Development of an IoT Platform for Ocean Observation Buoys

Si Moon Kim[1], Un Hyun Lee[1], Hyuk Jin Kwon[1], Joon-Young Kim[2], and Jeongchang Kim[1]

[1] Division of Electronics and Electrical Information Engineering, Korea Maritime and Ocean University / Busan, Korea
{ehdaudwjdqh0, dnsgus6035}@naver.com, gurwls0831@gmail.com, jchkim@kmou.ac.kr
[2] Division of Mechanical Engineering, Korea Maritime and Ocean University / Busan, Korea jykim@kmou.ac.kr

* Corresponding Author: Jeongchang Kim

Received October 18, 2016; Accepted February 9, 2017; Published April 30, 2017

** Regular Paper*

** Extended from a Conference: Preliminary results of this paper were presented at the ITC-CSCC 2016. This paper has been accepted by the editorial board through the regular review process that confirms the original contribution.*

***Abstract*:** In this paper, we propose an Internet of Things (IoT) platform for ocean observation buoys. The proposed system consists of various sensor modules, a gateway, and a remote monitoring site. In order to integrate sensor modules with various communications interfaces, we propose a controller area network (CAN)-based sensor data packet and a protocol for the gateway. The proposed scheme supports the registration and management of sensor modules so as to make it easier for the buoy system to manage various sensor modules. Also, in order to extend communication coverage between ocean observation buoys and the monitoring site, we implement a multi-hop relay network based on a mesh network that can provide greater communication coverage than conventional buoy systems. In addition, we verify the operation of the implemented multi-hop relay network by measuring the received signal strength indication between buoy nodes and by observing the collected data from the deployed buoy systems via our monitoring site.

***Keywords*:** Buoy, Controller area network (CAN), Internet of Things (IoT), Multi-hop relay network, ocean observation

1. Introduction

Recently, information and communications technologies have been evolving along with Internet of Things (IoT) technologies. IoT technologies have been applied to various services, such as the smart city, smart home, smart factory, smart vehicle, and smart health care. In the ocean, it is difficult to utilize IoT technology due to environmental limitations, such as communication coverage, power supply, and maintenance. Nevertheless, the importance of ocean observation has been increasing recently due to natural disasters like tsunamis.

In order to monitor ocean environments, buoy systems are widely utilized. Deep-ocean assessment and reporting of tsunamis (DART) buoys were developed to improve early detection and real-time reporting of tsunamis in the open ocean [1]. Mooring Systems, Inc. developed a wide range of surface buoys designed for meteorological and oceanographic instrumentation platforms [2].

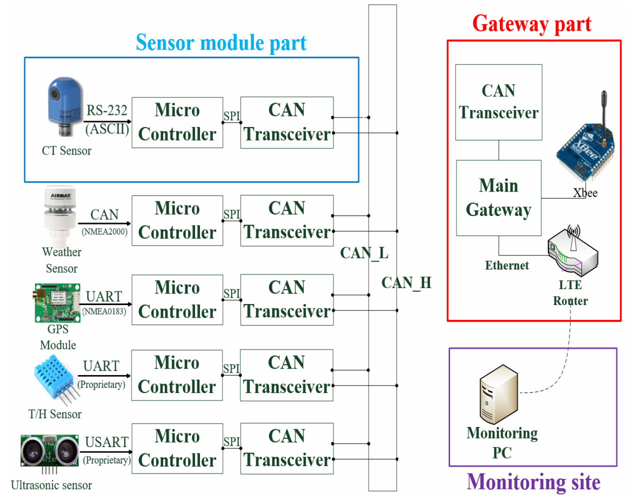
Ocean observation buoys have various ocean sensors to monitor ocean environments. Ocean sensors also have various input/output (I/O) interfaces such as the National Marine Electronic Association's NMEA0183 and NMEA2000. NMEA2000 was established by NMEA with a standard 1200 bps serial communications interface in 1980 and it is widely used for ships [3]. However, there are many ocean sensors with other interfaces, such as analog I/O, universal asynchronous receiver/transmitter (UART), and NMEA0183, which are not compatible with NMEA2000. Therefore, it is difficult to integrate ocean sensors in a single unified system. Furthermore, the buoy system operates in the distant ocean. Hence, it is also difficult to manage the system when the buoy system is damaged and/or should be modified.

