# Design of Multiband Maritime Network for Ships and its Applications

**Chang-Ho Yun, A-Ra Cho, Seung-Geun Kim, Jong-Won Park and Yong-Kon Lim**, *Member, KIMICS*

***Abstract***— Nowadays, maritime communication systems need high data rate, reliability, and consistency in order to equivalently provide navigating ships with diverse multimedia services as in terrestrial communication systems. For this purpose, we conceptualize and design the maritime network for ships equipped with a multiband communication system which cost-effectively supports multimedia services according to several radiofrequency bands, such as HF, VHF, and satellite frequencies. We also introduce two service scenarios targeted for the maritime network; ship multimedia service (SMS) and real-time maritime logistics location tracking (RML2T). In addition, we specify related works according to three lower network layers (i.e., physical, data-link, and network layers) upon designing the network.

***Index Terms***—Communication system, maritime, multiband, network, ships

## I. INTRODUCTION

So far, maritime communication services have been mainly supported ship security (e.g., ship location tracking, ship identification, and ship surveillance) via global maritime distress and safety system (GMDSS) [1] and automatic identification system (AIS) [2]. Although small-sized text message transfer using narrow band direct printing (NBDP) [3] or navigational telex (NAVTEX) [4] has been also executed, maritime communication still lacks the versatility of services, compared with its terrestrial counterpart because it has been considered premature for ships to provide multimedia services.

However, a variety of maritime multimedia services, including full-duplex digital data transfer regardless of ship security, video on demand (VoD), and seamless Internet service are gradually required for ships nowadays in order to keep communication consistency between land and sea. If these maritime multimedia services are applicable to ships, the type of data becomes various, and the volume of data enormously increases. To deal with the increasing data type and traffic, satellite communication may be one of good candidates due to its support of high data rate with reliability in the sea. However, satellite communication may be disadvantageous in that its remarkably high cost is burdensome to ship service subscribers. Accordingly, it is necessary to design both a new system and a network for the maritime communication which work on other radio frequency bands but provide ships with the maritime multimedia services in a cost-effective way.

Based on current standardization activities via World Radiocommunication Conference (WRC) [5], maritime communication in the band of high frequency (HF) and very high frequency (VHF) is considered as good running mates of satellite communication. Several maritime multimedia services using HF and VHF bands are exemplified in International Telecommunication Union- Radiocommunication (ITU-R) recommendation [6], [7]. However, a stand-alone communication using a specific frequency band may not efficiently support targeted maritime multimedia services since communication coverage, bandwidth, and data rate can vary according to frequency bands. For instance, HF band communication can be useful to provide low data rate multimedia services in the ocean. VHF band communication can be applicable to support comparably high data rate multimedia services in the seashore or near sea under an ad-hoc network topology. Satellite communication can be still used in case of emergency or the case that HF and VHF band communication are not applicable.

In this regard, a ship needs to equip a new communication system covering HF, VHF, and even satellite frequency bands. This system is thus referred to as a multiband communication system. In the multiband communication system, each frequency band communication is not executed independently but controlled by a ship operator in order to cost-

Manuscript received July 24, 2009 ; revised August 17, 2009.

Changho Yun is with the Department of Ocean Engineering Research, Korea Ocean Research & Development Institute (KORDI), 305-343, Korea (Tel: +82-42-866-3834, Fax: +82-42-866-3819, Email: sgn0178@moeri.re.kr)

effectively choose an adequate communication mode with respect to its desired multimedia service. To the best of our knowledge, the development of the multiband communication system and corresponding network for the maritime multimedia services has been not conceptualized, yet. It is necessary to specify several preliminary works before the realization of the maritime multimedia services for ships using the multiband communication system in practice. Accordingly, we describe related works which include proposing possible maritime multimedia services, designing a network with the multiband communication system, and drawing corresponding research topics.

