

ARENA : A Versatile and Multidisciplinary Scientific Submarine Cable Network of Next Generation

Yuichi Shirasaki¹⁾, Minoru Yoshida²⁾, Takao Nishida³⁾, Katsuyoshi Kawaguchi⁴⁾, Hitoshi Mikada⁴⁾ and Kenichi Asakawa⁴⁾ and members of committee on the submarine cable-network for scientific seafloor monitoring organized by IEEE OES Japan Chapter

1) Institute of Industrial Science, University of Tokyo (sirasaki@iis.u-tokyo.ac.jp)

2) Hakusan Corporation

3) OCC Corporation

4) Japan Marine Science and Technology Center

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ABSTRACT

Seafloor observation system using the underwater cable is one of the most reliable ways to provide high-speed data transmission and continuous power feeding to underwater devices. Recent evolution in the optical submarine cable and Internet technology make it possible to develop a versatile scientific submarine cable network. IEEE OES (Institute of Electrical and Electronics Engineers, Oceanic Engineering Society) Japan Chapter has conducted the feasibility study on the new scientific submarine cable network. The proposed scientific cable network named ARENA has the following feature. (1) mesh-like cable network configuration covering vast research area with 3,600km of total cable length, (2) over 66 observation nodes with 50km intervals, (3) robustness against failures, (4) wideband optical transmission system capable of transmitting plural HDTV (High definition Television) signal and synchronizing time signal with accuracy of one microsecond, (5) system extensibility, (6) exchangeability of sensors. This paper will describe the outline of ARENA.

1. INTRODUCTION

Japanese archipelago is located near plate boundaries, and it is well known that huge earthquakes occur periodically at plate boundaries. In order to study the nature of these earthquakes and mitigate disasters, several institutions in Japan installed cabled observatories⁽¹⁾. It was reported⁽²⁾ that these cabled observatories could improve the sensitivity, the accuracy of the localized hypocenters, and hence enhance the knowledge on earthquakes in the offshore. It was also recognized that by deploying plural cabled seismometers in seismic zone, we can get more accurate and holistic data that is required to advance the research on seismology.

Recently, technologies on the cabled observatories, underwater optical cable systems, Internet and related field have evolved very rapidly. WDM (Wavelength Division Multiplex) technology and optical amplifier technology provide us extremely high data-transmission capacity and flexible network easy to expand. As the network is bit-free, the freedom for the data transmission method becomes higher. The cost of the amplifier is reduced due to its simple configuration. WDM technology also enables to branch underwater optical data transmission line. Internet technology reduces the cost of the data transmission on land, and makes it easy to construct flexible underwater sensor network. Evolution in computer and semiconductor technology will also contribute to the development in the cabled observatories. This evolution in the related field makes it possible to develop a new kind of versatile and flexible scientific submarine cable

networks. It is expected that the new scientific submarine cable network will bring new advance in the scientific field.

Considering the above situations, IEEE OES Japan Chapter organized a technical committee on the scientific submarine cables. The purpose of the committee is to conduct a technical feasibility study on the scientific use of underwater cables. The committee was established in February 2002, and published a technical white paper in January 2003. Forty-five engineers with various backgrounds from private companies, universities and research institutes participate in the committee. The committee consists of the steering committee, the power feeding working group, the data transmission working group and the underwater system working group. The underwater system working group handled the configuration of the underwater system, reliability, construction and maintenance. The detail of the proposed power feeding system and the data transmission system are described in another papers⁽³⁾, ⁽⁴⁾ in this proceedings.

The proposed scientific submarine cable-network is named ARENA (Advanced Real-time Earth monitoring Network in the Area). As described by Kasahara et al.⁽⁵⁾, the ARENA can be used not only for seismology but also for many scientific fields such as geodynamics, oceanography, marine environmentology, ecology, biology and development of mineral resource. It will provide long-term, real-time continuous data of large amount from seafloor that can not be obtained otherwise.

The ARENA has the following features.