Also, without the aid of satellite communications, it is difficult for a distant buoy to deliver the measured data to a remote monitoring site. In order to extend the communication coverage of the buoy, a wireless mesh network (WMN) can be used. A WMN is a communications network made up of multiple radio nodes that consist of mesh routers and mesh clients organized in a mesh topology. Since mesh routers can forward a message from other nodes outside transmission coverage of their destination, a multi-hop relay network can be configured using WMN. A multi-hop relay network can extend the coverage of wireless communications and provides line-of-sight (LOS) links between two adjacent nodes. These features provide many advantages with WMNs, such as self-organization, self-configuration, robustness, and reliability [4].

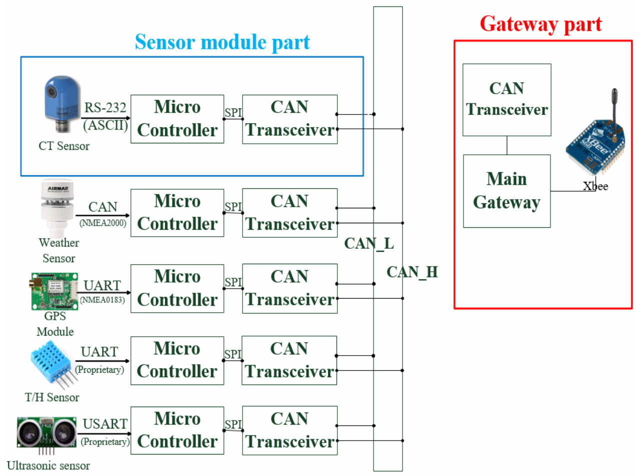
Therefore, by using a mesh-type multi-hop relay network, each buoy can communicate with other nodes outside of its own communication coverage area. Watthanawisuth et al. [5] developed a ZigBee-based wireless mesh network in order to make a tractor tracking system scale up to cover a large farm area. ZigBee wireless communications is widely used in various areas due to its many advantages, such as inexpensiveness, compact size, and distributed intelligence. In order to increase accessibility to remote sensor platforms, `Zolich et al. proposed a mesh-type wireless sensor network (WSN) between ocean observation sensors and unmanned vehicles (UV) [6]. Kim et al. [7] developed an IoT-based system for ocean observation buoys, and presented preliminarily results.

In this paper, we present an improved IoT-based system for ocean observation buoys and verify its operation. The proposed system consists of sensor modules, a gateway, and a remote monitoring site. In order to integrate sensor modules with various communications interfaces, we propose a control area network (CAN)-based sensor data packet and a protocol for the gateway of the buoy system. The CAN-Bus is widely used in ships. Also, it is well known that the CAN-Bus is a robust, low-cost, and simple event-triggered technology for connecting electronic control devices in manufacturing industries and vessels [8]. A CAN is a bus for broadcasting that can support a data rate of up to 1 Mbps with a distinct 29-bit identifier (ID). The distinct identifier of each device helps the system prevent data frame collisions [9]. Hence, the CAN-based system can be utilized to maintain compatibility with existing systems or devices for the buoys. Also, the proposed system supports the registration and management of sensor modules so as to make it easier for the buoy system to manage sensor modules. By utilizing the proposed scheme, we can develop a unified platform for a buoy system.

Also, in order to extend communication coverage of ocean observation buoys, we propose a multi-hop relay network based on a mesh network that can provide greater communication coverage than conventional buoy systems. Also, we verify the operation of the implemented multi-hop relay network by measuring the received signal strength indication (RSSI) between buoy nodes and by observing collected data from the deployed buoy systems via our monitoring site. The outdoor field test results show that the developed buoy system can transmit the measured data to the remote monitoring site from as far away as 6 km with a four-hop relay network.



(a)



(b)

Fig. 1. Block diagram of the proposed buoy system (a) main Buoy, (b) relay buoy.

The remainder of this paper is organized as follows. In Section 2, we introduce the configuration of the proposed buoy system, and we describe the packet structure and the protocol using the CAN frame in Section 3. In Section 4, the configuration of the mesh network for the proposed buoy system is derived, with hardware configurations of the proposed system described in Section 5. In Section 6, field test results of the proposed system are presented for a variety of environments. Finally, conclusions are drawn in Section 7.