The rest of paper is structured as follows. We survey and outline current standard activities and works on the maritime communication system and network in our target frequency bands in Section II. The proposed network architecture for ships with the multiband communication system is described in Section III, and two service scenarios, including ship multimedia service (SMS) and real-time maritime logistics location tracking (RML2T) are introduced in Section IV. Several related works are specified according to three lower network layers (i.e., physical, data-link, and network layers) in Section V. Finally, we conclude this paper in Section VI.

## II. CURRENT WORKS ON MARITIME COMMUNICATION SYSTEM AND NETWORK

In this section, we survey standards and technical trends of HF, VHF, satellite band communication which is applicable to the maritime communication system. In addition, we outline current works on mobile Ad-hoc network (MANET) which can be employed to VHF band communication. Here, these works are described with respect to frequency bands as follows.

### *A. HF band Communication*

For the purpose of adapting new digital technology to maritime mobile communication in HF band, ITU radio regulations (RRs) appendix 17 was revised [8] in accordance with Resolution 351 (Rev. WRC-03). Besides, several countries such as United States and Norway have already developed digital communication systems in the HF band and have made an effort to diversify corresponding services by revising RRs appendix 17.

In addition, HF band MODEMs and corresponding protocols for the maritime digital data communication system, which commonly uses frequencies between 1 MHz and 30 MHz, are developed by many companies. In particular, SCS, a German company has developed PACTOR protocol and PTC-II MODEM which are targeted for the maritime network transferring large binary data files and accomplishing Internet E-mail. Especially, PACTOR protocol has been standardized as a communication protocol for the maritime HF band digital data service by ITU-R [9].

### *B. VHF band communication*

As the demand for new digital technology in the maritime communication services increases, VHF band communication in the band between 156 to 174 MHz was assigned in ITU-R Resolution 342 (Rev. WRC-2000) [10]. ITU-R study group 8 (SG8) has worked on the technique to send digital data and e-mail in the VHF band. In 2007, ITU-R SG8 suggested a new draft regarding the technique to send digital data and e-mail in the VHF band [11]. Moreover, the SG8 proposed a new draft standard of VHF data system where several applications of the system are exemplified [12].

In addition, Automatic identification system (AIS) is one of currently standardized maritime VHF band communication system. The AIS keeps track of a ship location and identifies the ship under self-organizing time-division multiple access (SO-TDMA) scheme. In beginning of 2007, a new worldwide standard for AIS base stations was approved by IEC [13].

### *C. Satellite Communication*

Regardless of high communication cost, satellite communication is prerequisite for ships in case of sending urgent messages or supporting high data rate premium multimedia service at sea. OrbComm, GlobalStar, VoSAT belong to current satellite communication systems. In particular, one of the most typical maritime satellites is international maritime satellite (INMARSAT) [14], [15]. INMARSAT was established in 1979 in order to serve the maritime industry by developing satellite communications for ship distress, safety and management applications. Today, it operates a global satellite network for maritime, land and aeronautical subscribers. The INMARSAT network can be accessed via independent land earth station operators who offer a range of communications including voice and multimedia. Aside from its commercial services, INMARSAT provides GMDSS to ships and aircraft without charging, as a public service.