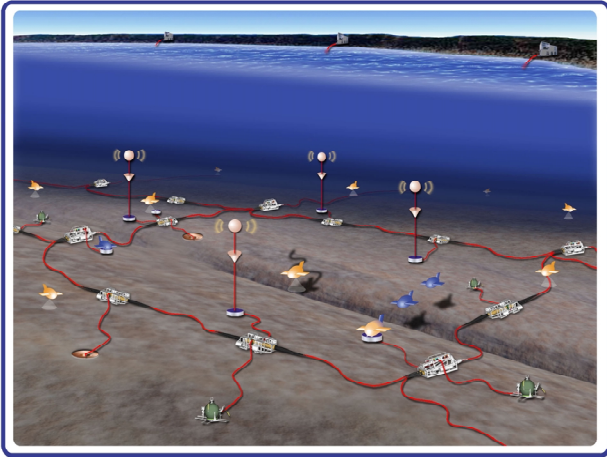


Figure 1: An artistic image of ARENA

- (1) Mesh-like cable network configuration covering vast research area with 3,600km of total cable length
- (2) Over 66 observation nodes with 50km intervals
- (3) Robust against failures
- (4) Wideband optical transmission system capable of transmitting plural HDTV (High definition Television) signal and synchronizing signal with accuracy of one microsecond
- (5) System extensibility
- (6) Exchangeability of sensors

In this paper, the outline of the ARENA will be presented.

2. OUTLINE OF ARENA

When initiating technical feasibility study, it is important to define technical requirements. The followings are general technical requirements for ARENA.

(1) Cost and Reliability

Reliability and robustness of the underwater system is one of the important practical issues as it is not easy to repair the underwater devices when it is broken. Conventional underwater telecommunication system is made with highly reliable devices and has a long MTBF (mean time between failures) of about ten years or more and a long system life. However it is not realistic to make all the underwater devices of ARENA with such highly reliable devices as used for the underwater telecommunication system, as it will extremely increase the development cost. It is important to realize a reliable system without increasing the construction cost.

(2) System Expandability

The backbone system is required to be expandable. It should be able to be constructed segment by segment, and be integrated into a large system. Sensors should be able to be added after the backbone system is completed.

(3) Fault point localization from landing stations



Figure 2: 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.

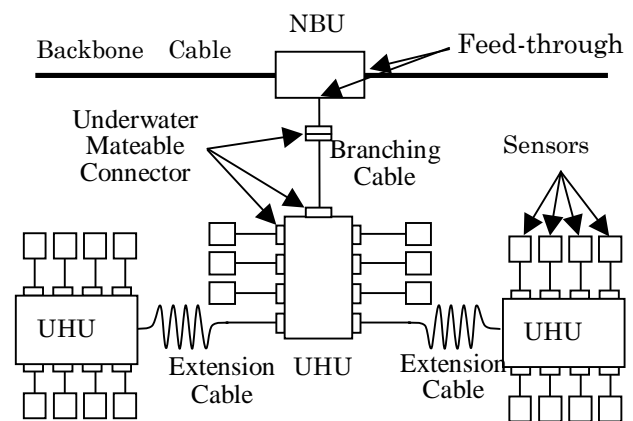


Figure 3: Basic structure of the observation node

When a serious fault occurred in the backbone system, it should be important to accurately localize the fault point from landing stations in order to repair the system quickly.

(4) Handling on a working ship

As space on a working ship and handling capacity is limited, handling on a working ship should be considered. Maintenance with working ship is also important issue.

(5) Flexible data management

In the ARENA, a variety of sensors are connected to the backbone system. Some of them should be for continuous monitoring such as seismometers and tsunami sensors, and some of them should be for cutting-edge researches. The requirement for the data management should differ according to objectives of monitoring and the stage of research. The data management system should be flexible to be able to adapt to various kind of requirement.

(6) Common interface for sensors

In order to lower the development and maintenance cost of the backbone system, common sensor interface should be developed.

(7) International cooperation

International cooperation is essential in various fields in order to improve the efficiency of development and enhance data exchange and distribution.

Figure 1 and figure 2 show the artistic illustration of ARENA and the envisioned future network of ARENA. Plural observation nodes are two-dimensionally deployed across the plate boundary, and many kinds of sensors are connected. These sensors include seismometers, tsunami sensors, physical sensors such as ADCPs, CTDs, hydrophones, chemical sensors, television cameras. Borehole observatories will also be connected to the cable network.. AUVs (Autonomous Underwater Vehicles) will play an important role to widen 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 when a special event occurs.

