Proposal of Next-generation Real-time Seafloor Globe Monitoring Cable-network

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Abstract

A feasibility study on a new scientific submarine cable network of next generation around Japanese Islands is presented. The proposed cable network has a mesh-like topology covering vast area and has many observation nodes with 50km intervals. In observation nodes, various sensors can be installed, that are exchangeable for maintenance and replace. The cable network supplies electric power to sensors and provides continuous and long-term data to researchers and agencies. It will be used in a vast research field such as seismology, geodynamics, marine environmentology, ecology and biology. In this paper, topology of the cable network, structure of the observation node, optical data transmission system and power feeding system will be described.

Introduction

The real-time, long-term earth observation is essential to understand the nature of the earth. However, the shortage of scientific data beneath the sea makes it difficult to comprehensively understand the nature. It is very important to consecutively obtain scientific data from underwater in vast research field such as seismology, geodynamics, marine environmentology, ecology and biology.

Seafloor monitoring system based on the submarine telecommunication cable is the most effective system to get real-time long-term data from seafloor. In Japan, several scientific submarine cable systems with seismometers and tsunami sensors have been constructed(1) and used to monitor the seismic activities from 1978.

On the other hand, recent evolution of the submarine optical cable technology makes it possible to develop a new kind of scientific submarine cable network in which various kinds of sensors can be installed. In 1998, a permanent deep ocean scientific research facility 'the Hawaii-2 Observatory(2)' was installed using a retired telecommunication cable connecting Hawaii and California. The facility consists of a junction box and multiple sensors. In 1999, VENUS (Versatile Eco-monitoring Network by Undersea Cable System)(3) project installed a submarine station having seven replaceable sensors using the retired telecommunication cable (former Trans-Pacific Cable-2). In 2001 JAMSTEC has developed an battery operated expandable and replaceable satellite measurement station called the adaptable observation system (AOS)(4) that are connected to a backbone cable with a 10km long thin fiber. The first AOS was installed off Kushiro Tokachi in Hokkaido. In 2001, science community in the USA started a new scientific underwater cable project called NEPTUNE(5) taking advantage of this technology breakthrough. The NEPTUNE system will connect 30 seafloor nodes distributed over a 500 by 1,000 km area.

In 2001, IEEE OES Japan Chapter organized a committee on the underwater cable-network for scientific seafloor monitoring. The mission of the committee is to do technical feasibility study on the scientific submarine cable network of next generation and to present a technical paper. The cable network is named ARENA (Advanced Real-Time Earth monitoring Network in the Area). The feasibility study is now under way, and its interim report will be issued soon. This paper will describe the outline of the interim report.

The ARENA will have the following features. (1) mesh-like cable network topology around Japanese Islands, (2) deployable up to 6,000m water depth, (3) observation nodes are located with 50km intervals, (4) exchangeable and relocatable sensors, (5) reliable and robust against failures, (6) high cost performance, and (7) system extensibility.

As the maintenance of these kind of underwater systems is not easy and repair works require long ship time and large expense, high reliability and robustness is required. However pursuing the high reliability will heighten the initial development cost. In order to fulfill these conflicting requirements, we propose that the backbone system including backbone cable, backbone power feeding system and backbone data transmission system should be highly reliable and robust while for other system including sensors and related devises we should use commercially available low-cost devises. In order to use these low-cost devices, any failure of these devices should not seriously affect the operation of the whole system. The area to be affected should be restricted. The devices should easily be recovered for maintenance and be redeployed to the same point as it was while the other system is operation during repair works. The underwater system configuration considering these conditions will be proposed.

Figure 1 shows future cable network of the ARENA. As the Japanese Islands are located on the plate boundaries on which large earthquakes occur, it is important to study the generation mechanism of earthquakes. Therefore the cable route of the ARENA is located near the plate boundaries. Many observation nodes can be installed in the cable network with 50km intervals, and various kinds of sensors can be placed within the observation nodes. Detailed structure and configuration of the ARENA will be shown in the following sections.

