The data transmission system for the real-time seafloor monitoring cable network

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ABSTRACT

The ARENA (Advanced Real-Time Earth monitoring Network in the Area) project has been proposed by JAMSTEC[1)2)]. The data transmission system for seafloor monitoring cable network has been discussed in the transmission sub-workgroup of ARENA Project. The paper reports the results of discussions in the sub-workgroup. In the ARENA Project, the total length of cable is more than 1000km, and observation nodes are set at about 50km intervals, with various sensors installed in these nodes. The objective is to construct the data transmission system from the sensors in the seafloor to the landing stations. Various conditions should be considered such as transmission range, time accuracy, extendibility, cost, affinity with IP, power consumption.

1. INTRODUCTION

In order to install a variety of sensors in the vast undersea network, various technical requirements are set for the data transmission system. The basic requirements for this system are (1) Signals and bandwidth, (2) Land communications link, (3) Timing accuracy, (4) Expandability, (5) Affinity with Internet. The present paper reports the results of these topics discussed by ARENA transmission sub-workgroup.

In the ARENA project, the total amount of data transmitted from the observation apparatus installed on the seafloor is estimated to be about 2Gbit/s. Most of them are due to high-definition television (HDTV) signals, while the total amount of the data from other sensors is only about 4.5Mbit/s. The data transmission system should be flexible so it can handle these data with various bit rates. As this cable network system is based on Internet Protocol (IP), Network Time Protocol (NTP) is usually used as the time synchronization method. However, the time accuracy of NTP is about 10 milliseconds. Some sensors need the time accuracy of 1 microsecond, therefore, an exclusive line for the time synchronization signal should be also prepared to provide the accurate signal. This signal is based on the PPS signal, which is synchronized by the GPS. Users can select the time synchronization signal as required for each sensor.

In order to transmit such a large amount of data, it is planed to use an optical cable. Optical cables will be used for the science layer to transmit the observed data, while a backbone layer will be used to transmit the data between a landing station and data server for the reduction of cost. Moreover, this system must have redundancy for data transmission and extendibility so it can be extend with new observing point easily. The ring network architecture is adopted to solve these problems. Any observation node on the network can be accessed from two landing stations, and the two routes are secured for robustness and redundancy. This architecture makes also possible to extend the network easily.

Moreover, data format and sensor interface are also important in the system. In order to realize an open and scalable system, suitable ones should be adopted, which can easily extend the system.

2. HDTV SIGNAL TRANSMISSION

The total amount of data uploaded by basic-set observation instruments to be connected to ARENA is estimated about 2 Gbps, most of which consists of image signals generated at “camera observation points”, with the data attributed to other observation points amounting to only 4.5 Mbps. It is therefore necessary to distinguish images signals from non-image observation data and control data, when examining the signal transmission system.

2-1. Supersensitive HDTV camera (Super-HARP camera)

HDTV cameras are still only used for commercial, industrial and other specialized purposes. The use of the Super-HARP camera is particularly limited. Nevertheless, it is ideal for deep-sea scientific observation as it is capable of capturing high-quality images under limited artificial lighting conditions, because of its extreme high resolution and sensitivity. For this reason, the Super-HARP camera has become an indispensable tool for scientific observation.

2-2. HDTV camera

Because of their relative low sensitivity, ordinary HDTV cameras have a shallow depth of field and narrow range of focus, compared to the Super-HARP camera. Despite this shortcoming, they are useful as a low-cost alternative for ocean-floor fixed-point observation, which involves the capturing of the images of slow-moving objects (e.g. topographical features, such as chimneys, and seashells). With compact products, including CCUs, available, they widen the range of equipment options for this application. The commonly used external I/F for image signals is the HD serial digital interface (HD-SDI), which has the same data transfer rate as the Super-HARP camera (1.5 Gbps).