2. System Configuration

Fig. 1 shows a block diagram of the proposed buoy system. In practice, various sensors can be used for ocean observation. In this paper, in order to implement a prototype for the proposed system, we consider the most widely used ocean observation sensors, such as the conductivity/temperature (CT) sensor, the weather sensor, and the global positioning system (GPS) module. Also, the

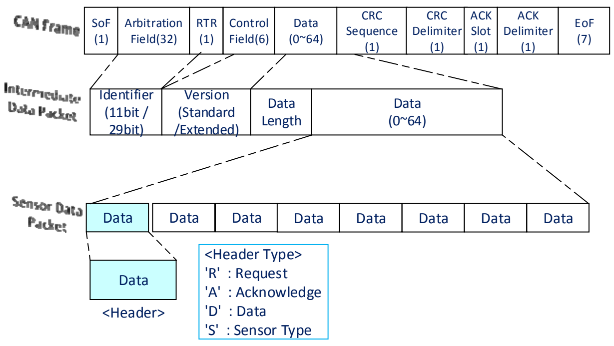


Fig. 2. Data packet structure for the proposed protocol.

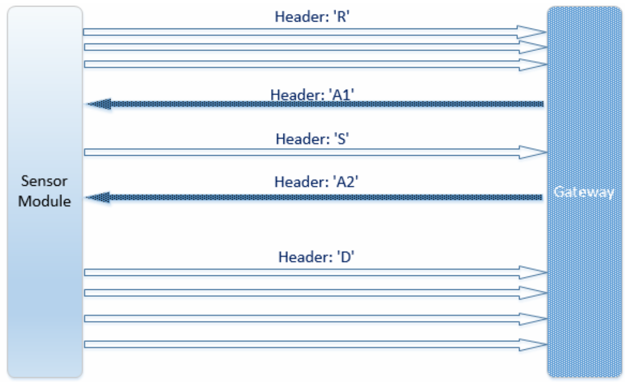


Fig. 3. Data flow diagram between the gateway and sensor module.

proposed system has temperature/humidity and ultrasonic sensors to monitor the buoy system.

The CT sensor measures various oceanic data, such as conductivity, temperature, and conductance in the sea. The weather sensor also measures various conditions, such as the direction and speed of the wind over the sea. The GPS is used to obtain the position of the buoy. The temperature/humidity sensor measures the temperature and humidity of the internal buoy system. The ultrasonic sensor detects the distance to objects near the buoy body. Fig. 1(a) shows a block diagram of a main buoy system. The main buoy is an end node, which can receive sensor data from other buoys in the same mesh network, and directly delivers the sensor data to a monitoring site using Long Term Evolution (LTE) communications. Fig. 1(b) shows a block diagram of a relay buoy system. The relay buoy is a relay node, which communicates with other buoys in the same mesh network and delivers both its own sensor data and sensor data of other relay buoys to the main buoy in the same mesh network.

The proposed system consists of three parts. The first part is the sensor module, which includes a sensor unit and a micro-controller unit. The variety of sensor units includes various interfaces with external devices like the NMEA0183, NMEA2000, and UART. The micro-controller of each sensor module parses the necessary information, such as conductivity, temperature, conductance, and speed and direction of the wind, and then, the CAN transceiver reshapes the parsed data into a CAN frame. Finally, the resulting frame is transmitted to the gateway via the CAN-Bus.

The second part is the gateway that receives the reshaped CAN frame from the sensor modules. Also, the gateway supports registration and management of the sensor modules. Each sensor module broadcasts its data with a unique CAN-ID to all devices, including the gateway, via the CAN-Bus [11]. Then, the gateway receives and stores data from all sensor modules. The gateway transmits the collected data to the monitoring site on the ground using LTE communications.

The third part is the monitoring site on the ground. The received data from the gateway of the buoy is stored in the database (DB) server of the monitoring site.