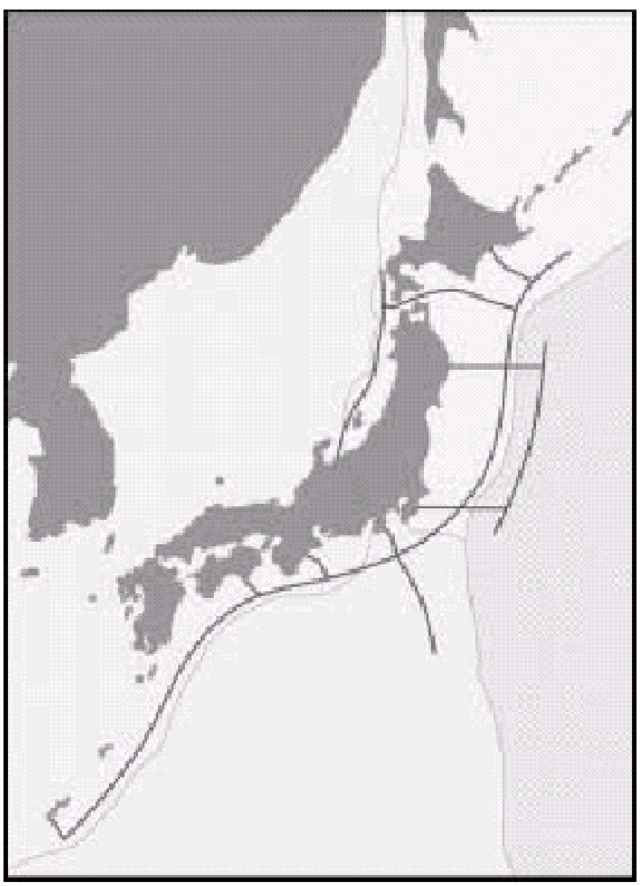

Figure1 Future cable network of ARENA

Although the cable route is located on the plate boundaries, the application field of the ARENA is not restricted to seismology. Geodynamics, marine environmentology, ecology, oceanography, geobiology, biology, and interdisciplinary field are possible field to be applied.

Power feeding is the most challenging topics. As the telecommunication submarine cable has only one conductor in it, the return current flows in ground. For conventional telecommunication submarine cable systems, constant current (CC) power feeding is used to supply electric power to repeaters through the cable, because it is robust to cable failures and it is easy to make power supply circuit in repeaters from CC source. However, it was not easy to make a mesh-like power feeding network with constant current. H. Kirkham, et. al[6] proposed constant voltage power feeding system for NEPTUNE. In this feasibility study, three method were compared, they were, (a) CC power feeding system (b) constant voltage (CV) power feeding system, and (c) hybrid system that comprise CV power feeding part and CC power feeding part. We have already published a paper[7] describing the preliminary result of the study. In this paper, we will propose a new power feeding technology for CC power feeding system.

The optical data transmission system will provide an extremely high-speed data transmission line between submarine observation nodes and researchers. Using wavelength division multiplex (WDM) and optical amplifier (OA), more than 1 Tbit/s data transmission over one optical fiber has already been realized in the cutting-edge optical submarine cable system. This data transmission capacity is more than enough for the seafloor globe monitoring. Ethernet technology also makes it easy to construct