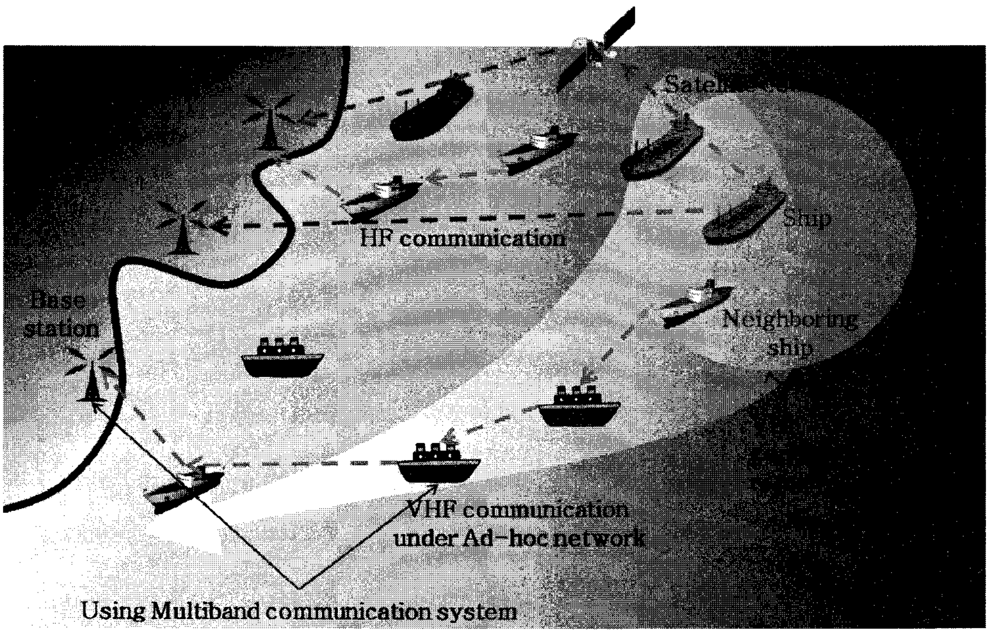


Fig. 1. An illustration of overall maritime network architecture for ships using the multiband communication system.

***D. Mobile Ad-hoc network for vehicles***

A Mobile Ad-hoc Network (MANET) is a dynamic and self-configuring multi-hop network that does not need any infrastructure such as a base station or an access point [16]. A vehicular Ad-Hoc Networks (VANET) is an application of MANET, which mostly focuses on controlling road traffic by considering vehicles' moving pattern. Its physical and data-link layer issues have been standardized in IEEE 802.11p wireless access in vehicular environments (WAVE) [17]. Several vehicles on the road can correspond to ship at sea. Therefore, it is expected that multi-hop VHF band communication in the maritime network can make a reference to VANET and WAVE.

## III. MARITIME NETWORK ARCHITECTURE FOR SHIPS USING MULTIBAND COMMUNICATION SYSTEM

In this section, we describe overall maritime network architecture. This network simply consists of ships equipped with the multiband communication system, terrestrial base stations, and a satellite, as shown in Fig. 1. Here, intermediate stations such as buoys are not considered due to its maintenance difficult and the return for common fishery right.

On one hand, a base station and a ship respectively have different roles. A base station can provide ships with various maritime multimedia services by operating application servers by itself. In addition, a base station connected to IP-based backbone networks enables ships to support IP-based multimedia services. Several ships are competitive to connect to base stations using a specific frequency band communication, and this competition can be solved by efficient channel access techniques in the data-link layer. To achieve multiband communication, both a base station and a ship are required to equip the multiband communication system.

On the other hand, a topology of the maritime network is not fixed because all ships in the sea navigate towards their destinations with different direction and speed although several ships may navigate along with a specific navigation route. Hence, it can be assumed that all ships are randomly but sparsely deployed in the sea at any time without loss of generality.

Under given network topology, a ship has connectivity to a base station with respect to frequency bands. Namely, a ship can reach a base station in a direct manner by using HF band communication due to its long transmission distance which is around few thousands of kilometers [18]. Also, a ship can communicate with a base station via a satellite wherever it navigates in the ocean. However, the transmission distance of VHF band communication is less than few tens of kilometers [19]. A ship using VHF band communication may not directly connect to a base station once it is located far away from the base

