FEASIBILITY STUDY ON LONG-TERM CONTINUOUS MONITORING FROM SEAFLOOR WITH UNDERWATER CABLE NETWORK

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ABSTRACT

Seafloor observation system using the underwater telecommunication cable is one of the most reliable ways to secure high-speed data transmission and continuous power feeding to underwater devices. In this paper a new scientific submarine cable system will be presented that were proposed by the technical committee organized by IEEE OES (Institute of Electrical and Electronics Engineers, Oceanic Engineering Society) Japan Chapter. The proposed scientific cable network will have the following feature. (1) mesh-like cable network configuration covering vast research area, (2) more than 3,000km total cable length, (3) deployable up to 6,000m water depth, (4) over 66 observation nodes with 50km intervals, (5) exchangeability of sensors, (6) system extensibility. This paper will also describe the role of the scientific submarine cable-network and its historical background.

1. INTRODUCTION

Japanese islands are located near the plate boundaries, and it is well known huge earthquakes occur periodically at the boundaries. In order to study the nature of these earthquakes and mitigate disasters, several institutions in Japan installed cabled observatories shown in Figure 1[1]. It is reported that these cabled observatories can improve sensitivity, accuracy of the localization of the hypocenters, and hence enhance the knowledge on the earthquakes in the offshore.

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However recent progress of the cabled observatories and underwater optical cable technology shows that the cabled

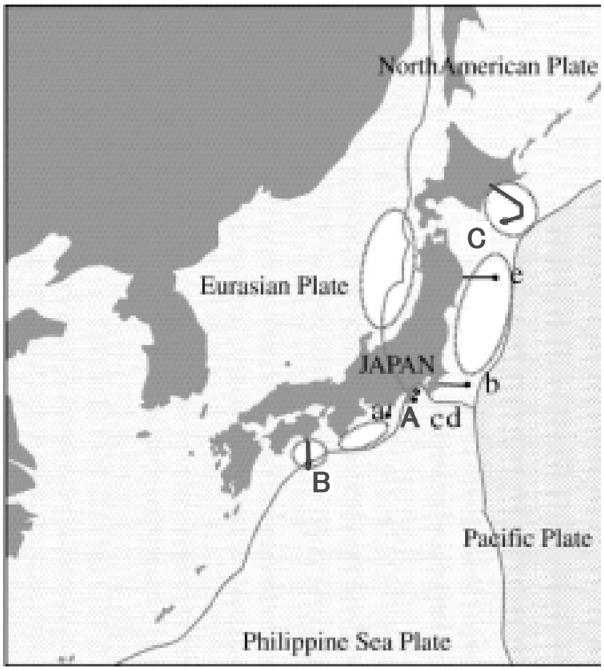

Figure 1: Cabled observatory systems around Japan

a) JMA Off-Suruga, b) JMA Off-Boso, c) ERI East Off-Izu Peninsula, d) NIED Sagami-Trough, e) ERI Off-Sanriku, A) JAMSTEC Hatsushima Engineering Development, B) JAMSTEC Off-Muroto, and C) JAMSTEC Off-Tokachi-Kushiro systems. Circled water areas were advocated by the Headquarters of Earthquake Research Promotion that the real-time observations are necessary for future potential of catastrophic earthquakes.

