Integrated Wireless Networking Architecture for Maritime Communications

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***Abstract*— To facilitate the mobile users on ships for communication effectively in the offshore areas at sea, this paper proposes an integrated wireless networking system that is composed of mobile ad hoc network, cellular mobile communication network, and satellite mobile network. The overall system architecture and relevant network elements of the proposed system are described. The proposed system can help to reduce the network deployment cost and calling charge, support more terminal types, and provide the mobile users richer maritime services.**

***Keywords*— mobile ad hoc network, mobile communications, maritime communications**

I. INTRODUCTION

With the development of ocean fishery and transportation, mobile users on ships need to be facilitated with effective communications and services at any sea area. Currently the communication technologies can be used for ships include single sideband (SSB) shortwave radio, VHF (Very High Frequency) radio, FM radio, cellular phone and satellite phone. Among them, the SSB shortwave transmission can be used for long-range communications because its signal is reflected by the ionosphere. However, blind zones exist in the SSB shortwave radio when the receiver is located away from the bounced distance. In addition, it often suffers from serious interference problems because of overcrowding on the wave-bands and atmospheric disturbances. The transmission distance of VHF radio is about 20 nautical miles and the VHF radio transceiver is mainly used for ship-to-ship and ship-to- shore voice communications. The FM radio is mainly used for short-distance ship-to-ship voice communications with about 8-nautical-mile effective transmission distance. Another option is cellular phone, such as CDMA mobile phone with a global positioning system (GPS), whose advantages are low equipment cost and cheap calling charge. The drawback of cellular mobile network is that the coverage of cellular base station signal is limited usually in the tens of nautical miles offshore. The last option is satellite mobile communication by the Inmarsat (International Maritime Satellite) system [1], which is suitable for ships far away from shores. However, the mobile users (e.g. fishermen) can not always afford it due to the expensiveness of satellite terminal equipment, high cost of maintenance and replacement, and high communication fee. From the above discussion on the available transmission devices, it is seen that maritime mobile users are still lack of the cost-effective transmission methods to be used at any sea area.

To address the faced problems, this paper proposes a technical solution by involving several wireless networks. Firstly, we advocate to employ mobile ad hoc network (MANET) for ship-to-ship communications. A MANET is a self-configuring multi-hop network that does not rely on available fixed infrastructure. Vehicular ad-hoc networks (VANET) are an application of MANET, with most research focusing on road traffic for cars [2]. In this paper, we discuss the feasibility to set up VANET between ships at sea. The benefit of using VANET is that ship-to-ship communications within a ship fleet can be achieved without involving satellite at sea areas faraway from shores. For ship-to-shore communications, we advocate to employ cellular mobile network when the mobile users are within the radio coverage of cellular network such as ports and offshore areas. The satellite mobile network gets involved in the ship-to-shore communications only when the mobile users are not covered by cellular mobile network. In the last situation, mobile terminals on board first access the VANET and then access satellite mobile network via a gateway. To accomplish both ship-to-ship and ship-to-shore communications, we further propose an integrated maritime communication system (IMCS) by combining three heterogeneous wireless networks (i.e.,

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VANET between ships, cellular mobile network, and satellite mobile network. Furthermore, we propose an integrated maritime service system (IMSS) to operate together with IMCS for providing mobile users a variety of value-added services, such as positioning, navigation, distress alarm, voice communications, whether forecast, fishery news, entertainment.

The rest of the paper is organized as follows. In Section II, we present the system architecture of integrated maritime communication system (IMCS). Section III describes the involved network elements and functionalities in the proposed IMCS. Section IV introduces the method for the mobile users to select an appropriate communication path in the proposed IMCS. Section V describes the architecture and discusses the realization issues of the proposed integrated maritime service system (IMSS). The Section VI makes the final conclusions.

II. INTEGRATED MARITIME COMMUNICATION SYSTEM

The integrated maritime communication system(IMCS) is composed of the VANET, cellular mobile network, and satellite mobile network. The block diagram of IMCS is shown in Fig. 1. In the IMCS, VANET between ships is the transmission network for ship-to-ship communications, and acts as the transit network for ship-to-shore communications. VANET connects with satellite network via shipborne satellite gateway (S-GW), and connects with cellular network via shipborne cellular gateway (C-GW). Satellite network connects with cellular network via a terrestrial gateway (T-GW).