3. Protocol Design

Fig. 2 shows the data packet structure for the proposed scheme. For the micro-controller of the sensor module, the measured data of the sensor unit is formatted into a data packet with a one-byte header. Then, the data packet is transferred to the CAN transceiver with a six-byte header, which is referred to as an intermediate data packet. The header of the intermediate data packet consists of three fields: ID, Ver, and LEN. The ID field holds the unique CAN-ID assigned to each piece of information from the sensor module. For example, the conductivity and conductance of the CT sensor are transmitted with different CAN-IDs. By using a unique CAN-ID for each piece of information, the proposed system can distinguish various types of information in a sensor module, and the measured data in a sensor module can be classified by the CAN-ID. The Ver field indicates whether the CAN-ID is the standard or extended version. In this paper, we adopt the extended version, since it can support both NMEA2000 and NMEA0183 formats. The LEN field determines the number of bytes in the data field, where the maximum value of the LEN field is 8. The CAN transceiver forms a CAN frame [12] with the intermediate data packet, and transmits the CAN frame to the gateway via the CAN-Bus [13].

Fig. 3 shows a data flow diagram between the gateway and a sensor module in the proposed buoy system. First, when a sensor module is attached to the proposed system, a registration procedure between gateway and sensor module is started. The sensor module broadcasts a request CAN frame via the CAN-Bus. When other sensor modules receive the request CAN frame, they ignore the received frame. Only the gateway accepts the request CAN frame. And then, the gateway sends an A1 frame to acknowledge the corresponding sensor module. After the sensor module receives the A1 frame, it sends a sensor type frame, which contains sensor information. After the gateway receives the sensor type frame, it sends an A2 frame to the corresponding sensor module. The A2 frame indicates that the registration procedure is over and the data exchange is ready between the gateway and the sensor module.

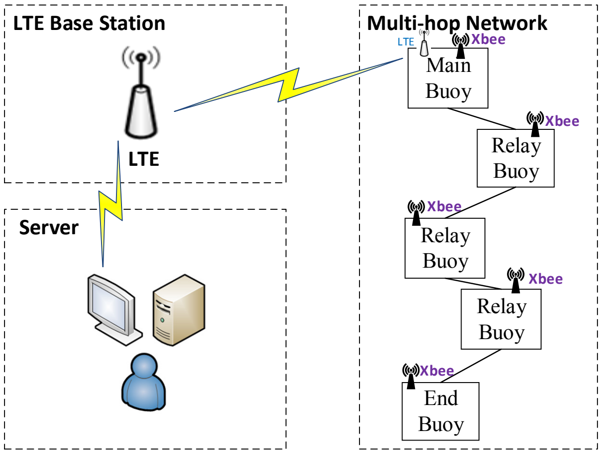


Fig. 4. Configuration of the mesh network for the proposed buoy system.

Table 1. Specification of the ZigBee-PRO Digi-Mesh module.

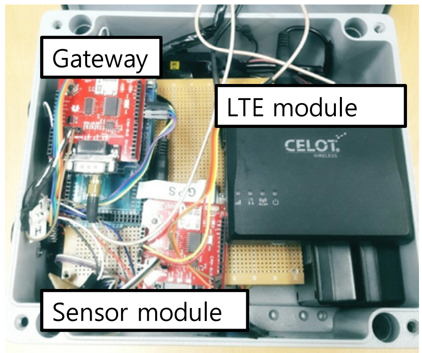
Item	Specifications
RF Data Rate	250kbps
Indoor/Urban Range	300ft (90m)
Outdoor/RF LOS Range	1 mile (1.6km)
Transmit Power	63mW(+18dBm)
RX Sensitivity (1% PER)	-100 dBm

4. Multi-hop Relay Network

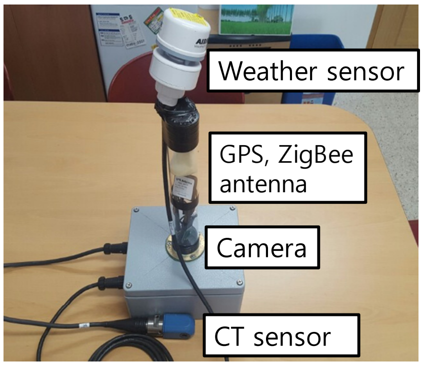
Fig. 4 shows the configuration of the mesh network for the proposed buoy system. The basic function of each node is to transfer data to adjacent nodes and eventually transmit the measured data to the destination node. The communications capability of the buoy to deliver the measured data to the remote monitoring site is extremely limited on the ocean without satellite communications. In order to extend the communication coverage of the buoy, the proposed system configures a multi-hop relay network using ZigBee modules that can support self-forming and self-configuration. In the multi-hop relay network, each buoy sends the measured data to other nodes within its radio range, and the other buoys relay the data to the destination node. In Fig. 4, the end buoy transmits the measured data to an adjacent relay node within its radio range, and three relay nodes relay the data of the end node to the main buoy within four hops. The main buoy equips communications devices that can directly transmit the data to the remote monitoring site. We assume that two adjacent relay nodes are within communication coverage and can communicate with each other. In this paper, we use ZigBee-PRO Digi-Mesh modules to implement the multi-hop relay network.