2-3. Motion video capturing using high-resolution digital still cameras

Digital still cameras using a CCD with a resolution of 1920 * 1080 pixels or more are capable of producing still images that are comparable to HDTV images in terms of resolution. With adequate buffer memory or delay memory provided, they can be used to produce HDTV-quality video clips lasting several seconds in Motion-JPEG format through continuous shooting at a rate of 30 frames per second. Most of the time, they are to be used for monitoring purposes - operated at the NTSC resolution (640 * 480 pixels), in black and white and at a reduced frame rate to keep data bit rate down - with high-resolution color video clips taken from time to time upon receiving an event trigger command from the land-based motion video monitoring system. As far as the continuous shooting speed and amount of buffer memory allow, they can also be used as event-trigger slow-motion cameras. For monitoring purposes, MPEG-2 data (about 6 Mbps in bit rate) from NTSC-resolution cameras may be used. Capturing an HDTV image in three colors and at 30 frames per second gives rise to 1.5

Gbps of data, while a three-color NTSC image only amounts to 211 Mbps at the same frame rate. Transmitting HDTV images from multiple observation points without data compression would require a high-speed Ethernet link capable of a transfer rate of 10 Gbps or more, while the transmission of compressed data would necessitate small-size and low-power MPEG-2 encoders suitable for incorporation into undersea equipment.

3. TIME SYNCHRONIZATION

The level of accuracy needed for time synchronization varies from observation item to observation item. For example, an ADCP is an instrument that measures the direction and speed of sea currents, and the observation time is essential information to specify the point in time at which currents have occurred. In this case, the required accuracy is only 1 sec, and observation accuracy is not affected by time synchronization.

On the other hand, geodetic observation, an important observation item for ARENA, aims to measure plate movement, and requires a measurement accuracy of several mm, since plate movement occurs at a rate of several cm per year. As geodetic observation is measured by underwater sound and the sound travels at a speed of about 1500 m/sec in the water, it needs a high time synchronization accuracy of about 1 μsec.

The conditions required for time synchronization are summarized below.

(1) Operation of observation instruments connected to the underwater network, which is about 1000 km long, under the same clock (time)

(2) Use of GPS as time reference

(3) Time accuracy of 1 μsec

Figure 1 shows an outline of the time synchronization-focused network configuration. As the time synchronization technique, a combination of a reference signal-based scheme and NTP is proposed. Although a reference signal-based scheme can provide a time synchronization accuracy of up to 1 μsec, it will make hardware complex due to the need for a separate signal channel on the network. On the other hand, NTP can only provide an accuracy of about 10 msec, but this is still sufficient for some observation instruments. The actual time synchronization method should be chosen by the users of observation instruments according to their respective accuracy requirements. GPS should be used as the absolute time reference for the land-side reference signal server and NTP server in Figure 1. In the case of NTP, the signal is distributed as part of data transmission since it is a protocol incorporated into TCP/IP.

NTP represents a technology devised to prevent the time synchronization communications traffic from concentrating on a single server by hierarchically connecting computers and limiting their NTP server access to the one at the same hierarchical level and the one immediately above. Under NTP, time adjustment is made on the basis of the time indicated by the NTP server and the time duration needed for the signal to make a round-trip travel from each node to the NTP server. This method, which is widely used under TCP/IP, provides an effective time synchronization accuracy of 10 msec. It offers an advantage of simple hardware configuration for observation items for which that level of accuracy is sufficient.

For geodetic measurement and other observation items that require more accurate time synchronization, a more accurate reference signal-based scheme is needed. As the protocol, a time code (IRIG timer code), PPS or PPS + delay information is to be used. All these schemes require a dedicated channel that is independent of IP. Under the IRIG time code scheme, the reference signal contains absolute time information. Under the PPS scheme, a precision pulse is sent every second over a dedicated channel. Under the PPS + delay information scheme, absolute time and delay information is sent between pulses that comprise a pulse per second signal. The IRIG time code scheme requires the transmission of delay information via a separate channel, while the PPS scheme requires the transmission of absolute time and delay information via a separate channel. Delay information needs to be obtained separately. Since transmission line delay is unlikely to change in a short time frame given that observation instruments are deployed at fixed locations on the ocean floor, time and delay information can be sent via TCP/IP. The PPS scheme uses a signal that is essentially the same as the GPS time signal, and is widely used when high-accuracy time synchronization is needed. The PPS + delay information scheme tends to increase the load on the time synchronization server due to individual time synchronization at each science node, although it offers the advantage of time adjustment being carried out via a dedicated channel alone. All the reference signal-based schemes proposed here meet the time synchronization accuracy requirements, but the PPS scheme may be slightly preferable because of its affinity for GPS, which provides the reference clock.

