.

We envision two versions of the JBox. The Medium Power (1 kW) JBox (MP JBox) takes 400 V and converts it to the appropriate voltages for its sensors. The input data link is at 1 GigE. The MP JBox also has an expansion port to allow another MP JBox to be connected to it, allowing daisy chaining. The MP JBoxes will be used instead of a Low Power JBox whenever more power or higher bandwidth is required. It will also be used when the sensors are located a long distance from the LVN such that 400 V is more appropriate than 48 V for the power transmission.

The Low Power (200 W) JBox (LP JBox) takes 48 V and converts it to the appropriate voltage for its sensors. Figure 8 shows a block diagram of a Low Power JBox. The input data link is at 100BASE-T. The LP JBox must be closer to the attached LV Node than an MP JBox because of the lower operating voltage. Also the lower voltage and data rate mean the LP JBoxes are not designed to be daisy chained together.

Specifications for the MP JBox and the LP JBox are summarized in Tables 5 and 6.

Figure 7. VENUS Instrument Platform– University of Victoria

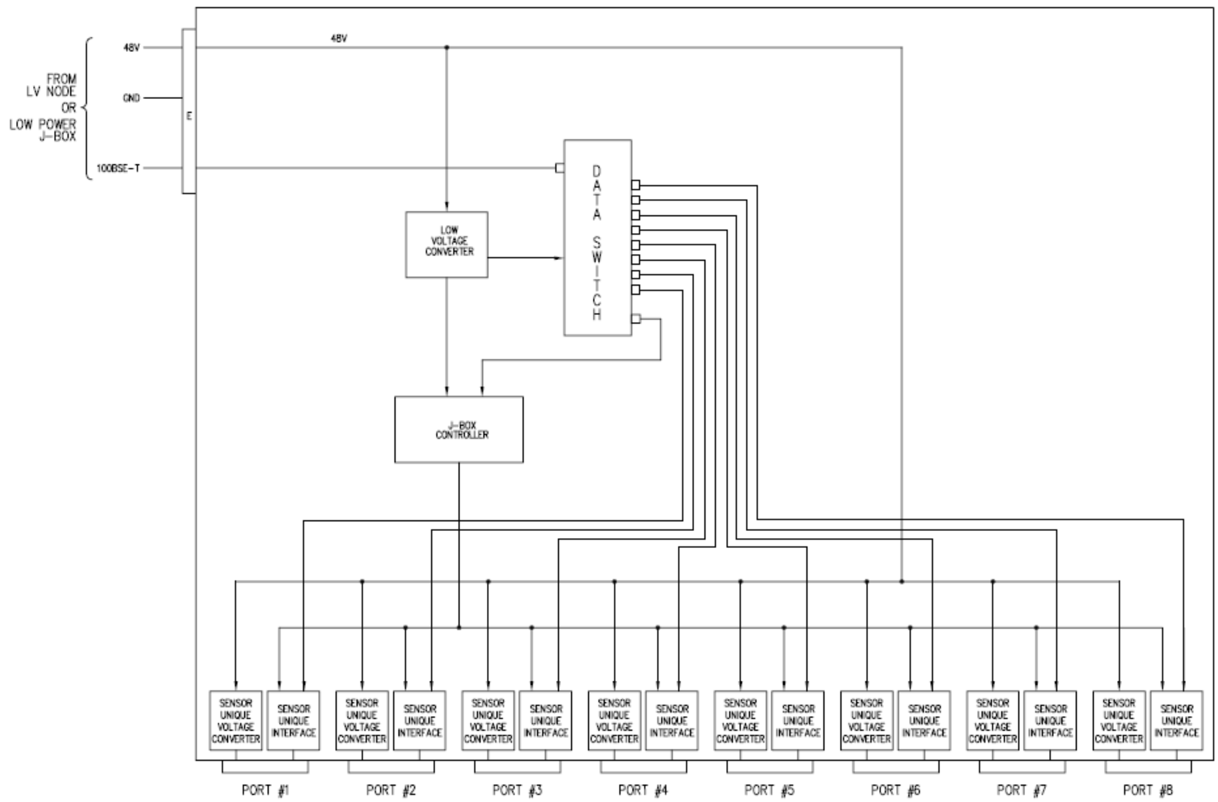


Figure 8. Low Power JBox Block Diagram

Table 5. Med Power JBox Specifications

Item	Specification
Connection From LVN or Other Med Power JBox	
Power	400 V – 2.5 Amps 1kW total power used by this node and attached sensors
Data/Command Communication	Electrical 1GigE
Max Distance to LVN	1 km
Sensor Ports	
Max Number Sensors	8
Power	3-48 V Preconfigured. Max Power 200W
Data/Command Communication	RS232 –RS485 -100BASE-T Selectable or Sensor Specific.
Maximum Distance to attached Sensor	Power and Protocol Dependent

Table 6. Low Power JBox Specifications

Item	Specification
Connection to LVN	
Power	48V – 4.2 Amps (200W) total power used by this node and attached sensors
Data/Command Communication	Electrical 100BASE-T
Max Distance to LVN	100 m
Sensor Ports	
Max Number Sensors	8
Power	3-48 V Preconfigured. Max Power 50Watts
Data	RS232 –RS485 -100BASE-T Sensor Specific
Maximum Distance to attached Sensor	Power and Protocol Dependent.

4.1. Data Switch

The JBox uses a Data Switch to aggregate all data from the Sensor Interfaces and send them back through the network to the Data Control Center. The Data Switch will be managed through the network link back to the Shore Station. After being powered on, the Data Switch will always return to a state that can be accessed by the Data Center. The Data Switch will automatically determine the correct data rate for each port.

4.2. Node Controller