Table 1 shows the specifications of a ZigBee-PRO Digi-Mesh module. The radio operates at 2.4 GHz, and the module provides a data rate of up to 250 Kbps. The power consumption during the transmitting and receiving procedures is about 55 mA for the radio and 340 mA for the module, with a supply voltage of 3.4 V.

Each ZigBee module is set to the same operating channel and ID. Then, the ZigBee RF module broadcasts data on the same channel. When the end buoy broadcasts the measured data, the relay buoy receives the data, and then broadcasts the received data from the end buoy. By forwarding the data over the multi-hop relay network, the main buoy can receive the data of the end buoy. The measured data from the end buoy are finally transmitted to the nearest LTE base station through the main buoy using LTE communications and are monitored at the remote monitoring site.



(a)



(b)

Fig. 5. Hardware configurations of the proposed system (a) Internal configuration, (b) External configuration.

5. Hardware Configuration

Fig. 5 shows the hardware configurations of the proposed system. The internal hardware of the proposed system is composed of the micro-controllers, the CAN-transceivers, the LTE module, the ZigBee module, some batteries, and the interface board, as shown in Fig. 5(a). These components are installed in a waterproof aluminum box. They are stacked in a two-layer form and arranged near the wall to dissipate the heat generated by the various modules, including the batteries. Also, the interface board and the CAN-Bus provide communications between sensor

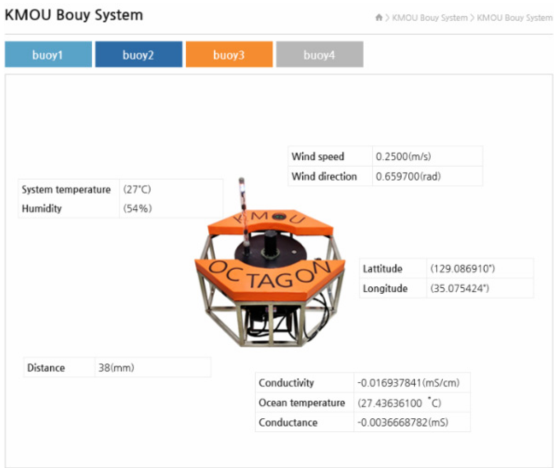


Fig. 6. Implemented web monitoring site.

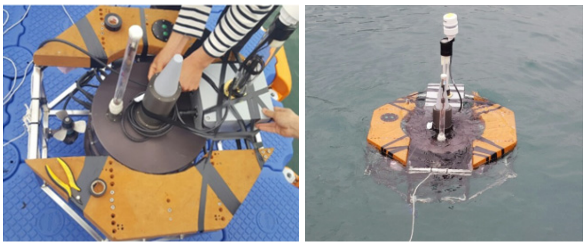


Fig. 7. Field test in the real environment.

modules and the gateway. On the other hand, the external hardware contains a camera module and antennas for the GPS, ZigBee, and LTE, as shown in Fig. 5(b). The camera module supports five-megapixel resolution with a fixed focus lens onboard, and utilizes a dedicated camera serial interface, which is capable of extremely high data rates for maritime surveillance.

6. Field Test Results

The measured data from each sensor are transmitted to the DB server of the remote monitoring site and are monitored at the server PC and/or on mobile phones. They can be arranged in time order to show variations in the sensor data over time. Also, the location of each buoy is tracked on a web-based map. Hence, at a glance, we can monitor the information of each buoy, such as latitude and longitude from the GPS, and wind speed and wind direction from the weather sensor, using the proposed buoy system.

Fig. 6 shows the implemented web monitoring site. The measured data from each buoy are finally transmitted to the main buoy and then transmitted to the DB server. We can monitor the measured data from each buoy in real time. Fig. 7 shows the installed buoy body for the field test on the sea. To verify the basic operation of the buoy, it was mounted on a remotely operated vehicle (ROV). Since the ROV can move on the sea, we can monitor the measured data according to the position of the buoy on the sea in real time.