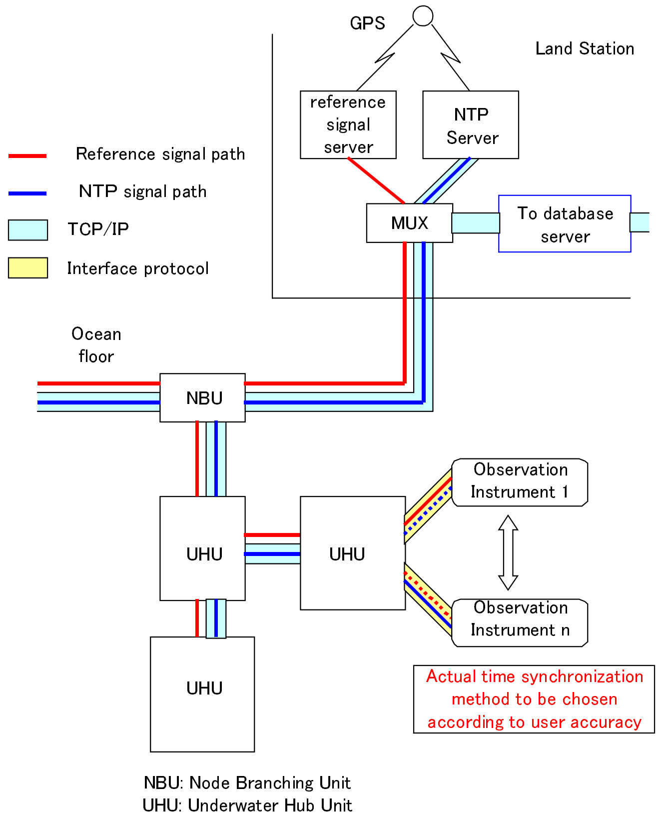

Figure1. Outline of Time Synchronization Network

4. OPTICAL DATA TRANSMISSON SYSTEM

In order to transmit such a large amount of data, it is planed to use an optical cable. Optical cables will be used for the science layer to transmit the observed data, while a backbone layer will be used to transmit the data between a landing station and data server for the reduction of cost. Moreover, this system must have redundancy for data transmission and extendibility so it can be extend with new observing point easily. The ring network architecture is adopted to solve these problems. Any observation node on the network can be accessed from two landing stations, and the two routes are secured for robustness and redundancy. This method makes also possible to extend the network easily.

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Every existing communications optical submarine cable system is basically only concerned with communications between two landing points. In contrast, the ARENA cable system is envisaged as a mesh network consisting of multiple ring subnetworks designed to enable data exchange between a vast number of observation points that are two-dimensionally distributed on the sea floor and landing stations, with a view to acquiring measurement data from these observation points on a real-time basis without data loss.

Such a network can be built relatively easily on land, but doing so under the sea requires thorough investigations into the reliability of transceivers and network equipment to be installed undersea.

4-1. Network design

(1) Network layers

It seems appropriate to design the proposed signal transmission network as a layered network consisting of two layers: the science layer designed to transmit observation data (science data) to landing stations; and the backbone layer designed to transfer the science data received at landing stations to central servers. Through an efficient use of network resources, the proposed network is believed to be able to transfer large amounts of observation data from landing stations to central servers and carry out mirroring between without using a land-based leased line network servers in addition to collecting observation data from observation instruments.

(2) Network configuration

From the viewpoint of reliability, fault protection and expandability, it is desirable to configure the network as a multi-ring network consisting of a number of ring subnetworks as shown in Figure 2, each containing a pair of landing stations. Since each ring contains one contiguous backbone communications circuit, this configuration helps ensure reliability by eliminating the need to incorporate complex routers into undersea communications equipment. Even in the event of a fault in a subnetwork, the ring topology allows all observation data along the communications circuit to be received by at least one landing station. Moreover, since each ring subnetwork is an independent network, the addition of new subnetworks does not affect any of the existing subnetworks, thus facilitating network expansion. However, for example, when an obstacle occurs on the transmission way to the central landing office 2, backbone-layer communications between landing station 1 and other landing stations would become impossible. To prevent a breakdown in backbone-layer communications due to the isolation of landing stations, it would be necessary to set up a data server at all landing stations.