The cable system has mesh-like topology to effectively deploy observation nodes in the vast research area. By deploying many sensors in the area, we can increase spatial resolution of monitoring. This feature is especially important for the seismic observation. Using many distributed seismometers, we can not only detect small earthquakes with plural sensors, but also can increase spatial resolution of the estimated hypocenters of earthquakes. We can deepen the understanding of earthquakes

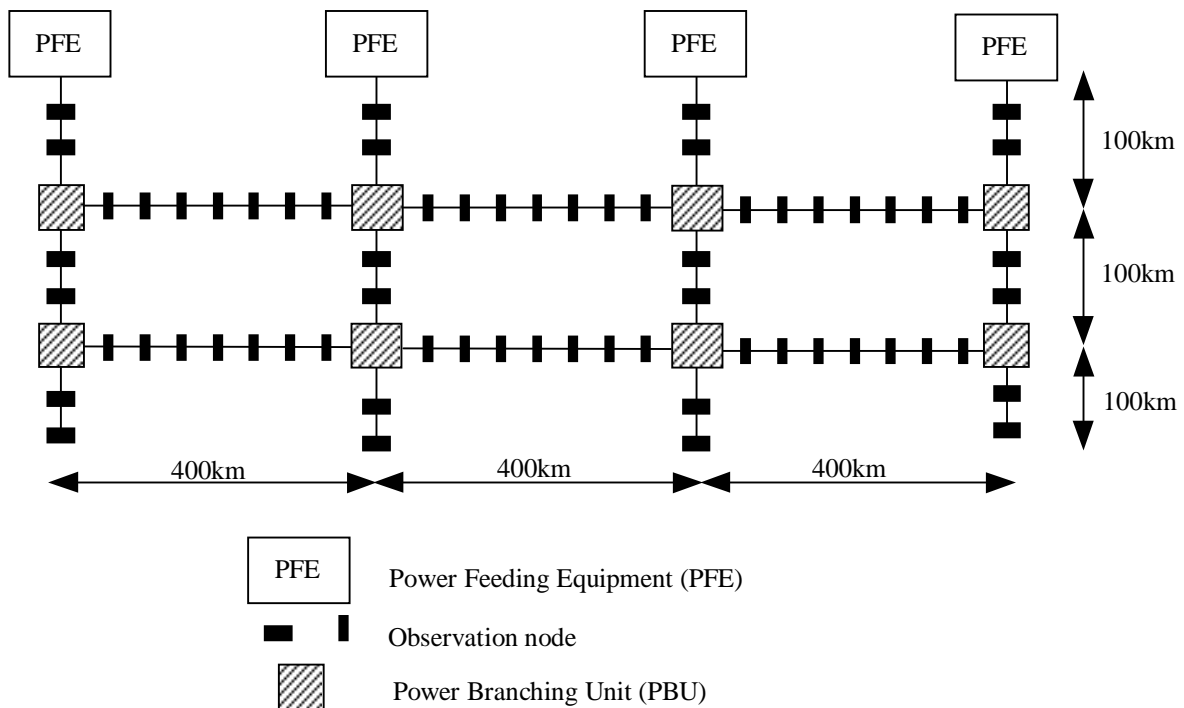


Figure 4: Engineering model of ARENA

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 2 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 backbone cables.

Table1 Estimated number of observatories and power consumption

	Average power (W)	Number of observatories	Subtotal (W)
Geophysical observatory	15	132	1,980
Downhole observatory	69	2	138
Oceanographical 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 power system	200	66	13,200
Total			18,273

with accurate data set.

The cable network has plural landing stations. The sensors can be accessed from more than two landing stations. This means that even if the cable is broken at any portion, and the access to sensors from the corresponding landing station is disturbed, the sensors can be accessed from the other landing station. This feature increases the reliability and robustness of the whole system.

Observation nodes can be placed in the cable with 50km intervals. Figure3 shows the basic configuration of the observation node. The observation node consists of a Node Branching Unit (NBU), underwater hub units (UHU), a branching cable, extension cables and sensors. UHUs acts like Ethernet hubs or Ethernet switches. These devices and sensors are connected through underwater mateable connectors. This means these instruments can be repaired when they are broken, or can be replaced when new devices become available. Hence these instruments can be made with ordinary inexpensive parts

3. POWER FEEDING SYSTEM

One of the most challenging issues to realize a mesh-like cable network is power feeding. For the underwater telecommunication cable system, CC (Constant Current) power feeding system is used, because it has the following advantages.

(1) It is robust against cable shunt fault. As the electric power is usually supplied from both end of the cable, even if the cable is broken at one point, the electric power can be continuously supplied from the both end, and only the electric potential of the cable changes.

(2) It is easy to electrically isolate underwater electric circuit from seawater, as there is no sea earth brought into the circuit.

(3) In case of cable shunt fault, the fault point can easily be localized with measuring the dc resistance between the power feeding line and the sea earth.