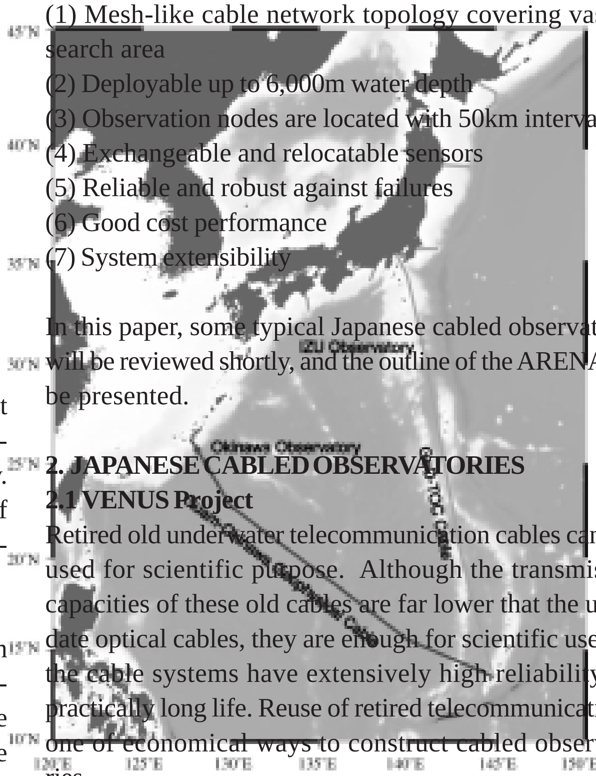

Figure 2: Re-use of the retired underwater telecommunication cables

Two cables were used for scientific purposes. Two other sites in the GEO-TOC cable (former TPC-1(Trans-Pacific Cable-) Co-axial cable with vacuum tube amplifiers, constructed in 1964) have been planned for future installation of a seismometer and geophysical observations. The Guam-Okinawa Geophysical Cable (former TPC-2: Co-axial cable with transistor amplifiers, constructed in 1976) was utilized to experimentally install a multidisciplinary observatory in the VENUS project.

observatories can be used not only for seismology but also for many scientific field such as geodynamics, oceanography, marine environmentology, ecology and biology. They will provide long-term, real-time continuous data of large amount from seafloor that can not be obtained otherwise.

In February 2002 IEEE Oceanic Engineering Society Japan Chapter organized a committee on the submarine cable-network for scientific observations. The purpose of the committee is to do the technical feasibility study on the scientific use of underwater cables and to issue a technical paper. The proposed scientific submarine cable-net-

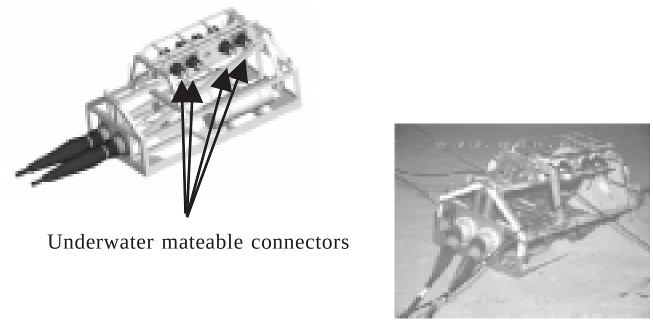

Figure 3: A junction box developed in the VENUS project.

The junction box provides electric power and data transmission line to multiple sensors including wide-band seismometer, tsunami sensor, geomagnetic and electric field observation system, hydrophone arrays, seafloor acoustic ranging system and television camera.

work is named ARENA (Advanced Real-time Earth monitoring Network in the Area).

The ARENA will have the following features.

(1) Mesh-like cable network topology covering vast research area
(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) Good cost performance
(7) System extensibility

In this paper, some typical Japanese cabled observatories will be reviewed shortly, and the outline of the ARENA will be presented.

2. JAPANESE CABLED OBSERVATORIES

2.1 VENUS Project

Retired old underwater telecommunication cables can also used for scientific purpose. Although the transmission capacities of these old cables are far lower that the up-to-date optical cables, they are enough for scientific use, and the cable systems have extensively high reliability and practically long life. Reuse of retired telecommunication is one of economical ways to construct cabled observatories.

Figure4: A adptable observation system off the coast of Kushiro-Tokachi

The expansion cable, that connects the branch MUX on the trunk cable and the adaptable remote observatory, was deployed using a deep-tow system and a ROV. The adaptable remote observatory consists of a joint MUX, sensors and battery pack which were connected by using underwater mateable connectors.

In 1999, a multidisciplinary observatory was experimentally installed in the Guam-Okinawa Geophysical Cable (Figure 2 and 3) in the VENUS project [2]. Several sensors are connected to the junction box through underwater mateable connectors. This means that the sensors can be replaced for renewal or maintenance, therefore extremely high reliability is no longer required. Until halting due to a failure in the connector, the VENUS system provided continuous data from seafloor. A similar cabled observatory [3] was installed using the retired underwater telecommunication cable connecting Hawaii and California a little time before the VENUS project. These projects showed that deploying multidisciplinary observatory having multiple sensors on the seafloor is feasible.

2.2 Off-Kushiro-Tokachi system

The off-Kushiro-Tokachi system [4] has a remote adaptable observatory that is up to 10 kilometers apart from the trunk optical fiber cable. The thin optical fiber expansion cable connects the branch MUX and the joint MUX using underwater mateable connectors. The power-branch is the next technical theme. The off-Kushiro-Tokachi system shows that we can deploy the sensors two dimensionally and place them precisely to the target point apart form the trunk cable.

Figure5: An example of the estimated earthquake hypocenters

Vertical cross sections along NS and EW directions are respectively shown at the right and the bottom. Cross marks and solid circles represent estimated hypocenters after and before the inclusion of data from the cabled seismometers. The Off Muroto cable system is used for the comparison. It is shown that underwater seismometer constrain the estimated depth of the seismic events.