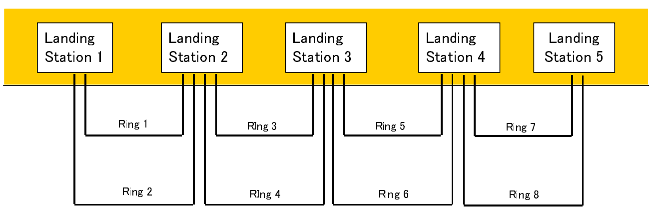

Figure 2. Multi-ring Network

Figure 3 shows the network design applied in ARENA system. It is possible to constitute a network from an ARENA system with 6 or 7 rings.

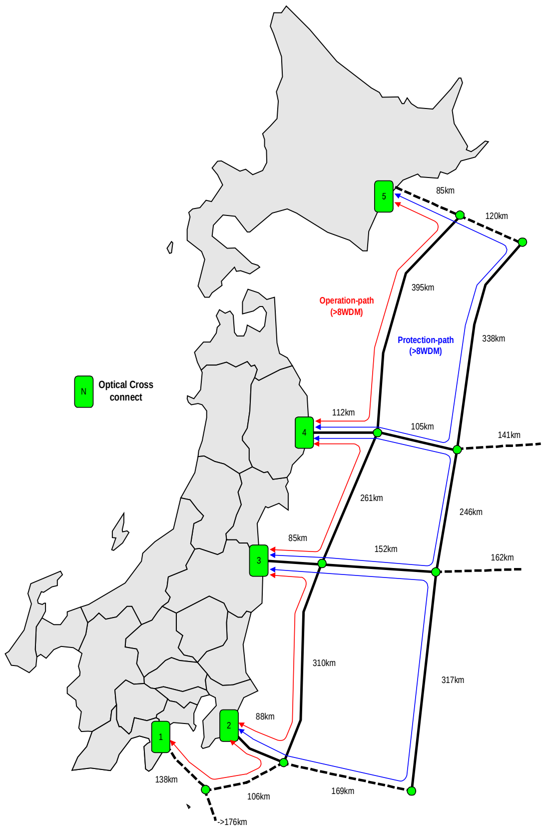

Figure 3. Multi-ring Network applied in ARENA system

4-2. Backbone-layer communications scheme

There are two alternatives schemes for backbone-layer communications. These are: the setting up of a new communications link on land; and the use of a part of the science data transmission path. Of these, the latter, which utilizes an excess resource of a large-capacity submarine cable network, is more realistic in terms of cost. Two methods of utilizing the science data transmission path can be considered: the addition of a fiber pair and the allocation of a wavelength. The addition of a fiber pair can completely isolate the backbone-layer communications path from the science data transmission path. Compared to the allocation of wavelengths, this method offers high transmission quality and reliability because it is free from the fluctuations in gain that arise from the use of optical add/drop multiplexing (OADM). However, it would push up the cost due to the need for an extra pair of optical fibers. The allocation of wavelengths is advantageous in terms of cost because of fewer fibers, although it is inferior in terms of transmission quality.

4-3. Science-layer communications scheme

As a way of implementing the science-layer communications path, a ring network that combines wavelength division multiplexing (WDM) and optical add/drop multiplexing (OADM) may be considered. This method offers a highly reliable backbone communications path since it does not require the installation of devices without a proven reliability record, such as optical transceivers and Ethernet switches, inside node branching units. This method also offers an easy way of establishing a backbone-layer communications link through the allocation of wavelengths.