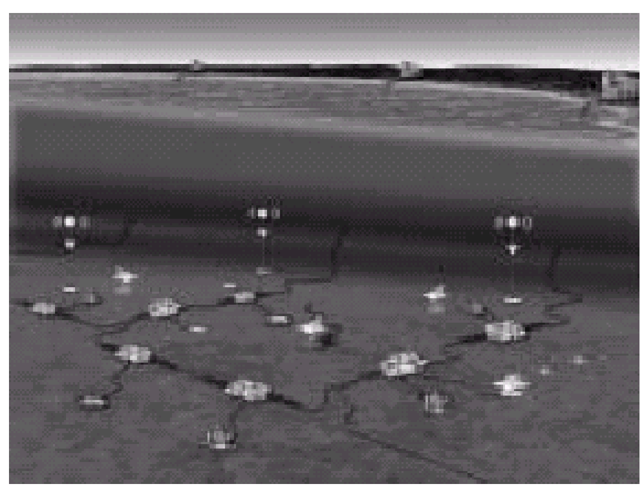

Figure 2 An image of ARENA

an underwater data transmission system. Using Ethernet and Internet technology, underwater observation nodes are directly connected to laboratories, and researchers can access sensors and get real-time data. Data can also simultaneously be delivered to all other related laboratories and agencies.

Structure of Observation Nodes

Figure 2 is an image of the ARENA The ARENA has many

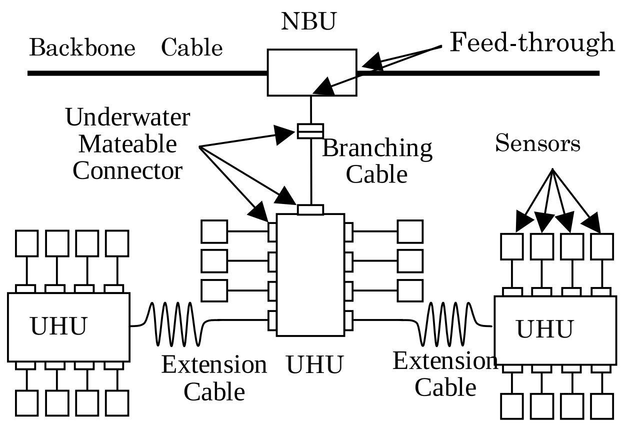

Figure 3 Basic structure of the observation node
NBU : Node Branching Unit
UHU : Underwater Hub Unit

scientific observation nodes with 50km intervals. Many kind of sensors can be installed in the observation node, including seismometers, tsunami sensors, CTD sensors, acoustic Doppler current profilers, electromagnetic sensors, television cameras, and heat flow sensors.

Autonomous Underwater Vehicles (AUV) will play an important role as the NEPTUNE project proposed. AUV will be stationed at the observation node for a long term and will periodically survey the area around the node. Or it will be dispatched when some anomalous phenomena are observed. AUV will get electric power from the cable network and exchange data and command through the cable network. It will significantly expand the observation area.

Some node will be located near boreholes drilled to inspect the inside of the earth. Sensors installed in boreholes will be connected to the cable network, and will provide continuous data for a long term. These sensors will include seismometers, pore pressure meters, tilt sensors and temperature sensors, and are expected to give us new information on the geodynamics under ground.

The observation node consists of a node branching unit (NBU), underwater hub units (UHU), sensors, a branching cable and extension cables as depicted in **Figure 3**. The UHU acts like an Ethernet switch or an Ethernet hub. Various sensors can be