2.3 Scientific advances

Figure 5 shows an example of the estimated earthquake hypocenters with one of these cabled observatories. It compares the estimated earthquake hypocenters after and before the inclusion of data from underwater seismometers. It is quite clear that the underwater seismometers increase the accuracy of localizing earthquake hypocenters, and then enhance the understanding of the earthquake mechanism.

3. OUTLINE OF ARENA

In addition to the progress of the cabled observatories, recent evolution in optical underwater cable technology and network technology represented by Internet enable to realize a noble versatile scientific submarine cable network of next-generation. WDM (Wavelength Division Multiplex) technology and optical amplifier technology provide us extremely high data-transmission capacity of bit-rate free and flexible network easy to expand. Using

Figure 6: An artistic image of ARENA

Multiple observatories will be two-dimensionally distributed across plate boundaries, and many kinds of sensors will be connected to the trunk cables. The cable system has mesh-like topology in order to deploy observatories in wide area, and to increase the reliability and redundancy of the whole system. Some observatories have borehole sensors that will be used to explore the inner of the earth crust and get seismic data from underground. AUVs (Autonomous Underwater Vehicles) will play an important role to enlarge the observation area. It will usually be stationed on a platform to get electric power and to send/receive data. It will explore the surroundings periodically, or will be dispatched in case of special events.

Ethernet and Internet technology, underwater sensors can be directly connected to laboratories.

Considering these situations, IEEE OES Japan Chapter initiated a feasibility study on the scientific submarine cables.

Figure 6 and Figure 7 show the artistic image and the cable network of ARENA respectively. In ARENA mesh-like cable topology is proposed in order to deploy sensors two-dimensionally. Observation nodes are placed with 50km intervals.

Figure 8 shows the structure of the observation node. The node has an Internet-like topology, and consists of multiple sensors. Using extension cables, sensors can be deployed in a place apart from the NBU (Node Branching Unit) and the backbone cable.

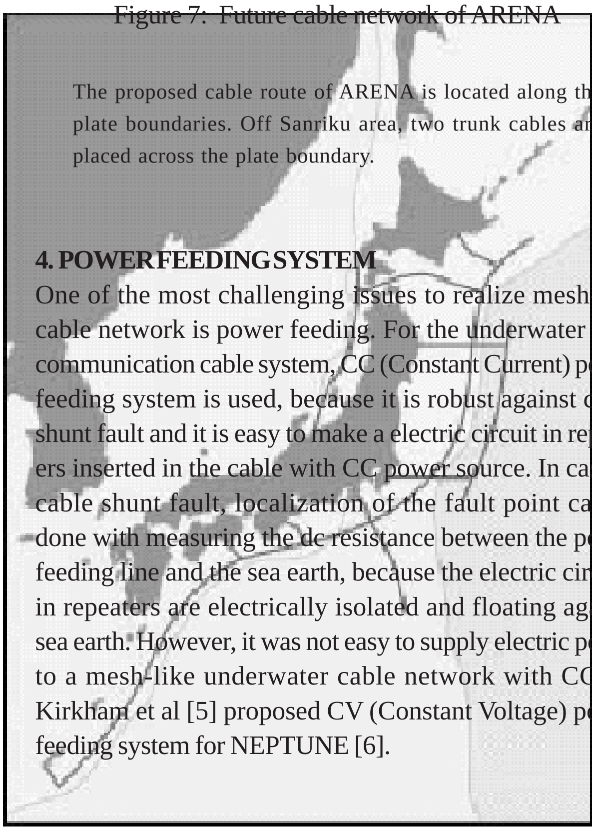

Figure 7: Future cable network of ARENA

The proposed cable route of ARENA is located along the plate boundaries. Off Sanriku area, two trunk cables are placed across the plate boundary.

4. POWER FEEDING SYSTEM

One of the most challenging issues to realize mesh-like cable network is power feeding. For the underwater telecommunication cable system, CC (Constant Current) power feeding system is used, because it is robust against cable shunt fault and it is easy to make a electric circuit in repeaters inserted in the cable with CC power source. In case of cable shunt fault, localization of the fault point can be done with measuring the dc resistance between the power feeding line and the sea earth, because the electric circuits in repeaters are electrically isolated and floating against sea earth. However, it was not easy to supply electric power to a mesh-like underwater cable network with CC. H. Kirkham et al [5] proposed CV (Constant Voltage) power feeding system for NEPTUNE [6].