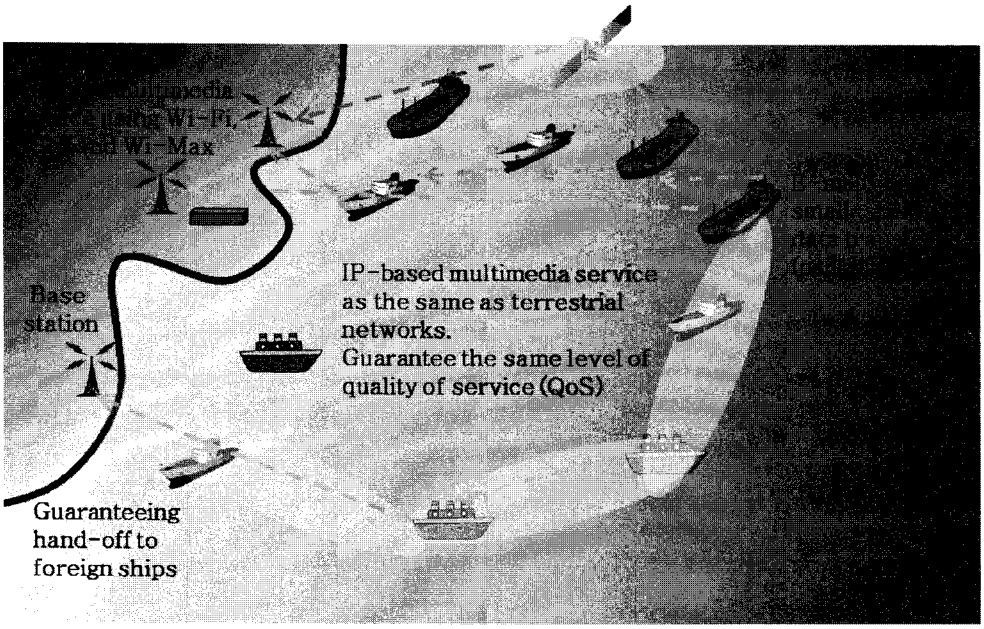


Fig. 2. An illustration of ship multimedia service.

station. Thus, a ship should send data to its neighboring ships to finally reach to a base station in an Ad-hoc manner, as illustrated in Fig. 1. If a ship is not able to find neighboring ships in the range of its transmission range, it should change other operating frequency band in the multiband communication system.

## IV. MARITIME MULTIMEDIA SERVICE SCENARIO

In this section, we introduce two services for the maritime network, including the SMS service and the RML2T service. The SMS is proposed to show the possibility of diverse multimedia services under the maritime network. Also, the RML2T service is shown as an application example how to efficiently utilize proposed maritime network in the context of ship security which has been prevalently considered.

### *A. SMS service*

The SMS service is on the basis of realization of diverse multimedia services by pursuing cost-effectiveness at sea as in terrestrial wired and wireless networks. Also, the SMS is targeted to support service consistency regardless of the location of ships by provisioning quality of service (QoS) of a ship and charging policy according to multimedia services. The QoS of a ship can be guaranteed by handover technique base stations [22]. As a ship equips the multiband communication system, it can efficiently choose the type of communication mode according to desired multimedia service.

The SMS is exemplified as follows.

- A ship may use as equivalent IP-based multimedia services as terrestrial base station when it is at anchor with the help of commercial communication services such as Wireless Broadband (WiBro) and Wi-Fi [23], [24]. Apart from the multiband communication system, a ship is required to have corresponding terminals to use these commercial services.
- A ship may use HF band communication to employ low data rate data transfer (e.g., text message) or e-mail services anywhere in the sea, as shown in Fig. 2.
- A ship may use VHF band communication to employ comparably high data rate and IP based multimedia services in seashore or near sea when Ad-hoc networking is available. If a ship detects that Ad-hoc networking does not work any longer, it quickly switches communication mode between HF band and satellite communication. This is totally dependent on the type of multimedia services that the ship is now in the use.
- Satellite communication can provide ships with the most reliable wireless link with high data rate and delay-tolerance at the expense of high cost. Thus, a ship can use this communication in case of emergency or that the demand of high QoS services arises.