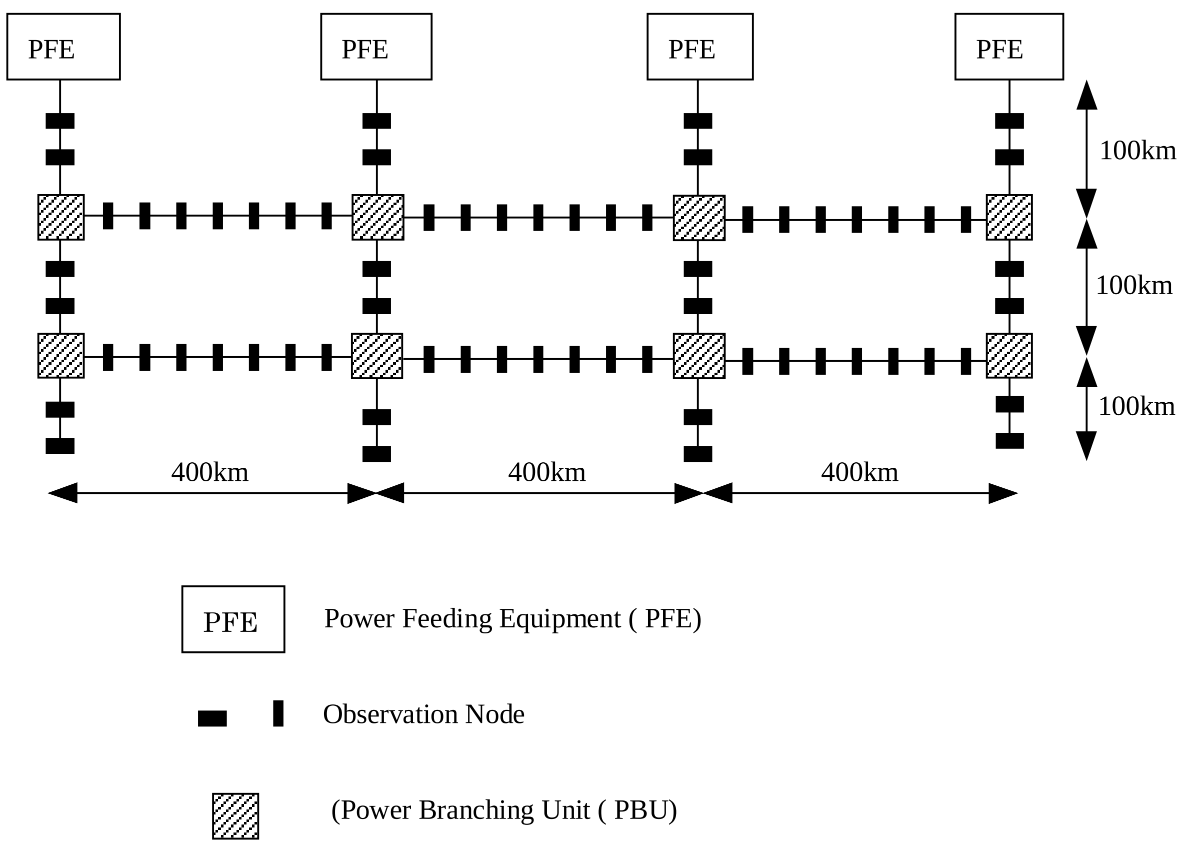

Figure 4 Engineering model of the scientific submarine cable network

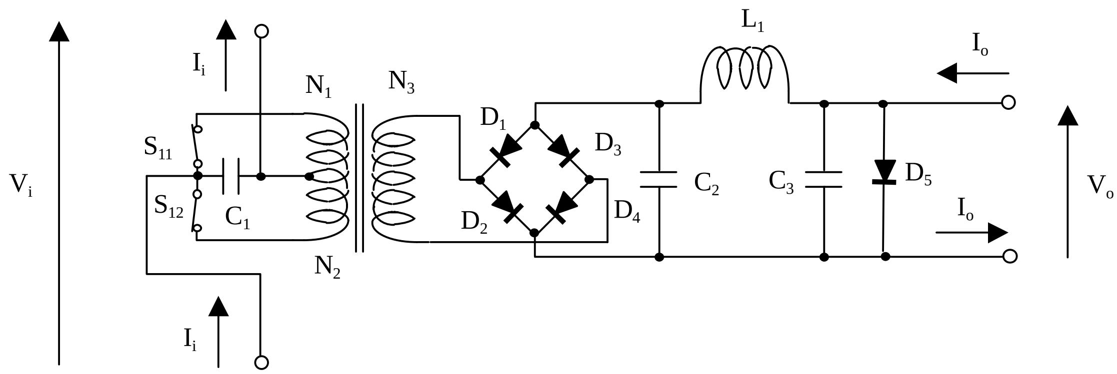

Figure 5 Basic circuit daigram of current to current converter

connected to the UHU, and another UHU can be connected to the UHU. Using the AOS(4), we can deploy an another UHU 10km apart.