However, it was not easy to supply electric power to a mesh-like underwater cable network with CC power feeding system, as there was no device reported to branch constant current.

In the feasibility study, we had compared three systems, which are (1) CC power feeding system, (2) CV Constant Voltage) power feeding system, and (3) hybrid power feeding system that consists of CV power feeding part and CC power feeding part.

Constant voltage power feeding system has the advantage that it can easily branch electric power. H. Kirkham et al.(6) proposed CV power feeding system for NEPTUNE(7). However, there are some issues to be addressed such as localization and disconnection of fault point, DC/DC converter with higher input voltage in each observation node.

In order to analyze the power feeding system and data transmission system, we made an engineering model depicted in Figure 4. 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 branches a constant current into two constant currents, and enables to realize a mesh-like cable network with CC power feeding system. The proposed current to current converter is a key device in PBU (Power Branching Unit). The detail of the comparison of the three power feeding system and the proposed current to current converter is described in the other paper(3) in this proceedings.

JAMSTEC has made the prototype of the current to current converter and is now doing the fundamental test with the prototype. The result of the test will be published in near future.

4. OPTICAL DATA TRANSMISSION SYSTEM

In the feasibility study, several possible optical transmission systems were compared, and finally the ring network with OADM (Optical Add/Drop Multiplexer) shown in Figure 5 and 6 is proposed for ARENA. Optical amplifiers and passive optical devices are used in the data transmission system for the backbone cable. These devices are commonly used for underwater telecommunication cables. As the configuration of these devices is simple, it is easy to secure high reliabilities without extremely increase of cost.

In the proposed system, one wavelength at least is assigned to each observation node. A Level 2 Ethernet switch is placed in each observation node, and is directly connected to the landing station. No other Ethernet switch is incorporated between the Ethernet switch in the observation node and the landing station. This means that even if one of the Ethernet switches broken, its impact is limited and only the corresponding observation node is

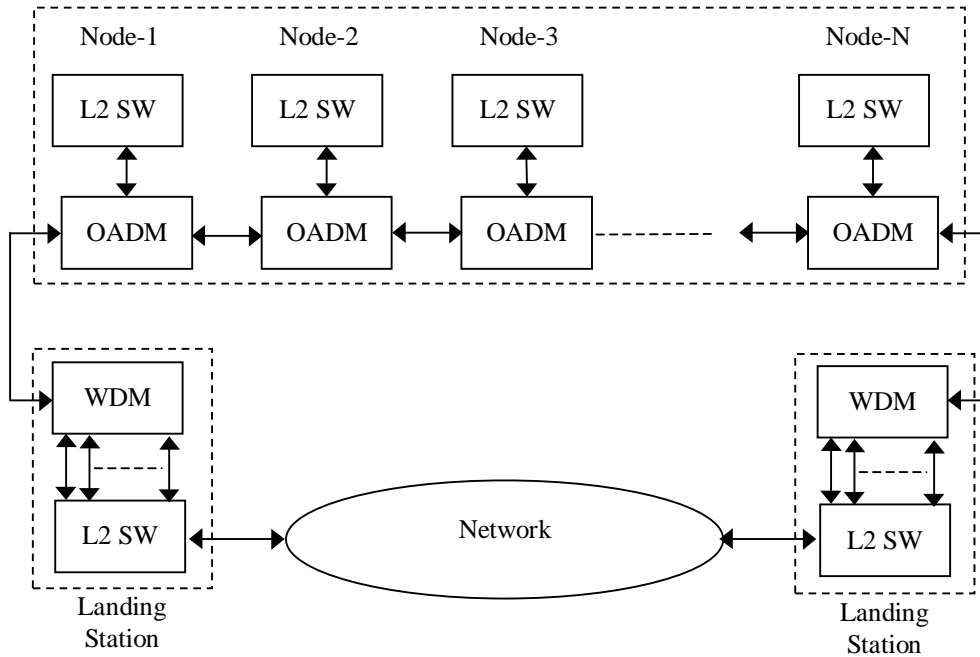


Figure 5: Ring network with OADM (Optical Add/Drop Multiplexer)

affected. We can use commercially available low cost Ethernet switches for the observation nodes without lowering the reliability of the whole system.

Figure 12 shows an example of 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 even if the cable is broken at one point and the data transmission line is interrupted, we can access the observation node through the opposite landing station. By using two optical fibers, we can increase the robustness of the optical data transmission system. HDTV (High-Definition Television) signal can be transmitted on the wavelength assigned to the observation node or another wavelength can be additionally assigned to the HDTV data. Other wavelengths include one 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 in order to increase the flexibility and robustness of the network.