The Node Controller for the JBox is a very simple processor with a network interface. As in the Primary Node, the Controller is responsible for measuring system status parameters like internal temperature. It is also responsible for turning on and off power to downstream infrastructure and for monitoring and reporting power usage. The Data Center can set the JBox configuration and retrieve system information through the Network Interface connection to the Node Controller.

4.3. Low Voltage Converter

The Low Voltage Converter converts the input 48 V or 400 V into voltages needed by the Data Switch, the Node Controller, and other internal electronics. This is a low-power, commercial-off-the-shelf device on the order of 50 Watts.

4.4. Power Monitor and Switching

The Node Controller can turn power on and off to individual ports through the Sensor Interface attached to each port. There will be both slow-acting software controlled electronic switches and mechanical deadface switches to provide galvanic isolation. Additionally ground fault isolation circuits will detect high- and low-resistance shorts to ground, so that corrective action can be taken.

4.5. Sensor Interface

The sensor interface is a simple processor that contains a network interface. It has a unique IP address and can be programmed to talk to the different science instruments. The sensor interface is re-programmable *in situ*. Additionally, the sensor interface will have the capability to store metadata for the sensor and will have a physical interface unique to each attached device (RS232 or RS485).

5.0 Mooring

The Moorings, if affordable, will measure the vertical variation of ocean parameters at a fixed horizontal location using a variety of sensors in the water column, some of which will be mounted to a mobile vertical Profiler and some of which are fixed. Mooring specifications are shown in Table 7.

The Mooring consists of an electrical/optical/mechanical (EOM) cable that is connected to a LVN and anchored to the seafloor. The cable rises to a buoyant platform 200 meters below the sea surface. The platform keeps the EOM cable taut. A winch on the platform allows a tethered, sensor-populated float to travel from the platform to the sea surface; the winch system will be ROV-serviceable.

A Profiler continuously moves up and down the EOM cable between the seafloor to the 200-meter platform; instruments on the Profiler measure ocean conditions. At the platform, an inductive data and power coupler allows the Profiler to transmit data to the 200-meter J-Box and to recharge the Profiler batteries. Real-time communication with the Profiler is accomplished using a low data-rate inductive modem for command and control and data transfer. The Profiler can be installed and removed using an ROV to facilitate service.