As the UHU and sensors are connected through underwater mateable connectors, it can be exchanged or replaced for maintenance. These operation can be done with conventional vessels and remotely operated vehicles (ROVs). Moreover, it is possible to make a system in which even if an UHU or sensors failed it will not seriously effect the operation of the whole system. Therefore, we can use commercially available low-cost devices for UHUs and sensors without deteriorating the reliability of the whole system.

Power Feeding System

In order to quantitatively analyze the power feeding system and the optical data transmission system, an engineering model depicted in **Figure 4** was assumed. In this model, the cable network has four landing points and forms a mesh-like cable network. The total cable length is 3,600km, and 66 observation nodes are placed with 50km intervals. This model corresponds to the northeast part of ARENA depicted in **Figure 1** where the two parallel backbone cables are placed on the both sides of the plate boundary.

The sensors connected to the cable network can be categorized according to application field or type of sensors. For example, geophysical sensors includes a seismometer, a tsunami sensor, a gravimeter and a heat flowmeter, and an observation cite that consists of these geophysical sensors is called a geophysical observatory. **Table 1** shows the estimated number of the observatories included in the cable network depicted in **Figure 4** and the estimated power consumption of these observatories. These observatories are placed in the 66 observation nodes. The total power consumption is about 18kW, and the averaged power consumption at each node is 277W.

As described above, the conventional CC power feeding technology used for submarine telecommunication cable systems has many advantages. One of the merits is its robustness against cable faults. As the constant current is supplied by two power feeding equipments (PFEs) located at the both ends of the cable, even if the cable is shunt to the earth, the output voltages of the PFEs will automatically vary so that the voltage at the fault point becomes ground level. Moreover as electric circuits in repeaters are floating against sea water, a cable fault point can be located by measuring DC resistance between the power feeding line and sea water in case of a shunt fault, or by measuring capacitance between the power feeding line and sea water in case of an open cable fault. However the constant current can hardly be divided into two constant currents by using existing technologies, and could not easily be applied to a mesh-like cable network depicted in **Figure 4**. Here, we propose a new current to current converter that will be used to make a cable network based on the CC power feeding system.

	Average power (W)	Number of observatorie	Subtotal (W)
Geophysical observatory	15	132	1,980
Downhole observatory	69	2	138
Oceanographical	121	10	1,210
Geodetic observatory	11	43	473
Array sensors	4	2	8
Camera observatory	212	2	424
AUV station	60	10	600
Acoustic tomography	60	4	240
Transmission and power system	200	66	13,200
Total			18,273

Table1 Estimated number of observatories and power consumption

Figure 5 shows a basic circuit diagram of the current to current converter. The input electric power is supplied in CC mode. With switching devices like MOS-FETs at the input stage, the input dc current is converted to AC current and fed to a transformer. The output current of the transformer is rectified to make a dc output current. If the duty ratio of the switching devises is 50 to 50%, and numbers or turns N1, N2, N3 of the transformer are the same, the output current is almost equal to the input current. This means that the output current is also the constant current equal to the input current.