(1) One wavelength to each node

This method accommodates the transmission of synchronization signals and monitoring & control signals to each underwater hub unit (UHU), as well as the uploading of data in the opposite direction. It offers expandability and flexibility since it allows sensors to be connected to any sensor port of a UHU, regardless of their bit rates. To enhance robustness to faults in the communications circuit, all UHUs are deployed in such a manner that they are accessible from both landing stations. This means that they will remain accessible in the event of a fault occurring at one location in a ring subnetwork, as long as power supply is maintained. A distinct disadvantage of this method is too high a data transmission capacity relative to the amount of data to be transmitted, given that the overall transmission capacity snowballs to 25.6 Gbps even on the assumption of a transmission capacity per wavelength of only 1.6 Gbps.

(2) Dedicated wavelengths for high-bit-rate data items

A single wavelength was allocated to science data. This wavelength is added/dropped at each node to transmit science data. These wavelengths take care of the transmission of high-bit-rate data from any node, thus allowing the connection of high-bit-rate sensors at all nodes. This scheme needs twice as many OADMs and transceivers as the case with the one-wavelength-to-each-node scheme due to the need to add/drop two wavelengths. Because of the greater number of components, it is inferior to the one-wavelength-to-each-node scheme in terms of both equipment cost and reliability. Its expandability (flexibility) is also poor due to the need to use special ports for high-bit-rate sensors in UHUs.

5. COMMUNICATION PROTOCOLS

5-1. Communication protocols

In establishing communications protocols, standardized techniques, such as the widely-used seven-layer OSI model, will be taken into account.

ARENA uses a variety of sensors are due to install. As will be discussed in the previous section, TCP/IP should be used as an infrastructural data transmission protocol, particularly in view of its compatibility with other systems.

5-2. Data formats

There are no particular requirements for data formats except for compatibility with TCP/IP as the data transmission protocol. In this sense, it is more important to focus on compatibility with existing systems. Regarding non-seismic data, including geodetic, image, heat and other observation data and research data relating to the development of new means of observation and the like, it is necessary to select the most suitable data format according to the data type and circumstances.

6. SENSOR INTERFACE

Since ARENA uses a variety of sensors, it is necessary to standardize their interfaces with the Internet switch hub, which connects them to the network for data transmission. Figure 4 shows a schematic diagram.

A sensor unit can be divided into two parts. These are the sensor module, which is developed by the user, and the interface module, which takes care of the connection between the sensor module and Ethernet switch hub. In this regard, the interface module is considered to be the key to the popularity of ARENA among potential users since a well-designed interface would readily allow them to use existing sensor modules, thus sparing them added technical and financial burdens.

The interface module plays an important role in sensor control from land, sensor management (identification) and fault detection/diagnosis (for sensor module).

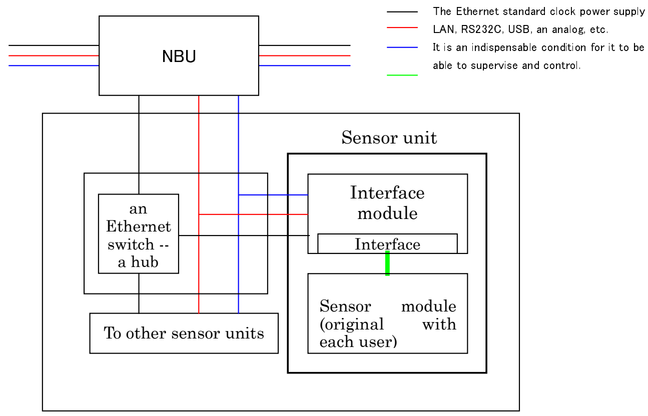

Figure 4. Schematic Diagram of Interface

7. SUMMARY

The paper examines the subjects related to the data communications over a submarine cable network. Since it is expected that for the picture transmission a small MPEG encoder will be developed, the transmission of the MPEG encoded signal of the HDTV pictures over the current 1.5Gbps network structure becomes feasible. For the time synchronization, a dual time synchronization methods approach was proposed, based on NTP and the reference signal-based scheme. Although a dedicated line for time signal is needed, the required level of accuracy for each observation item is achieved. Moreover, in order to transmit a large volume of data, the optical cable system was adopted, and in order to give redundancy and extendibility, the network system composed of two or more rings was proposed. TCP/IP should be used for communication protocol in this system, considering the compatibility with Internet. A modular sensor unit should be divided into sensor module and interface module in order to connect various sensors with the same interface.

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