The 200-meter platform has a set of fixed sensors that can provide a set of temporally and spatially continuous measurements at this fixed point in the water column. (A 600-m fixed platform has been proposed in several science fora.) In the future, additional sensor packages will be able to be mounted on the platform and plugged in with an ROV. (The block diagram of the Mooring in Figure 9 does not show this capability.) Another set of fixed instruments at the base of the Mooring on the seafloor provides additional continuous measurements.

In concert, these four groups of sensors will give a comprehensive view of the dynamics of the ocean environment through the entire water column.

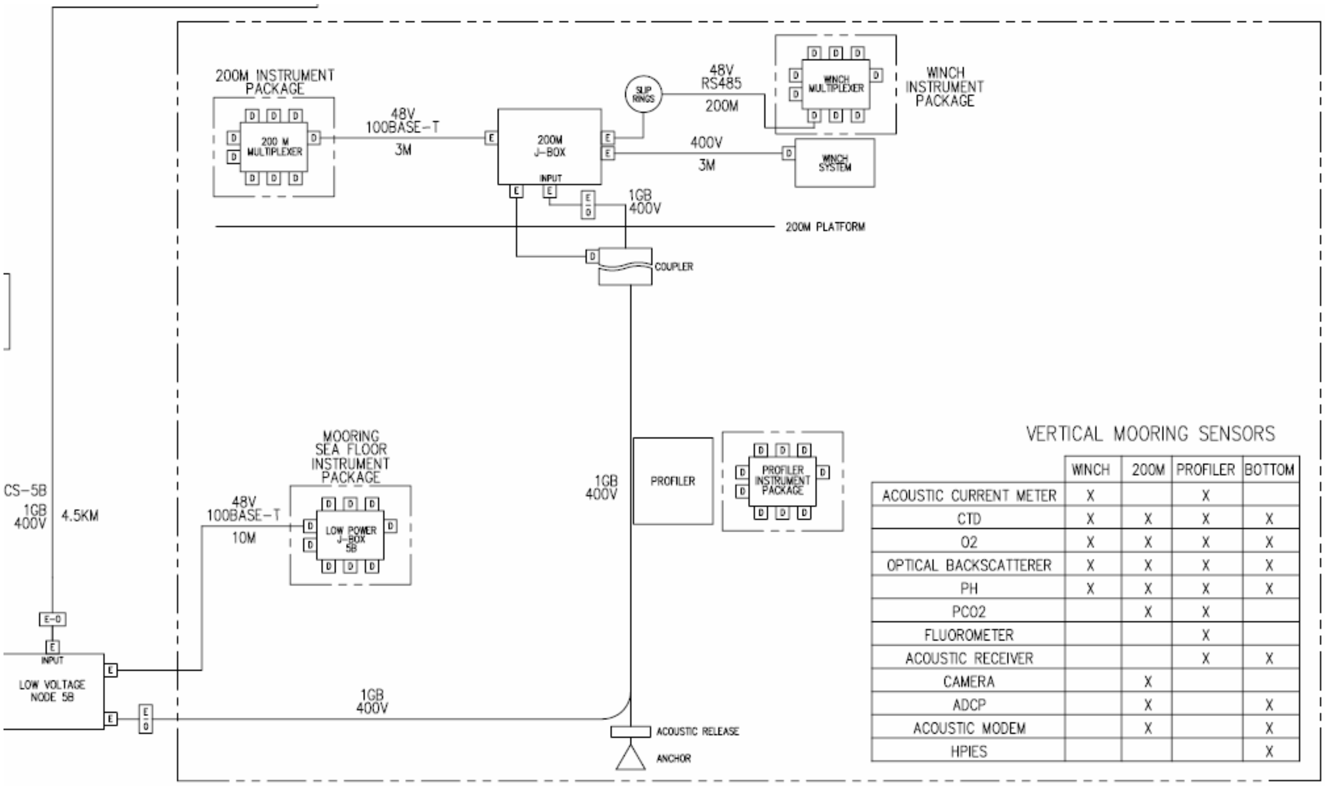
Much of the Mooring design will be based on the work done for the NSF-funded Aloha Mooring project at APL (http://www.alohamooring.apl.washington.edu) (Figure 10). The Aloha Mooring has many of the features of the envisioned RSN Mooring, but on a more modest scale. It has a Profiler, but no winch, fewer sensors overall, less total power, and is currently configured with a 1-km vertical EOM cable.