In the feasibility study, we had compared three systems, which are (1) CC power feeding system, (2) CV power feeding system [7], and (3) hybrid power feeding system that consists of CV power feeding part and CC power feeding part. In order to analyze the power feeding system and data transmission system, we made an engineering model depicted in Figure 9. Table 1 shows the estimated number of observatories and power consumption in the engineering model. As the result of the feasibility study, we proposed a noble current to current converter that divide a CC into two CCs, and enables to realize a mesh-like cable network with CC power feeding system. The proposed current to current converter is a key unit comprising PBU (Power Branching Unit).

The basic electric circuit of the proposed current to current converter is depicted in Figure 10. As the basic circuit is very simple and there is no feedback loop, high reliability and high conversion efficiency can be expected.

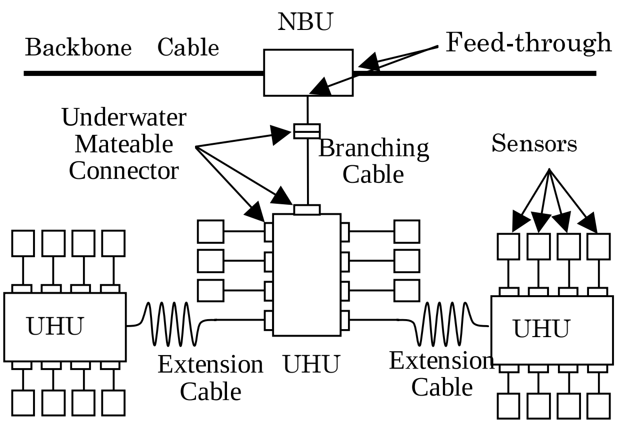

Figure 8: Basic structure of the observation node

The observation node consists of a NBU (Node Branching Unit), an UHU (Underwater Hub Unit), a branching cable, extension cables and sensors. The UHU acts like an Ethernet hub or Ethernet switch. These devices are connected with underwater mateable connectors.

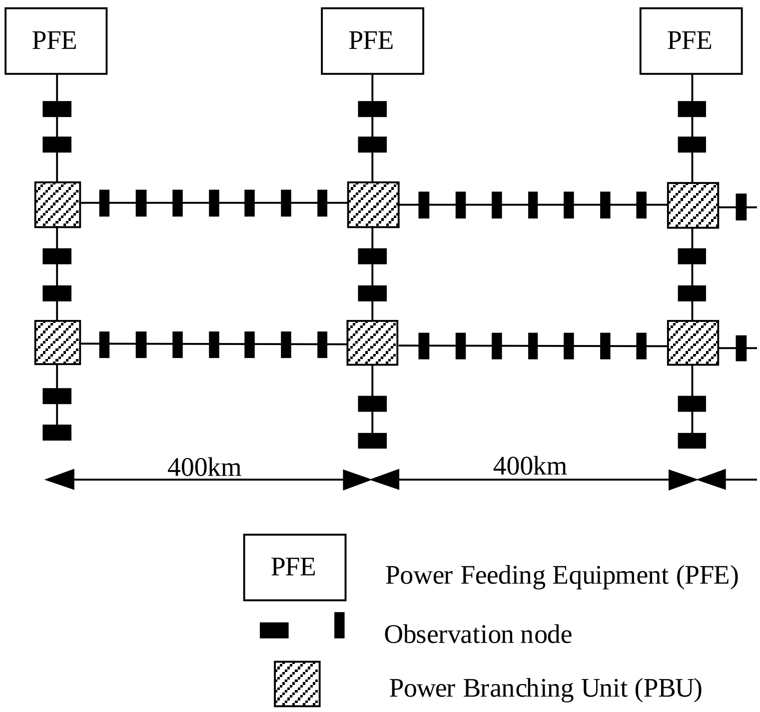

Figure 9: Engineering model of ARENA

This engineering model was made to analyze the power feeding system. In this model, the network has four landing point and mesh-like topology corresponding to the off Sanriku area in Figure 7 where two backbone cables are placed on both side of the plate boundary. 66 observation nodes are placed with 50km intervals. PBUs (Power Branching Unit) receive electric power from PFEs (Power Feeding Equipment) on the landing stations, and provide electric power to the laterally stretching cables.

Two current sources should be placed at the both ends of the cable in order to increase redundancy and heighten reliability. It means that even if one of the two current sources fails, the other will continue to provide all the electric power to the cable. In order to place two current sources at the both end of the cable, output currents should precisely be adjusted to the same value to keep the balance between the two current sources. Changing the duty ratio of the switching devices can do this adjustment. Output admittance of the current sources also plays the important role in the current adjustment.

As the output current level can be adjusted, this current to current converters can be connected in series in order to heighten the input and the output voltage range.