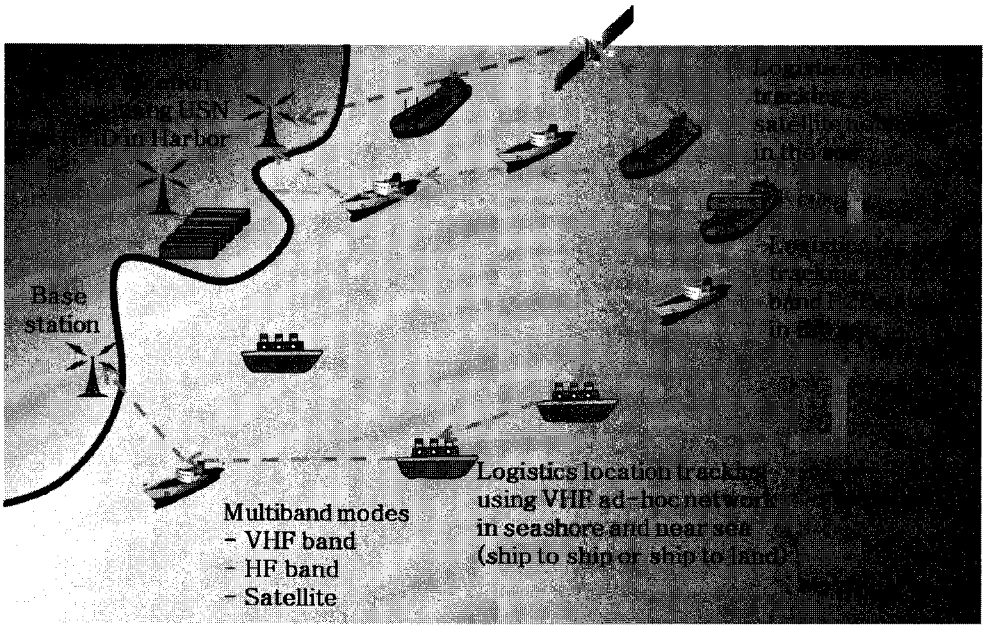


Fig. 3. An illustration of real-time maritime logistics location tracking.

### *B. RML2T service*

The RML2T service focuses on supporting remote control and surveillance for ships logistics. The service can also prevent any accident induced by loading dangerous items and containers with the help of real-time ship logistics monitoring. Thus, although an accident occurs at sea, it can be quickly settled down using the RML2T service under the maritime network.

In case of a harbor, there are a number of containers. Radio-frequency identification (RFID) [20] such as e-Seal and RTLS is attached to each container in order to track its location. With the help of wireless technology such as ubiquitous sensor network (USN) [21] and RFID techniques, the location of a specific container (or logistics) can be detected in the harbor, as illustrated in Fig. 3. In addition, once a ship loading containers departs from a port, a base station can keep track of the location and the safety of a specific container by asking the information to the ship. The ship just investigates the status of the container by using USN and RFID. Furthermore, when a ship finds any fault or accident of a container, it can inform a base station of detected information in a reverse way.

The real-time message, including the status inquiry and the location of a specific container between a ship and a base station is transmitted and received under following rules. A ship primarily tries VHF band communication by detecting its neighboring ships in order to transmit information. If the ship cannot detect any neighboring ship, it tries HF band communication rather than satellite communication due to its less expensive cost. Satellite communication is used in case that both HF and VHF band communication are not applicable. Or, satellite communication can be employed to inform a base station of emergency such as accident and terror.

## V. RELATED WORKS ON MARITIME NETWORK USING MULTIBAND COMMUNICATION SYSTEM

In this section, we introduce several research topics in order to realize the maritime network for ships equipped with the multiband communication system. We specify corresponding works with respect to layers, including physical layer, data-link layer, and network layer, as illustrated in Fig. 4.

### *A. Physical layer*

Related works in the physical layer mainly concern the realization of the multiband communication system. The system can be designed under following procedures. First, following requirements need to be preliminarily determined according to frequency bands before designing the multiband communication system.