The profiler version of the Aloha Mooring is being tested in Puget Sound in the summer of 2007 and the whole system is scheduled for testing on MARS in spring 2008. The design experience and lessons learned from this project will be very valuable to the RSN Mooring development.

The block diagram shown in Figure 9 shows electro-optical converters in the Mooring; the Aloha Mooring also uses this approach. The Mooring uses an optical fiber in the cable because of the long transmission length from the platform to the LVN.

Table 7. Mooring Specifications

Item	Specification
Connection to LVN	
Power	2000 watts at 400 V total power used by this mooring and attached sensors
Data/Command Communication	1 GigE
Max Height	3km
Max Distance to Primary Node	5km
Profiler	
Speed	0.5 m/s (min 4 samples through the depth range, here 5000 m, in one M2 tidal cycle 12.42 hours)
Max Payload	50 kg
Charge Time	4 hours charging, 96 hours operating
Data Couple Transfer Rate	19,200 baud real time, >10 Mb/s when docked
Winch	
Power	200 W Average (assuming 10% duty cycle with local energy storage)
Speed	Selectable in range 0-0.5 m/s
Sensors	
Total Number	34



VERTICAL MOORING SENSORS

	WINCH	200M	PROFILER	BOTTOM
ACOUSTIC CURRENT METER	X		X	
CTD	X	X	X	X
O2	X	X	X	X
OPTICAL BACKSCATTERER	X	X	X	X
PH	X	X	X	X
PCO2		X	X	
FLUOROMETER			X	
ACOUSTIC RECEIVER			X	X
CAMERA		X		
ADCP		X		X
ACOUSTIC MODEM		X		X
HPIES				X

Figure 9. Mooring Block Diagram (Sensors are assumed for design purposes only and may not represent the final sensor suite which will be determined by the science traceability and by affordability.)