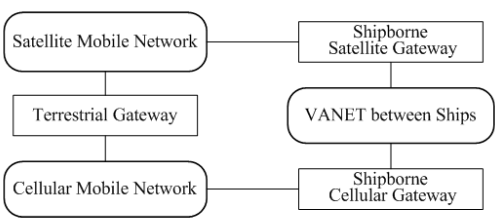

Fig.1. Block diagram of integrated maritime communication system

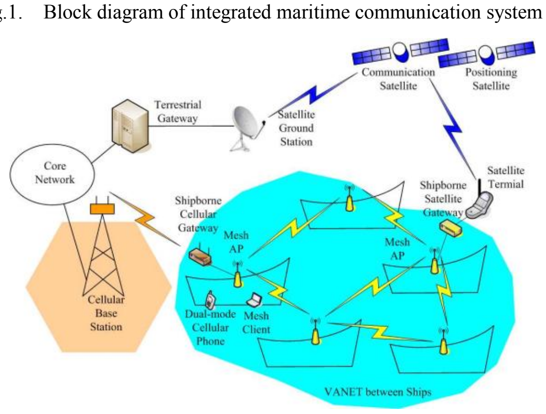

Fig.2. Illustrative diagram of integrated maritime communication system

To give a more clarified illustration of the proposed system, the illustrative diagram of the proposed IMCS is shown in Fig. 2. It needs to be noted that only the essential (but no all involved) network elements are shown in Fig. 2.

III. NETWORK ELEMENTS IN IMCS

In this section, we give more detailed description of the involved network elements and their functionalities in the proposed IMCS.

A. VANET between Ships

In the proposed IMCS, VANET between ships is established to provide ship-to-ship wireless communications. The practical implementation of VANET between ships can be established by the IEEE 802.11s wireless mesh network [3] [4]. IEEE 802.11s defines how wireless devices interconnect together to create a WLAN mesh network, which may be used for static topologies and ad-hoc network. It extends the IEEE 802.11 MAC standard by defining an architecture and protocol that support both broadcast multicast and unicast delivery using radio-aware metrics over self-configuring multi-hop topologies.

In the IEEE 802.11 mesh network, the network devices include mesh Mesh Access Points (Mesh APs) and Mesh Clients. Multiple Mesh APs form a backbone network of the wireless mesh network, and provide the Mesh Clients to access the mesh network. Mesh Clients are individual devices communicating with other devices using the mesh network. Mesh APs form mesh links with one another, over which mesh paths can be established using a routing protocol. IEEE 802.11s defines a default mandatory routing protocol (Hybrid Wireless Mesh Protocol, or HWMP), yet allows vendors to operate using alternate protocols. HWMP is inspired by a combination of AODV (Ad hoc On-Demand Distance Vector) and tree-based routing.

To establish a mesh network between ships, each ship firstly sets up a Mesh AP. One-hop wireless link is formed between neighboring ships, and then multi-hop wireless route via Mesh APs on the whole ship fleet can be established to support ship- to-ship communications.

To enable the radio signal reach adjacent APs, Mesh APs transmit power is preferred to be adjustable according to the conditions of wireless transmission path between adjacent APs. It is presumable that a small disaster site can be covered by just using a wireless access point such as a high-power WiFi access point. This case can be regarded as a special case of the wireless mesh network.

Considering high mobility of marine vessels, more stable and robust routing protocol is preferred. Location-based routing protocols can be used since they are not sensitive to network topology changes. The ship location information can be collected by using a high-precision GPS receiver or a shipborne navigation instrument, and then delivered to other mobile terminals in the fleet via VANET between ships.

After VANET between ships is established, ship-to-ship data communications can be achieved via standard IP protocol, and ship-to-ship voice and video communications can be accomplished through the VoIP (Voice over IP) protocols.

B. Mobile User Devices

IEEE 802.11s mesh network is compatible to those devices that are based on IEEE 802.11. Hence, all mobile terminals with WiFi interface (e.g., the dual-mode phone with both cellular and WiFi interfaces, laptop computers with WiFi interface) can be used as Mesh Clients to access the wire- less mesh network. In addition, marine vessels require high-precision positioning and navigation. The accuracy of GPS on cellular handset can not satisfy this demand. It is suggested that a high-precision GPS receiver terminal equipped with ECDIS (Electronic Chart Display and Information System) sends the navigation information to other ships through the Mesh network to make the navigation information available to the entire fleet. This means can reduce the number of high-precision GPS terminals required for the whole fleet.

C. Shipborne Gateways

Shipborne cellular gateway (C-GW) enables those shipborne user devices that are lack of cellular interface (e.g., laptop PC) to access the cellular services. Shipborne cellular gateway achieves the network interface between the VANET and the cellular mobile communication network, and hence it needs to accomplish the conversions of the communication protocols and data formats between the VANET and the cellular mobile network.