Table 2. RSSI test results for the indoor environment.

	RSSI	Packet sent	Packet Received	Reception Rate (%)
A-B	-79dBm	95	80	86
B-C	-88dBm	51	51	100
C-D	-78dBm	53	53	100

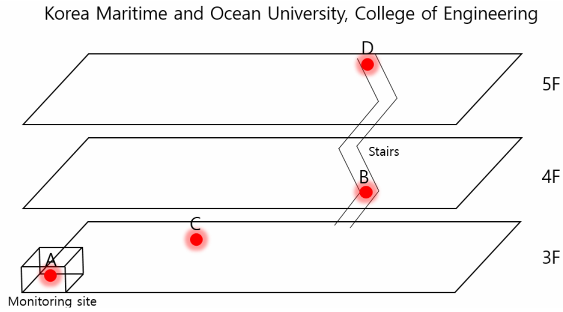


Fig. 8. Indoor multi-hop relay network test configuration.

Also, we performed the field test in both indoor and outdoor environments to verify the multi-hop relay communications of the proposed buoy system. For the indoor environment, Fig. 8 shows the configuration of the multi-hop relay network for the indoor test. All nodes were located within a building in Korea Maritime and Ocean University. To deploy sensor nodes for the multi-hop relay network, four points (A, B, C, D) were selected so that it was possible to communicate between only two adjacent points. And then, we measured RSSI values for the selected four points.

Table 2 shows the measured RSSI values and successful reception rates for the indoor environment in Fig. 8. The RSSI values for A-B, B-C, and C-D paths are -79dBm, -88dBm, and -78dBm, respectively. Also, the successful reception rates for A-B, B-C, and C-D paths are 86%, 100%, and 100%, respectively. We know that each node can reliably communicate with the adjacent node. Also, we tested the operation of the multi-hop relay network with two relay nodes (B, C). The source node at point D transmits its data to the destination node at point A over the multi-hop relay network, and then, the destination node transmits the data from the source node to the DB server of the remote monitoring site using LTE communications.

Fig. 9 shows the locations of buoy nodes for the outdoor field test of the multi-hop relay network. The test was carried out on Eulsuk-do Island, Sasang-gu, Busan, Republic of Korea. The source and destination nodes were located at points A and E, respectively, and three relay nodes were located at points B, C, and D. Note that each point was selected so that LOS was guaranteed between two adjacent points. Table 3 shows the distances between two adjacent nodes, and Table 4 shows the weather

Fig. 9. Locations of the end buoy (A), relay buoys (B, C, D), and the main buoy (E) for the outdoor field test.

Table 3. Distances between two adjacent points (in meters).

A-B	B-C	C-D	D-E
1500	1500	1700	1200

Table 4. Weather conditions for the outdoor environment.

Wind (m/s)	Cloud cover	Temperature (℃)	Humidity (%)	Rainy percent(%)
Southwest 3m/s	6	31	70	0.2

Cloud cover : Sunny(0~2), little cloudy(3~5), cloudy(6~8)

conditions for the outdoor environment.

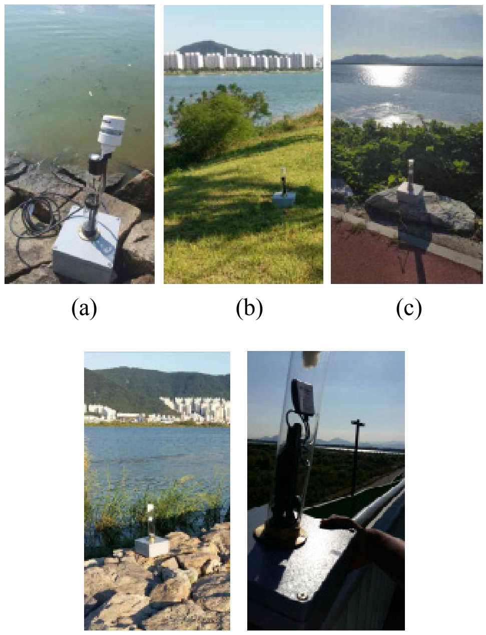
For the outdoor test, we measured RSSI value and successful reception rate to evaluate the communication performance between two adjacent nodes. Table 5 shows the measured RSSI values and successful reception rates for the outdoor environment of Fig. 9.