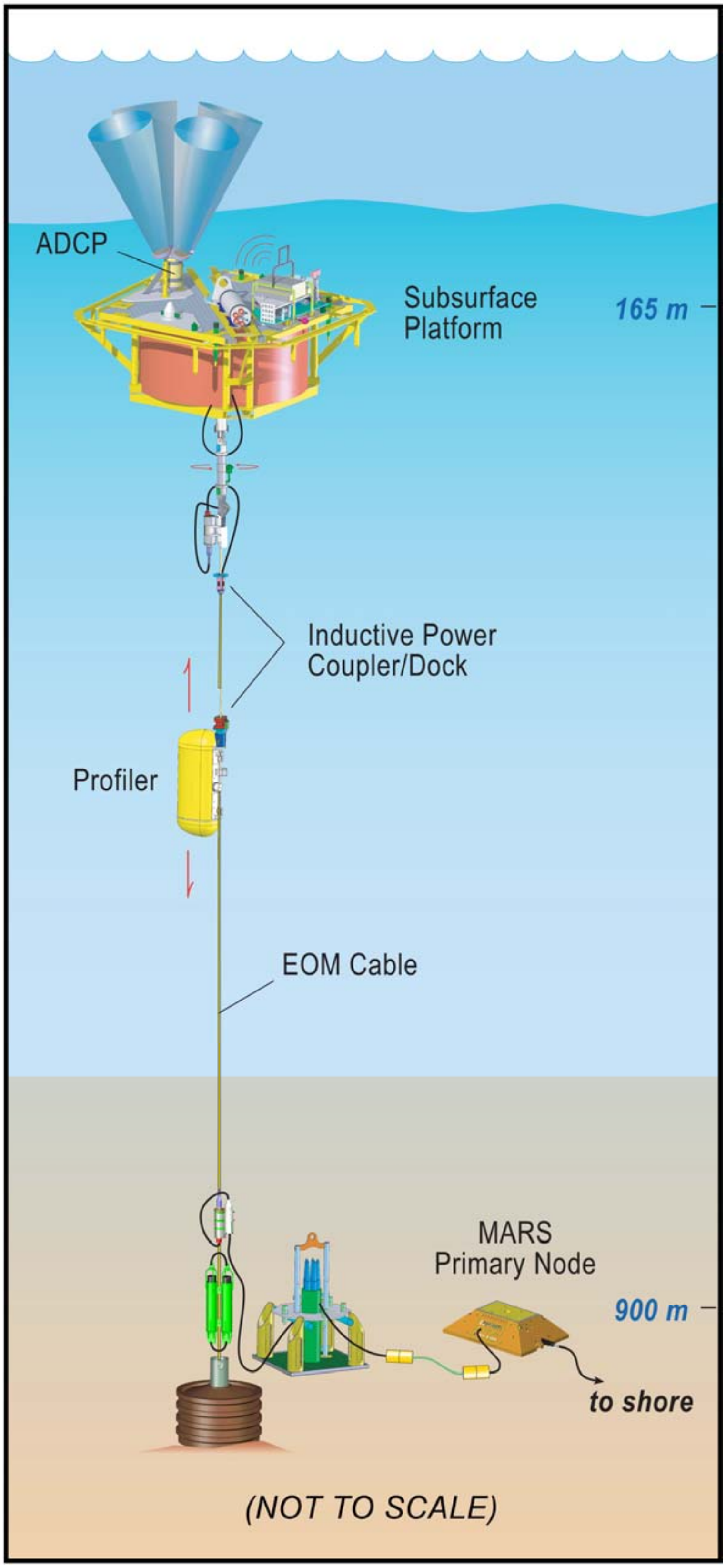


Figure 10. Aloha Mooring

5.1. Profiler

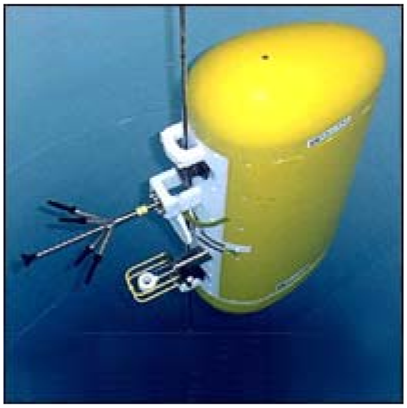


Figure 11. McLane Research Profiler

The Profiler is a near-neutrally buoyant device that moves up and down the vertical cable. One possible candidate uses a wheel driven by a motor; another uses a buoyancy engine. The Profiler does not have a direct connection to the cable. Instead, the electric motors and payload sensors are driven using batteries that are inductively charged in the docking station at the 200-meter JBox. Data and Commands are also transferred using an inductive method. This can occur at the platform in a docking station and also while the Profiler is moving. The Aloha project modified a profiler from McLane Research to allow custom sensors to be added to the package (Figure 11); an inductive charger was also developed. Another recently funded NSF project (*HOT Profiler*, M. Alford PI) will be working with the Ocean Origo buoyancy driven profiler (*SeaTramp*). Decisions on which profiler(s) will be used in the OOI network will be made in the future. The development of a standard docking station and the capability to install/remove profilers with an ROV will facilitate the interchange of different profilers as they naturally evolve over time.

5.2. Winch

Several winch systems are under consideration for profiling the upper 200 m. The Wet Labs AMP X-10 has the winch in the profiling body and is presently being modified as part of an NSF funded project (J. Barth, PI) to dock like the Aloha Mooring profiler for inductive power transfer and communications. Presently, the winch does not allow real-time communications. The NGK AES-3 has the winch on the fixed platform; an existing version is being modified for use by NEPTUNE Canada over a depth range of 400 m. Lastly, WHOI has used a cable-connected winch system for several years in shallow water and has recently extensively modified it for use in Antarctica under ice. Additional study and development are needed before a winch system is chosen for the RSN. There are on-going discussions regarding testing one or more of these when the Aloha Mooring is installed on MARS.

5.3. 200-Meter JBox

The JBox on the 200-meter platform differs from a normal JBox in that it must control the workings of the Profiler and the winch. Both of these systems will have unique interfaces for communication.