Shipborne satellite gateway (S-GW) enables those user devices that are lack of satellite interface (such as dual-mode phone, laptop PC) to access the satellite mobile network. S-GW achieves the network interface between the MANET and the satellite mobile network, and hence it needs to accomplish the conversions of the communication protocols and data formats between the VANET and the satellite mobile network.

When using satellite mobile network alone without VANET at offshore areas, each ship needs to deploy satellite terminal. In the proposed IMCS, VANET between ships operating with one satellite gateway satellite terminal on one ship can finish the job. Thus, the proposed IMCS helps to reduce the number of necessary satellite terminals and the deployment and maintenance costs caused by the satellite mobile network. Of cause, depending on the fleet size and the amount of communication data, more shipborne satellite gateways and satellite terminals can be deployed on the fleet.

D. Satellite Terminal

In the proposed IMCS, satellite terminal is mainly used for transferring data between VANET and the satellite mobile network. To ensure sufficient link capacity, Inmarsat Fleet-Broadband satellite terminal is a preferred choice [5].

Using the latest generation Inmarsat satellite, Fleet Broadband service can provide broadband voice and data services with data rate up to 432 kbps for the global maritime users. The interface for voice communications can be telephone line (RJ11/RJ 45). The data services can also be supported by a variety of methods such as Ethernet, ISDN for connection with personal computers or PDAs. We suggest selecting a commercial Fleet Broadband terminal model streaming multimedia capabilities. Thus, the satellite gateway can be easily combined with satellite terminal. When aided by a WiFi interface, a satellite terminal can act as an 802.11s Mesh Client, and communicate directly with other Mesh Clients with WiFi inter- face. In addition, satellite terminal with streaming multimedia capability can support VoIP communications seamlessly across 802.11s Mesh network.

E. Terrestrial gateway

The interconnection of satellite mobile communication net- work and 3G cellular mobile communication system has been defined by 3GPP. The integrated system of satellite network and WCDMA-based UMTS network is termed as S-UMTS (Satellite component of the Universal Mobile Telecommunication System) [6]. In the S-UMTS system architecture, the satellite system is connected to the UMTS core network via Iu interface through the terrestrial gateway and becomes one integrated part of the UMTS system. The terrestrial gateway combines the Node B and RNC functions and achieves the network interface between the cellular mobile communication network and the satellite mobile communication. Hence, the satellite communication system is considered to extend UTRAN (UMTS Terrestrial Access Network) and is called USRAN (UMTS Satellite Radio Access Network). The system structure with S-UMTS concept is shown in Fig. 3

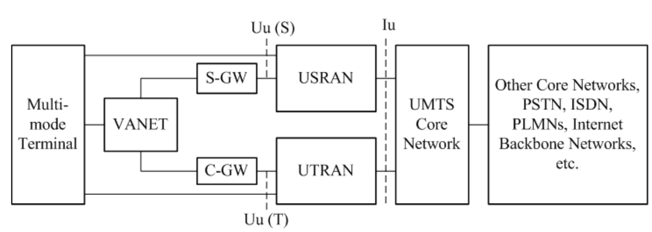

Fig.3. System structure with S-UMTS concept

IV. COMMUNICATION PATH SELECTION

The IMCS provides multiple wireless communication options, i.e., the VANET between ships, cellular network, and satellite network, for the mobile users on board to select. The selection of appropriate communication path can be based on service requirement (ship-to-ship or ship-to-shore), the network conditions, and the location of ships.

For ship-to-ship communications, the mobile users can use the VANET between ships only, as in Fig. 4. For ship-to-shore communications, a ship-to-shore radio link can be established by only using the cellular network when the ships are within the coverage of cellular network. On the other hand, if the ships are out of the coverage of cellular network, a ship-to- shore communication path can be established by using VANET between ships, satellite gateway, and satellite system. Hence, the communication scenarios that the satellite system needs to be involved are reduced by using the proposed IMCS. The procedure to select the wireless communication path is presented as follows by using the example that mobile user shipborne acts as the caller.