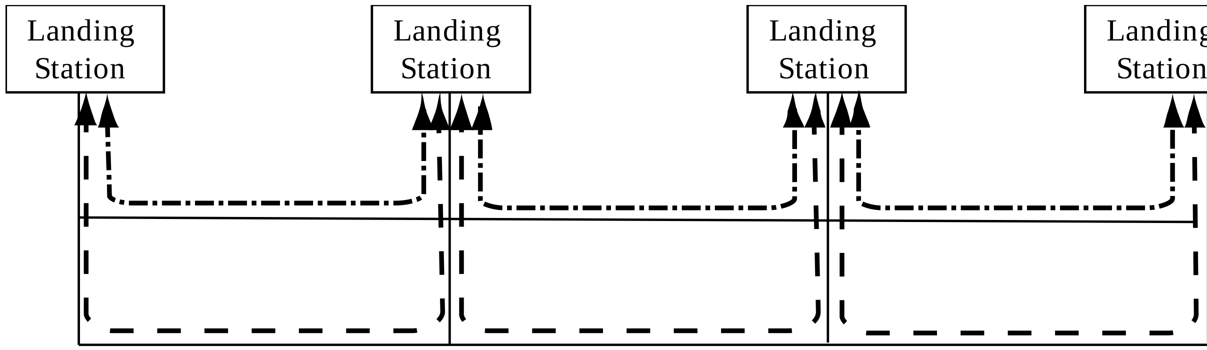

Figure 6 Basic ring network architecture of the optical data transmission system

As the basic circuit is very simple and there is no feedback loop, high reliability and high conversion efficiency can be expected. However there are some issues to be examined to realize the current to current converter. Followings are these issues.

(1) current adjustment
The current to current converters should be placed at the both ends of the cable in order to make redundancy and heighten reliability. In this case, output currents should precisely be adjusted to the same value to keep the balance between the two currents to current converters. We think that changing the duty ratio of the switching can adjust the current.

(2) serial connection
The switching devises mainly restrict the output voltage of the current to current converter. In order to heighten the output voltage, plural current to current converters are required to be connected serially. In this case, the output currents also should be precisely adjusted to the same value.

(3) protection against open output circuit
When the output circuit is open, the output and the input voltage will increase rapidly. A protection circuit is needed to prevent such high voltage from breaking down electric devises.

(4) stability
As the network is complex, stability of the power feeding system should be carefully examined.

(5) reliability
Reliability is one of the most important issues to be examined because the power feeding system is one of the backbone systems, and its failure will affect the wide range of the system. In order to heighten the reliability while preventing cost inflation, appropriate redundancy and derating of devices is needed. Failure rate or lifetime should be examined carefully.

We will continue the study on the current to current converter, and the results of the study will be published elsewhere.

Optical Data Transmission System

In the ARENA system, the amount of data is estimated to be about 2Gbit/s, but most of them is due to high-definition television (HDTV) signals, and data from other sensors is only about 4.5Mbit/s. The optical data transmission system should be flexible that can handle these data with various bit rate. The system also should provide a time synchronization signal with accuracy of 10^{-6}sec to sensors.

Cost and reliability are important factors that are conflicting with each other. Another requirement includes expendability and low power consumption.

Recently, WDM, OA and Internet technology have expanded rapidly as mentioned above. This expansion makes the cost of these devices low and makes their procurement easy. WDM and OA consist of only a few optical components. Therefore, it is possible to make a simple and robust optical data transmission system with appropriate cost.

Figure 6 shows overview of the basic ring network architecture of ARENA. Any observation node on the network can be accessed from two landing stations. By segmentizing the network, we can increase the robustness of the network as the extent over which a single failure will affect is restricted within the segment. And it is easy to expand the network. There are some other modified ring network architectures to be compared.

Figure 7 shows detailed network architecture of a segment. In this case, one or a few wavelength is assigned to each observation node. The transmission protocol is Internet protocol (IP). As Ethernet switches or routers with large-scale electric circuits are not used in the backbone data transmission system, it is easy to increase the reliability of the system. Even if one of the Ethernet switches is failed, it will not affect other nodes of the network.