Table1 Estimated number of observatories and power consumption

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

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

5. OPTICAL DATA TRANSMISSION SYSTEM

The proposed ring network with OADM (Optical Add/ Drop Multiplexer) is shown in Figure 11. In this case, one wavelength at least is assigned to each observation node. The transmission protocol is Internet protocol. A Level 2 Ethernet switch is placed in each observation node, and is directly connected to the landing station, that is no other Ethernet switch in incorporated between the Ethernet switch and the landing station. As the data transmission system in the backbone cable consists of optical amplifiers and passive optical devices, those are commonly used for underwater telecommunication cables, high reliability can be expected. Even if one of the L2 Ethernet switches faulted, only the communication with the corresponding observation node is affected. Increasing the number of wavelength can expand the network.

Figure 12 shows an example of the 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. It means that the system is robust against cable faults. High-bit-rate data for HDTV (High-Definition Television) can be included in the assigned wavelength or another wavelength can be added for the HDTV data. Other wavelengths include one

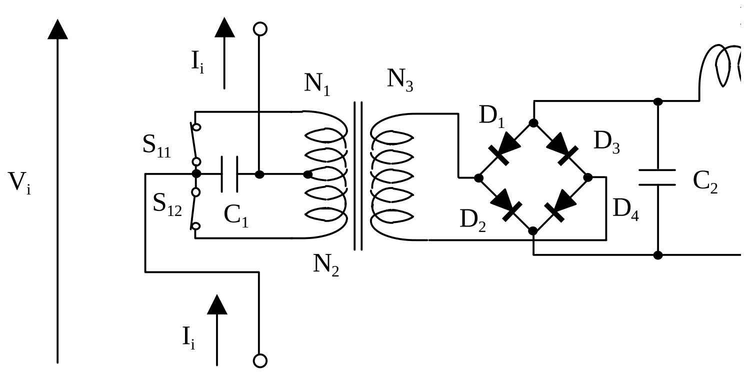

Figure 10: Basic electric circuit of the current to current converter

At the input stage the input constant current I_i is converted to AC current with switching devices such as MOS-FET, and fed into the transformer. The output of the transformer is rectified and filtered to make output DC current I_o.

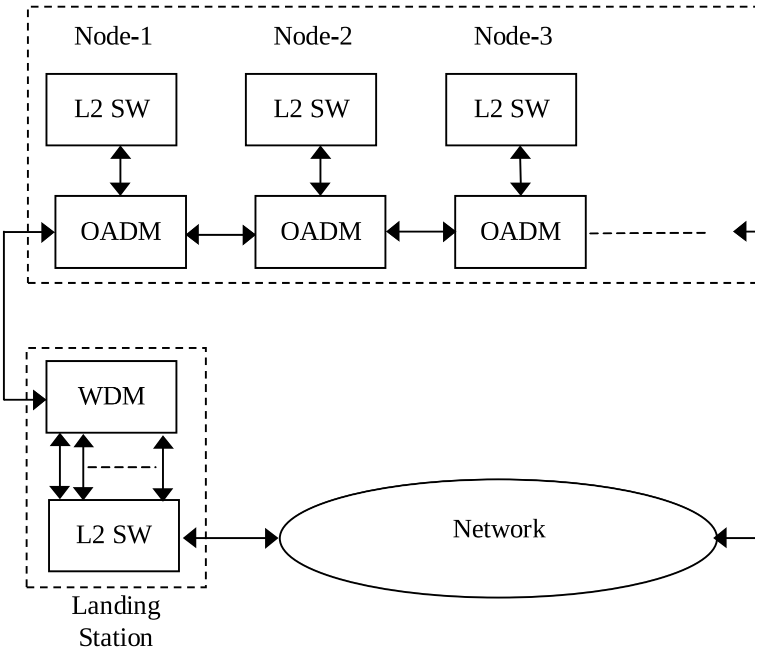

Figure 11: Ring network with OADM (Optical Add/Drop Multiplexer)

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

6. CONCLUSIONS

Current status of cabled observatories in Japan was reviewed briefly, and outline of the newly proposed scientific submarine cable network ARENA was presented.

Recent evolution of cabled observatories and related technologies including optical underwater cable technology and Internet technology enables the development of versatile cabled observatory system of next-generation.

The cable route of ARENA is located along the plate boundaries and the future system will stretch along Japanese islands. Observation nodes are placed with 50km interval.

A new current to current converter was proposed that enables utilization of CC power feeding system for the mesh-like cable network.

The simple and robust optical data transmission system based on WDM 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 submarine 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 12: Wavelength assignment to each observation node

Other OADMs inserted in the monitoring and timing signal line are not depicted in the figure.

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