- Channel modeling considering multipath fading, signal attenuation, and signal refraction
- Transmission coverage
- An adequate carrier frequency and bandwidth
- Modulation and demodulation techniques

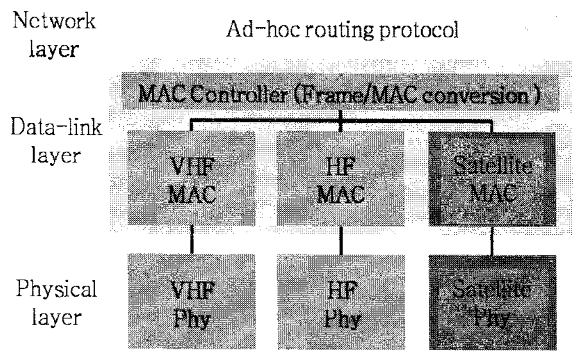


Fig. 4. Corresponding works for the maritime network according to three layers.

- Multiplexing and demultiplexing techniques
- Target data rate
- Transmission power level
- Power supply
- Target performance such as bit error rate (BER)
- Data interface

Apart from the above information, there are still rooms for other requirements further included.

Second, it is necessary to survey current standards as references to achieve the multiband communication system, like ITU, international maritime organization (IMO) [25], international electrotechnical commission (IEC) [26], or european telecommunications standards institute (ETSI) [27]. Third, several modules, parts of the multiband communication system, including communication and antenna modules are required to be investigated. Finally, basic system architecture needs to be designed, which includes the integration of several modules, defining communication interfaces, and thus making communication system platform by considering aforementioned requirements.

### B. Data-link layer

The works in the data-link layer in order to achieve the maritime network are briefly summarized as follows.

- Management of channel access among ships using medium access control (MAC) protocols according to frequency bands
- MAC protocol and frame conversion according to frequency bands

At first, a proper MAC protocol with respect to frequency bands needs to be primarily designed. Here, we directly employ MAC protocols for satellite and HF band communication, which have been already standardized or studied. Thus, we mainly focus on designing a MAC protocol for VHF band communication due to its multi-hop communication environment under an Ad-hoc manner.

There are two candidates of a MAC protocol for the maritime VHF band communication. One is IEEE 802.11 carrier sense multiple access/collision avoidance (CSMA/CA) [28]. Another is ITU-R carrier sense-time division multiple access (CS-TDMA) [29]. Each MAC protocol has pros and cons, respectively. CSMA/CA is advantageous to terrestrial Ad-hoc networks, but it has been not verified as a MAC protocol for the maritime network. Also, CSMA/CA may still expose the hidden terminal problem. On the other hand, CS-TDMA has been considered as a MAC protocol for the maritime VHF band communication by ITU-R. However, it can result in severe under-utilization when ships are sparsely deployed in the sea. In this regard, a MAC protocol for VHF band communication needs to be determined between these two MAC protocol types with respect to target multimedia services by considering their pros and cons.

In case of MAC protocol and frame conversion, a ship can change its communication mode, including operating frequency band, communication system, MAC protocol, and frame format with the help of a MAC controller according to channel condition and a ship's request. We propose that a ship can choose a communication mode by using cost determination using weighting method. To do this, we need to define several cost metrics, including data rate, signal power, service expense, and so on. Also, the weight of each cost metric should be differently determined. Hence, a ship can choose a communication mode which supports the least cost. Apart from aforementioned works, error control method, MAC frame formatting, or power control method can be considered as related works.

### C. Network layer

The work in the network layer mainly concerns proposing a routing protocol which is used to determine an adequate communication path between a ship and a base station. This is especially for VHF band communication due to its multi-hop communication in an Ad-hoc manner. Several routing protocols have been proposed for terrestrial, mobile, and vehicular Ad-hoc networks. They are broadly categorized into two parts.

One is a proactive routing (table-driven) protocol where route creation and maintenance are performed via both periodic and event-driven message. Destination-sequenced distance-vector (DSDV) [30], wireless routing protocol (WRP) [31], and cluster-head gateway switching routing (CGSR) [32] belong to proactive routing protocols. Another is a reactive routing (on-demand) protocol where the route between two ships is discovered when only requested. Ad-hoc on-demand distance vector (AODV) [33] routing protocol and dynamic source routing (DSR) [34] belong to reactive routing protocols.