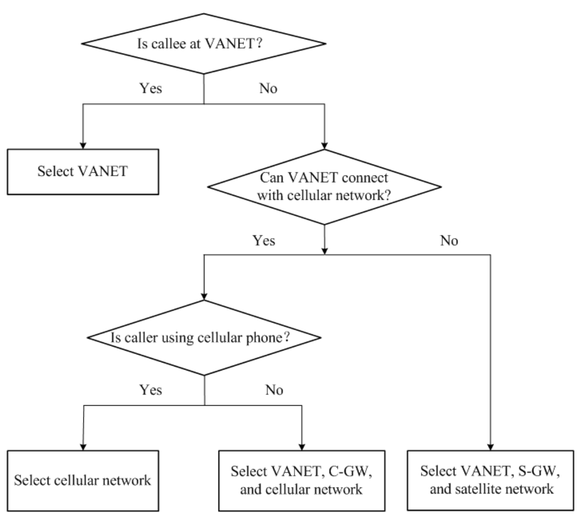

Fig.4. Procedure of communication path selection by mobile users on board

Step 1 Determine whether the callee is a mobile user within the VANET between ships at sea, if yes, goto Step 2; otherwise, goto step 3.

Step 2 The caller uses the VANET between ships to establish a connection with the callee.

Step 3 Determine whether the VANET between ships can be connected with the cellular network, if yes, goto Step 4; otherwise, goto step 7.

Step 4 Determine whether the caller uses a cellular phone, if yes, goto Step 5; otherwise, goto step 5.

Step 5 The caller uses the cellular network to establish a connection with the callee.

Step 6 The caller uses the VANET between ships, shipborne cellular gateway, and the cellular network (C-GW) to establish a connection with the callee.

Step 7 The caller uses the VANET between ships, shipborne satellite gateway (S-GW), and the satellite network to establish a connection with the callee.

V. Integrated Maritime Service System

The proposed IMSS can be established based on OSA (Open Service Access, formerly Open Service Architecture) defined in 3G network. OSA enables applications to make use of network functionality through an open standardized interface (the OSA API). The OSA enables applications implementing the services to make use of but keep independence from underlying network functionality. Hence, OSA offers a very flexible framework for service creation and provisioning. Through these OSA APIs, service applications can easily use the operational capabilities of the bearer network, such as call control, user information query, without having to understand the details of the bearer network signaling.

In an integrated service system, mobility management of users is crucial and it can be achieved by the concept of VHE (Virtual Home Environment) in 3G IP Multimedia Subsystem (IMS). VHE is defined as a concept for personal service environment portability across network boundaries and between terminals. The concept of the VHE is such that users are consistently presented with the same personalized features, User Interface customization and services in whatever network and whatever terminal (within the capabilities of the terminal and network), where ever the user may be located.

The user profile data concerning VHE services is stored in the Home Subscriber Server (HSS). It contains the subscription-related information (subscriber profiles), performs authentication and authorization of the user, and can provide information about the subscriber's location and IP information. The positions of mobile users on board can be reported to the HSS through satellite gateway on board and satellite system. The architectural diagram of the integrated maritime service system with IMS framework is shown in Fig. 5.

The ship-to-shore voice service can be provided via SIP (Session Initiation Protocol) protocol with IMS [8]. Application servers (AS) host and execute services, and interface with

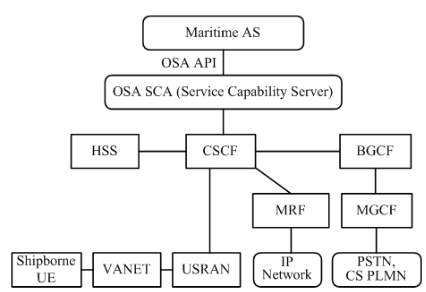

Fig. 5. Integrated maritime service system with IMS framework

the S-CSCF using SIP. A SIP call initiated from mobile users on board is routed via the USRAN (including satellite systems and terrestrial gateways) and then controlled by IMS S-CSCF. S-CSCF downloads the relevant service profile from the HSS. VoIP data transmission are controlled by MRF (Media Resource Function) to connect to other SIP users or by BGCF (Breakout Gateway Control Function) and MGCF (Media Gateway Controller Function) to connect to users in CS (Circuit Switched) Networks such as PSTN (Public Switched Telephone Network) or the CS PLMN (Public land mobile network).

VI. Conclusions

To support ship-to-ship and ship-to-shore communications at any sea area, this paper proposes an integrated maritime communication system (IMCS) by combining three heterogeneous wireless communications networks. The IMCS can help to reduce the number of satellite terminals on board and network deployment and maintenance costs. Additionally, shipborne mobile users can select appropriate communication path according to their locations and wireless network coverage conditions. Hence, the scenarios of using satellite system are reduced, which yields the benefit of decreased calling charge. Moreover, an integrated maritime service system (IMSS) can operate together with the IMCS to support value-added services for mobile users at sea.

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