Communication to and from the Profiler occurs over an inductive data link. All data returning from the sensor package on the profiler will use this link. The JBox Controller will receive the data packets, decode them, and transmit the sensor data to the Data Center through IP. The JBox Controller will also control and will monitor the frequency and speed of the Profiler’s movement up and down the vertical cable and will control and monitor the charging of the batteries in the Profiler.

We envision that communication to and from the Winch will occur over an electrical link because communication must go through a slip ring configuration from the 200-Meter platform and onto the cable on the winch. Data from the payload sensors will be packed together over this link and then unpacked by the Controller in the 200-Meter JBox. The Controller will decode the data and transmit them as unique sensor data over the IP link back to the Data Center. The Controller will control and monitor the frequency and speed at which the winch operates and the power used for performance monitoring of the system.

6.0 Connectors

An important requirement of the RSN system is the ability to efficiently maintain and repair pieces of the system over the 25-year design lifetime. In addition, the system must be expandable and the components reconfigurable to meet evolving scientific needs. The key enabling technology to make this happen in a submarine cabled underwater observatory is wet-mateable connectors (WMCs) that can be mated using an ROV.

At depths of 3000 meters it is not practical to bring equipment that is connected to cables to the surface for repair without severing the link. Wet-mateable connectors, therefore, allow equipment to be unplugged from the rest of the system before bringing equipment to the surface.

WMCs are very expensive with prices ranging from $___ to $___ per pair depending upon its characteristics. Unfortunately, there are no industry standards for WMCs so it is not possible to cross reference parts between vendors.

Both MARS and NEPTUNE Canada use ODI (www.odi.com) as their vendor for ROV compatible WMCs. Three types of ODI connectors of interest to the RSN project are described below in Tables 8–10 and illustrated in Figures 12–14.

6.1. Nautilus Standard Wet-Mate Connectors*

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Table 8. Nautilus Standard Specifications

Estimated cost per pair	$___
Number of pins	1-126 – 12 Typical
Current	30 A per circuit
Voltage	3.3 kVDC
Pressure	10,000 PSI
Mate/Demate Cycles	1,000
Design Life	25 years

**These pass lower power electrical signals*

Figure 12. ODI Nautilus Standard

6.2. Nautilus High Power Wet-Mate Connectors*

Table 9. Nautilus High Power Specifications

Estimated cost pair	$___
Number of pins	4
Current	200 A per circuit
Voltage	10 kVDC
Pressure	10,000 PSI
Mate/Demate Cycles	1,000
Design Life	25 years

**These are used for 10 kV power.*

Figure 13. Nautilus HP ROV Connector

6.3. ODI Hybrid ROV Wet-Mate Connectors*

Table 10. Hybrid ROV Specifications

Estimated cost pair	$___
Number of pins	8 (electrical or optical)
Current	8 A per circuit
Voltage	1k VDC
Pressure	10,000 PSI
Insertion Loss	<0.5 dB
Fiber Type	SM or MM
Mate/Demate Cycles	100
Design Life	25 years

**These are used for fiber connections where 10GigE is used.*

Figure 14. ODI Hybrid ROV

For connections between the backbone cable at 10 kV and 10 GigE, there is no single WMC that can handle both of these specifications because the 10 GigE must use a fiber connector. For this reason, the backbone cable will be terminated with two connector plugs, one with only fiber-optic connections and one that is a high-power connector. The Primary Node will have the two corresponding receptacles. Figure 15 presents the wet-mate connection scheme. This same configuration will be used for connections between Primary and Secondary Nodes, which also have these connections at 10kV and 10 GigE.

For all of the connections at 400 V and 1 GigE, the 1 GigE signal will use a fiber connection only if the extension cable is greater than 10s of meters (TBD). While it is possible to use the Hybrid connector from ODI throughout the system, the cost is prohibitive. Instead, a Standard ROV WMC will be used and the 1 GigE will be passed through the bulkhead over electrical circuits.