We propose that a reactive routing protocol is more suitable than a proactive routing protocol. This is because ships are randomly deployed and corresponding topology is not deterministic such that keeping routing table is hard to achieve for the maritime network. Accordingly, a routing protocol for the maritime network needs to be designed as an on-demand routing protocol by reflecting on multimedia service scenarios and network environments. Besides routing protocols, there are still several works in the network layer, including optimal route determination, achieving IP connectivity, or QoS control, and so forth.

## V. CONCLUSIONS

In this paper, we introduced a framework for future maritime network and multimedia service scenarios for ships equipped with the multiband communication system. The use of HF, VHF, and satellite frequency bands in the multiband communication system is expected that a ship can cost-effectively use diverse multimedia services as in its terrestrial counterpart. We also outlined corresponding works according to three lower network layers, which can be useful upon designing the maritime network and several services for ships. In addition, this is part of our on-going research project. We consider the realization of the proposed multiband communication system as well as the maritime network in the sequel of this paper.

## ACKNOWLEDGMENT

This work was conducted as a part of the research projects of "Development of marine RF based ad-hoc network for ship" financially supported by the Ministry of Land, Transport and Maritime Affairs (MLTM) of Korea.

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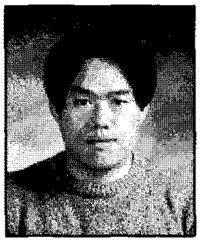
**Changho Yun** was born in Busan, South Korea on Sept. 23, 1976. He received the M.S. and Ph. D. degrees in department of information and communication from Gwangju Institute of Science and Technology (GIST) in 2004 and 2007, respectively. He was a post-doc researcher in department of Computer Science in North Carolina State univ. Currently, He is a senior researcher in department of ocean engineering research from Korea Ocean Research & Development Institute (KORDI). His current research interests include broadband convergence network (BcN), next generation network (NGN), IP multimedia subsystem (IMS), as well as underwater acoustic network (UANet).

**A-Ra Cho** was born in Jinhae, South Korea on Oct. 17, 1979. She received the B.S. degree in electronic engineering from the Kyunghee University in 2002. She is a Ph. D. candidate in underwater acoustic communication engineering from the University of Science Technology (UST), and a researcher in the department of ocean engineering research from Korea Ocean Research & Development Institute (KORDI). Her current research interests include mobile ad-hoc network (MANET) and underwater acoustic network (UANet).

**Seung-Geun Kim** received the B.S. degree in Electronic Engineering from Inha University, Inchon, Korea, in 1995, and M.S. and Ph.D. degree in Information and Communications from Gwangju Institute of Science and Technology (GIST), Gwangju, Korea, in 1997 and 2002, respectively. Since 2002, he has worked for the Maritime & Ocean Engineering Research Institute (MOERI), KORDI, as a senior researcher. His research interests include acoustic underwater communication system and maritime communication system design and implementation.



**Jong-Won Park** was born in Hwasung, South Korea on Feb. 1, 1973. He received the M.S. and Ph. D. degrees in department of electronic engineering from Ajou University in 1997 and 2006, respectively. Currently, He is a senior researcher in department of ocean engineering research from Korea Ocean Research & Development Institute (KORDI). His current research interests include underwater robot(AUV, ROV) system, maritime logistics, ship's navigation system, integrated network for ship and naval vessels, as well as underwater acoustic communication and network (UANet).

**Yong-Kon Lim** received the M.S. degrees in power and electrical engineering from the Chung-Nam University in 1984 and Ph. D. degrees in electronic engineering from the A-Jou University in 1994, respectively. He has been working at Korea Ocean Research & Development Institute (KORDI) since 1980. Presently, he is the general-director of KORDI and a professor in the department of underwater acoustic communication engineering at University of Science and Technology (UST) and an affiliate professor in that of Ocean Systems Engineering (OSE) at Korea Advanced Institute of Science and Technology (KAIST). His main interests are underwater acoustic telecommunication, underwater acoustic network, integrated logistic system for Ocean, and integrated communication system for ships.