Figure 8 shows a wavelength assignment to each observation node. The network consists of two optical fibers. By using two optical fibers, the observation node can be accessed from two landing stations located at the both ends of the cable, and can take the most advantage of the ring network. One wavelength at least is assigned to each observation node. High-bit-rate data for HDTV can be included in the assigned wavelength or another wavelength can be assigned to the HDTV data. Other

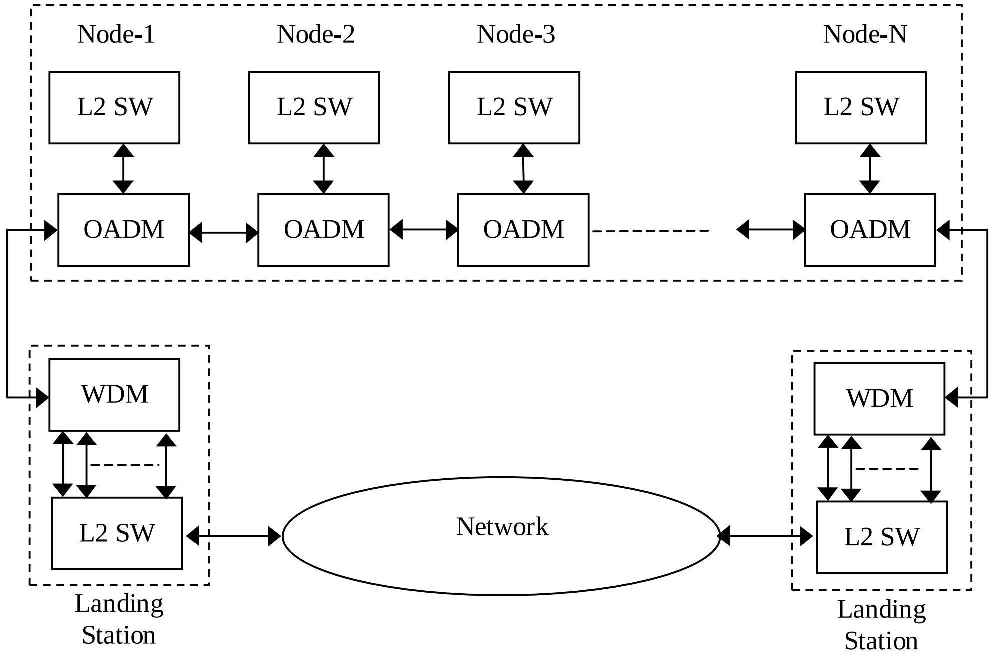

Figure 7 Ring network with OADM

L2 SW : Level 2 Ethernet Switch, OADM : Optical Add/Drop Multiplexer
WDM : Wavelength Division Multiplexer

wavelengths include one for distribution of time synchronization signal, one for spare, two for monitoring of backbone data transmission system, and two for backbone layer. The backbone layer is used to connect landing stations to increase the flexibility and robustness of the network.

Conclusions

New scientific cable network named ARENA is proposed that has a mesh-like cable topology surrounding Japanese Islands.

The UHU and sensors are connected to the backbone cable through underwater mateable connectors. Therefore even if the UHU and sensors failed, it can be exchanged and redeployed at the same point it was. The failure of UHU and sensors will not affect the other portion of the network.

Engineering model of ARENA was made to qualitatively analyze the power feeding system and the optical data transmission system. Power feeding system is the most challenging topics, because conventional constant current power feeding system can not directly be applied to a mesh-like cable network of ARENA. In this paper, an idea of new current to current converter was presented that makes it possible to apply constant current power feeding system to ARENA. Issues to be examined are also pointed out.

The simple and robust optical data transmission system based on WDM, OA and Ethernet technology was also presented.

The backbone system is simple and have reliability, while the UHU and sensors consist of commercially available low-cost devices that can be exchanged and redeployed for maintenance and replace.

The feasibility study is still ongoing and an interim report will be published soon.

Acknowledgment

This paper is based on the discussion being done within the committee on the underwater cable-network for scientific seafloor monitoring organized by IEEE OES Japan Chapter. The committee consists of 45 persons from 17 organizations. The committee is too large to list all the members here. The authors would like to express sincere appreciation to the member of the committee who contributes to present this paper.