The ROV WMCs have oil-filled hoses attached to them; these hoses will be converted to regular cable using a small pressure cylinder for any distance greater than 100 m. An Electrical-to-Optical converter will be placed in the pressure cylinder to convert the electrical signals that are passed through the bulkhead to an optical signal that can travel long distances.

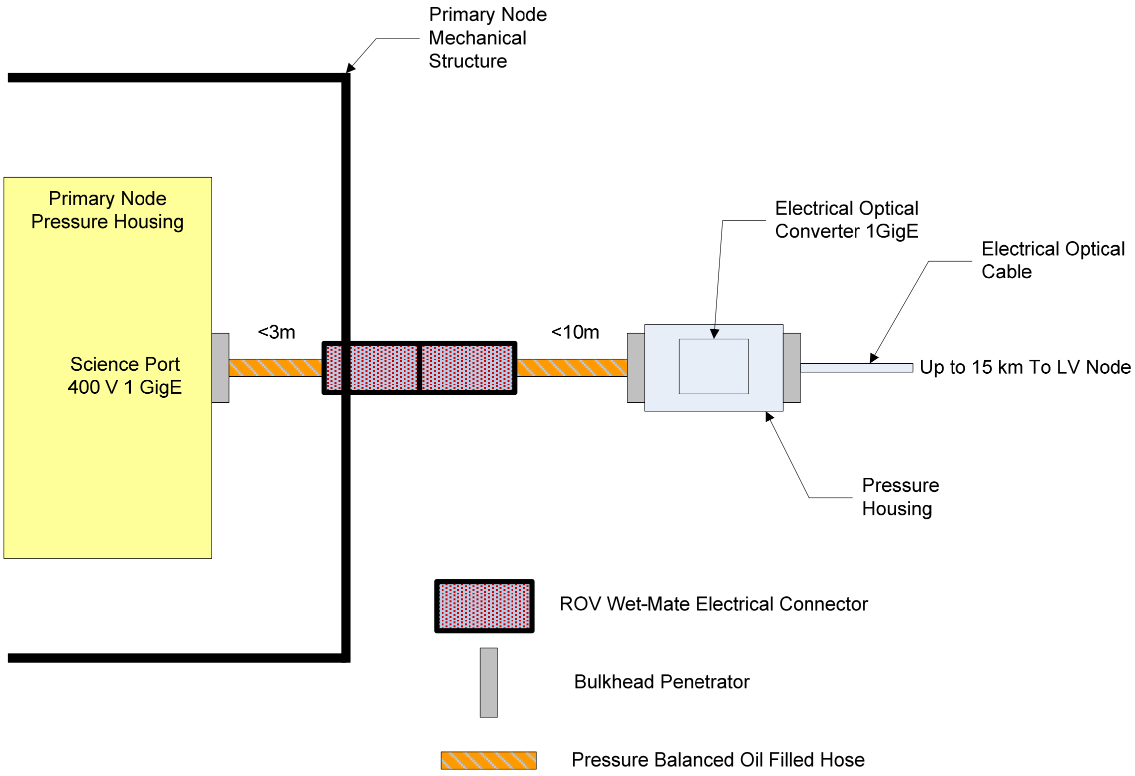

Figure 15. ROV Wet-Mate Connection Schematic

For short connections (<200 meters) at 48 V and 100/10BASE-T it will be possible to use the Standard ROV Wet-Mate Connectors and to keep the signals all electrical with no fiber-optic converters. This is typical between a Low Power J-Box and a Low Voltage Node or a multiplexer box on the profiler and associated JBox. This will help us control costs on the RSN.

In addition, we will be meeting with other vendors of WMCs to evaluate whether their capabilities meet our connector requirements.

7.0 Cables

Transmitting large amounts of DC power over long distances underwater requires special considerations when designing cables to support the infrastructure. There are two main types of cable required for the RSN. These two types differ by their approach to the ground return.