The RSSI values for A-B, B-C, C-D, and D-E paths were -87dBm, -81dBm, -86dBm, -83dBm, respectively. Also, the successful reception rates for A-B, B-C, C-D, and D-E paths were 86.00%, 83.78%, 32.91%, and 49.06%, respectively.

For the case of D-E path, although the distance is shorter than B-C path, the RSSI value and the reception rate are relatively degraded due to several obstacles in the field test environment. We know that each node can successfully communicate with the adjacent node. Also, we tested the operation of the multi-hop relay network with three relay nodes (B, C, D). The measured sensor data of the source node (buoy A) were delivered to the destination node (buoy E) over the multi-hop relay network, and then buoy E transmitted the data from buoy A to the remote monitoring site using LTE communications. Fig. 10 shows buoy nodes at five test points for the outdoor experiment.

Table 5. RSSI test results for the outdoor environment.

	RSSI	Packet sent	Packet Received	Reception Rate (%)
A-B	-87dBm	101	86	86.00
B-C	-81dBm	37	31	83.78
C-D	-86dBm	79	26	32.91
D-E	-83dBm	53	26	49.06



(a) (b) (c)

(d) (e)

Fig. 10. Buoy systems of each point in the outdoor experiment (a) point A, (b) point B, (c) point C, (d) point D, (e) point E.

In this field test, we verified that the measured data can be transmitted to the monitoring site over the multi-hop relay network with coverage of approximately 6 km in real time.

7. Conclusion

In this paper, we presented an improved IoT-based system for ocean observation buoys, and verified its operation in both indoor and outdoor environments. In order to integrate sensor modules with various communications interfaces, we proposed a CAN-based sensor data packet and a protocol for the gateway of the buoy system. By applying the proposed system to a conventional buoy, it is possible to make it easier for the buoy system to manage various sensor modules. Also, in order to extend communication coverage of ocean observation buoys, we developed a multi-hop relay network based on a mesh network with greater communication coverage. We performed a field test with the developed system and verified that the developed buoy system can transmit the measured data. In addition, we monitored data in real time at the monitoring site over the multi-hop relay network, with coverage of approximately 6 km.

Acknowledgment

This work was supported by the R&D program of the Korea Institute of Ocean Science and Technology (KIOST) [Development of a marine IoT standard platform for ocean observation buoy].

References

[1] http://www.srh.noaa.gov/jetstream/tsunami/dart.htm
[2] http://www.mooringsystems.com/surface.htm
[3] K.-Y. Kim, D.-H. Park, J.-B. Shim, and Y.-H. Yu, "A study of marine network NMEA2000 for e-navigation," *Journal of the Korean Society of Marine Engineering*, vol. 34, no. 1, pp. 133-140, Jan. 2010. Article (CrossRefLink)
[4] I. F. Akyildiz, X. Wang, and W. Wang, "Wireless mesh networks: a survey," *Computer networks*, vol. 47 no. 4, pp. 445-487, Mar. 2005. Article (CrossRefLink)
[5] N. Watthanawisuth, N. Tongrod, T. Kerdcharoen, and A. Tuantranont, "Real-time monitoring of GPS-tracking tractor based on ZigBee multi-hop mesh network," in *Proc. of IEEE Conference on Electrical Engineering/Electronics Computer Telecommunications and Information Technology (ECTI-CON)*, May 2010. Article (CrossRefLink)
[6] A. Zolich, J. A. Alfredsen, and T. A. Johansen, "A communication bridge between underwater sensors and Unmanned Vehicles using a surface wireless sensor network–design and validation," in *Proc. of IEEE Conference on Electrical Engineering/ Electronics Computer Telecommunications and Information Technology (ECTI-CON)*, May 2010. Article (CrossRefLink)
[7] S. M. Kim, W. H. Lee, H. J. Kwon, and J. Kim, "Design and preliminary implementation of an IoT-based system for ocean observation buoys," in *Proc. of ITC-CSCC*, Okinawa, Japan, pp. 865-867, July 2016. Article (CrossRefLink)
[8] J. Sommer and R. Blind, "Optimized resource dimensioning in an embedded CAN-CAN gateway," in *Proc. of International Symposium on Industrial Embedded Systems*, pp. 55-62, July 2007. Article (CrossRefLink)
[9] K. W. Tindell, H. Hansson, and A. J. Wellings, "Analysing real-time communications: controller area network (CAN)," in *Proc. of IEEE Real-Time Systems Symposium*, Dec. 1994. Article (Cross RefLink)
[10] A. Piętak and M. Mikulski, "On the adaptation of CAN BUS network for use in the ship electronic systems," *Polish Maritime Research*, Vol. 16, no. 4 pp. 62-69, Mar. 2010. Article (CrossRefLink)
[11] J.-S. Yang, S. Lee, and K. C. Lee, "Design of FlexRay-CAN gateway using node mapping method for in-vehicle networking systems," in *Proc. of IEEE Conference on Control, Automation and Systems (ICCAS)*, Oct. 2011. Article (CrossRefLink)
[12] C. Watterson, "Controller area network (CAN) implementation guide," AN-1123, Article (Cross RefLink)
[13] International Organization for Standardization, "Road vehicles - Controller area network (CAN) - Part 1: Data link layer and physical signaling," *ISO 11898-1:2003*, Nov. 2003. Article (CrossRefLink)