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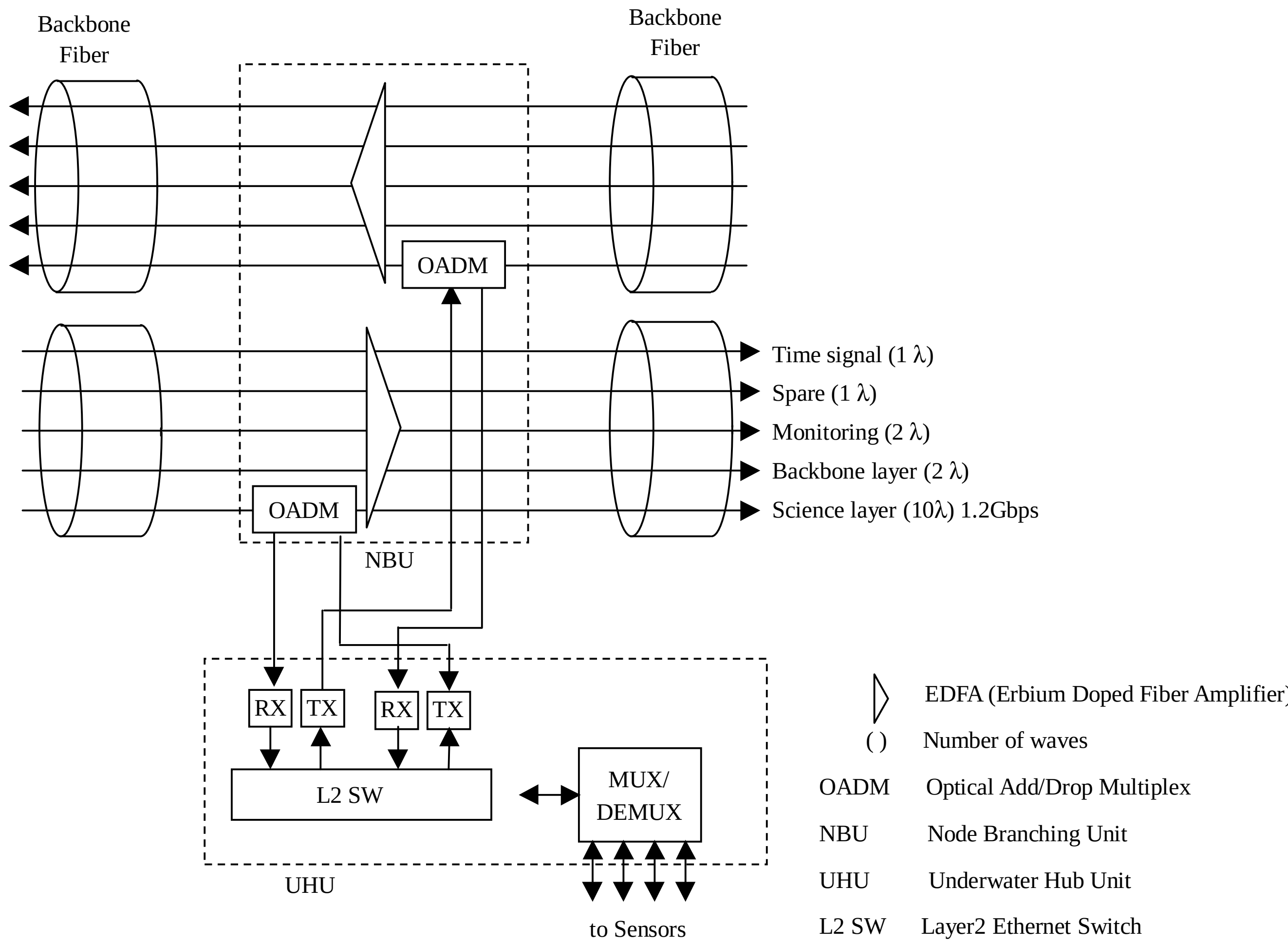

Figure 8 Wavelength assignment to each observation node

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