The first type is a single conductor electrical-optical cable typically used in long distance submarine telecommunication applications. These cables typically have a nominal resistance of 1 ohm/km (ranges from 0.7 to 1.6 ohms). Because they have only a single conductor there is no return ground path, instead a sea ground at the far end of the cable and a ground bed at the Shore Station complete the ground loop. Also because of the long distances involved (>400 km), the input voltage must be high enough to overcome the cable resistance losses. Assuming that a Node is 400 km offshore and requires 1A, there will be a 400 V drop between the Shore Station and the MVC in the Primary Node. The Shore Station PFE will be designed to operate at 10 kV to keep the voltages above 9 kV at the Primary Nodes.

The second type of cable is a multi-conductor electrical-optical or electrical only cable. With this cable type it is possible to implement a return ground path through the cable. This configuration increases the total resistance in the cable. For a cable that has a nominal 1 ohm/km rating, if half the conductors are used for power and the other half are used for ground then the resistance in each of those paths is 2 ohms/km. Further, the current has to travel through the cable twice, once out and once back. Therefore, the real resistance is 4 ohms/km. This cable can be used at 400 V to go medium distances (<15 km) between Primary Nodes and LV Nodes.

If the second type of cable has a nominal resistance of 1 ohm/km and a working voltage of 400 V, then it has a power capacity of 9100 watt-km. This means that the most power the cable can deliver with a safety margin is 9100 watts to a node 1 km away. At a distance of 15 km, the maximum load would be only 600 watts. To increase the power handling capability of this cable, the number/cross sectional area of conductors can be increased or the working voltage can be increased; these modifications come with impacts to cost, design complexity, and possibly reliability. For these reasons, the use of some intermediate voltage, say 1600 V or 3200 V, will be studied further.

Other considerations for the cable design are the type of outer protection and the cable strength. Steel armor might be required in areas with very rocky and abrasive seafloor or in areas with aggressive fishing activities. Steel or synthetic strength members will be needed if the cable needs to cross a wide chasm. More cable strength is required for surface ship installation than if the cable is laid by an ROV (with cable sled) near the seafloor. The vertical mooring cables are a special case, using synthetic fibers for strength. Typical cable parameters are presented in Tables 11 and 12.

Table 11. Submarine Telecommunications Cable Cost Estimates from Wet Plant White Paper

Cable Type	Unit Price/Meter
Double Armor	$__
Single Armor	$__
Light Weight Armor	$__
Special Purpose Armor	$__
Light Weight Cable	$__

Table 12. Standard (Multiconductor) Cable Cost Estimates

Cable Type	Unit Price/Meter	Nominal Ohms/km	Power Capacity (w/km)	Maximum Load (pounds)
Low Power Seafloor No Special Armor	$__	1	9100	300
High Power Seafloor No Special Armor	$__	0.65	14000	300
Low Power Mooring No Special Armor	$__	1	9100	6000
High Power Mooring No Special Armor	$__	0.65	14000	6000

8.0 Conclusions

This paper has provided details of the major secondary infrastructure components of the RSN as presented in the Preliminary Design Document. Together these components will enable groundbreaking science to answer critical questions about ocean processes that have profound impacts for all of us. As the project moves forward through the more detailed design process, additional engineering tradeoffs will be made that may affect some of the details presented here. We do not anticipate significant changes in the general architecture or cost structure of the system.

Some examples of engineering tradeoff issues alluded to in this document include the following:

- How best to provide Synchronized Time Distribution
- How to switch 10 kV to Secondary Nodes
- Where redundant components can provide better reliability
- How best to amplify the optical signal from shore to the nodes over long distances
- How to accommodate subsea backbone interconnections to facilitate expansion and improved capabilities and availability
- What are the intermediate voltages needed between secondary infrastructures, and
- How to optimize the infrastructure to reduce O&M costs, and total system lifetime costs.

Information that will affect the tradeoff conclusions include the following:

- Input from selected Wet Plant and other key vendors
- Solidifying interfaces with partners in the OOI
- Details about specific sensors, profilers, and winches to be used
- Reliability and availability estimates
- New products that become available on the market, and
- Decisions about the final RSN configuration.

As detailed component requirements are derived for the RSN infrastructure and as advances are made in state-of-the-art technologies, we will continue to evolve and refine the RSN design in order to provide the most cost effective and reliable solution for the OOI Network.