5. CONCLUDING REMARKS

The outline of the newly proposed scientific submarine cable network ARENA was presented.

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

IEEE OES Japan Chapter organized a technical committee on the scientific submarine cables, and conducted a technical feasibility study on the scientific use of underwater cables.

Technical requirement for ARENA is defined to conduct the feasibility study efficiently. Reliability and cost is one of the most important requirements to be addressed.

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.

CC power feeding system was proposed. A new current to current converter was also proposed to 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.

Development of the basic technology such as current to current converter has been initiated and will be reported in near future.

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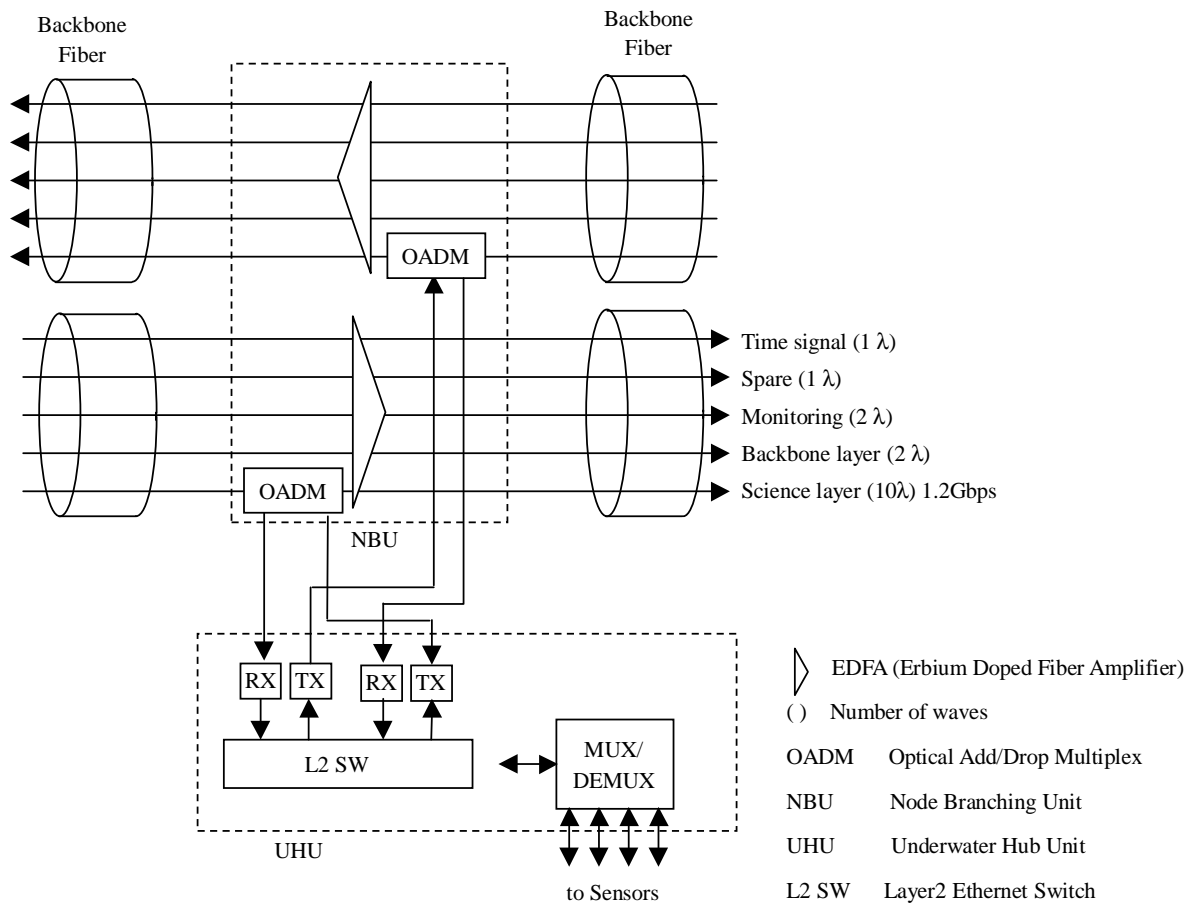


Figure 12: Wavelength assignment to each observation node

Other OADMs inserted in the monitoring and time signal line are not depicted in the Figure.

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