Simoon Kim received his BSc in Electronic Material Engineering from Korea Maritime and Ocean University (KMOU), Korea, in 2016. He has been doing research in the Communication Systems and Signal Processing (CSSP) laboratory since 2015. Currently, he is pursuing an MSc in electronic communication engineering from KMOU. His research interests include MIMO, wireless communications, digital communications, and IoT platforms.

UnHyun Lee received his BSc in Electronic Material Engineering from Korea Maritime and Ocean University (KMOU), Korea, in 2016. He has been doing research in the Communication Systems and Signal Processing (CSSP) laboratory since 2015. Currently, he is pursuing an MSc in electronic communication engineering from KMOU. His research interests include MIMO, wireless communications, digital communications, and IoT platforms related to marine environments.

HyukJin Kwon received his BSc in Electronic Communication Engineering from Korea Maritime and Ocean University (KMOU), Korea, in 2015. He has been doing research in the Communication Systems and Signal Processing (CSSP) laboratory since 2015. Currently, he is pursuing an MSc in electronic communication engineering from KMOU. His research interests include Digital Signal Processing, Wireless Communications, Digital Communications, and IoT platforms related to marine environments.

Joon-Young Kim received a BSc and an MSc in Naval Architecture and Ocean Engineering from Inha University, Incheon, South Korea, in 1989 and 1993, respectively, and a PhD in Precision Mechanical Engineering from Hanyang University, Seoul, South Korea, in 1999. From 2000 to 2002, he was a Full-time Researcher at RIMSE Research Laboratories, Seoul, South Korea, and from 2003 to 2005, he was a Post-doctoral Research Fellow at the Univ. of Hawaii and the Univ. of Miami. From 2005 to 2011, he was a Professor in Ocean System Engineering, Jeju National University. In 2011, he joined the Division of Mechanical Engineering at Korea Maritime and Ocean University (KMOU), Busan, South Korea, where he is currently a Professor. His research interests include Underwater Vehicles and Robots, such as AUV, ROV, UUV, Underwater Gliders, and Underwater Construction Robots.

Jeongchang Kim received a BSc in Electronics, Communication and Radio Engineering from Hanyang University, Seoul, South Korea, in 2000, and an MSc and a PhD from Pohang University of Science and Technology (POSTECH), Pohang, South Korea, in 2002 and 2006, respectively, both in Electronic and Electrical Engineering. From 2006 to 2008, he was a Full-Time Researcher at POSTECH Information Research Laboratories (PIRL), Pohang, South Korea, and from 2008 to 2009, he was with the Educational Institute of Future Information Technology at POSTECH as a Research Assistant Professor. In 2009 and 2010, he was with the Broadcasting System Research Department at the Electronics and Telecommunications Research Institute (ETRI) as a Senior Researcher. In 2010, he joined the Division of Electronics and Electrical Information Engineering at Korea Maritime and Ocean University (KMOU), Busan, South Korea, where he is currently a Professor. His research interests include MIMO, OFDM, DTV transmission, digital communications, and IoT platforms.