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A Ship Area Network with WiMedia Wireless Gateway Applying a Cooperative Transmission

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Abstract

A typical ship area network provides the connection devices, instruments, and sensors embedded or boarded on a ship. This is mainly based on wired networks such as dedicated connections, instrument networks, and shipboard control networks. For this, WiMedia-based wireless gateway is essential to support high-speed and multimedia data transmission with high quality and energy efficiency. This paper proposes the integrated ship area network architecture with WiMedia wireless gateway applying a cooperative transmission scheme with distributed MAC protocol. The performance evaluation results show that the proposed architecture can guarantee data throughput even under severe channel conditions. The proposed scheme would be a meaningful approach in implementing e-Navigation system combining with other wireless communication techniques such as ubiquitous sensor network (USN), 3G-LTE, femto-cell, and cognitive radio.

Keywords: Ship area network, WiMedia, wireless communications, MAC, e-navigation, USN

1. Introduction

A typical ship area network (SAN) delivers main operations such as the integration of shipboard systems embedded with a variety of devices and instruments, sensing and control within systems, and collection/management of crucial data/information for safety and navigation. These operations are happening in many parts of the vessel from the engine room, to the bridge, to the administrative personnel, and even off of the ship to the owner's office. The general ship area network architecture is generally organized as a single network with a backbone network comprised of three levels, which is standardized by the international maritime organization (IMO) or the international electro-technical commission (IEC) [1-2]. The conventional network hierarchy with the international standard is mainly based on wired networks such as dedicated connections, instrument networks, and shipboard control networks with Ethernet connection. By these reasons, this paper focuses on designing an integrated network architecture of the SAN with wireless gateway.

For higher cost benefit shipbuilding, many researchers recently have been focusing on developing an integrated ship area network applying state of the art wireless communication technologies such as wireless sensor network (WSN), 3G-LTE, etc. This integrated network essentially deals with a controller area network (CAN) of shipboard instruments. However, the maximum throughput of the navigational instrument's bus supported by the current CAN connection is just 125 kbps. With this, a typical CAN cannot satisfy the increasing need for high speed/amount of data transmission on board between a bunch of instruments and an integrated gateway for a high-cost digital equipped ship in the near future. Moreover, besides control and navigational information between instruments devices, the need for various data services within a vessel is essential for such a vessel. For this purpose, wireless transmission between devices (sensors) and a gateway is a reasonable option regarding energy efficiency, system deployment cost, and recovery and management convenience.

Thus, this paper presents a wireless gateway applying the state of the art wireless transmission between instrument (devices, or sensors) and gateway. As a wireless transmission of a wireless gateway, WiMedia with distributed MAC is chosen because it can satisfy the demand of multimedia services for high quality in a wireless home network environment, as well as a variety of applications such as wireless USB, wireless IP, and wireless 1394 [3]. Moreover, a relay-based cooperative MAC protocol is also taken into account in this paper for improving throughput and reducing energy consumption by virtue of cooperative transmission techniques [4]. The proposed network architecture with wireless gateway and with relay-based cooperative transmission scheme can increase communication reliability between cluster headers, irrespective of channel variation. Section 2 in this paper describes the proposed ship area architecture with WiMedia gateway and distributed MAC protocol with relay-based cooperative transmission selection algorithm. Section 3 shows the simulation results and discussion of the proposed wireless gateway with cooperative transmission, followed by the conclusion.

2. Proposed Ship Area Network Architecture with WiMedia Gateway

2.1. Conventional Ship Area Network

A conventional ship area network has the functionality of a remote control and autonomous management of various sensors and instruments embedded or boarded on a ship. An integrated navigation system on board the ship using National Marine Electronics Association (NMEA) 2000 standard is primarily designed to provide two-way communication between the ship's navigational equipment such as radar, GPS receiver, automatic identification system (AIS), Gyro compass etc. NMEA 2000 is based on CAN, which is standardized by ISO. NMEA 2000 standard also became the international standard under IEC. ISO 11898 specifies physical and data link layer of serial communication technology called CAN that supports distributed real-time control and multiplexing. The protocol is used to create a network of electronic devices, mainly marine instruments, on a vessel. Various instruments with the NMEA standard are connected to one central wired cable; i.e., a backbone. The backbone powers each instrument and relays data among all of the instruments on the network [6].

The first version of shipboard data architecture developed by the IEC standard is the Maritime Information technology Standard (MiTS) project. This uses four layers: instrument, process, system, and administrative. MiTS was developed as an integrated ship control (ISC) protocol, which could integrate an NMEA network on the bridge with industrial data network in the automation system [7]. The conventional ship area network architecture is shown in Figure 1.

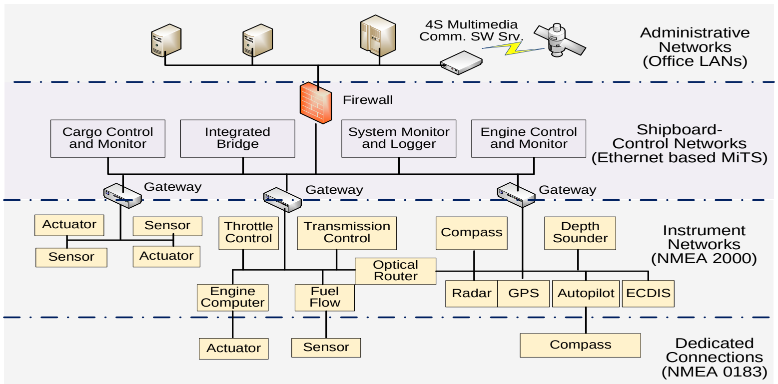

Fig. 1. Conventional layered ship area network architecture based on international standards [7].

2.2. Architecture of WiMedia Wireless Gateway

The typical ship area network is mainly based on wired networks such as dedicated connections (NMEA 0183), instrument networks (NMEA 2000), and shipboard control networks (Ethernet-based MiTS). The lowest level instruments and devices are connected to a gateway. The data throughput of the conventional ship area network is not sufficient to satisfy the increasing amount of data caused by a bunch of various instruments, devices, and sensors. Moreover, its system deployment cost, and recovery and management convenience is always an inherent drawback of the wired network. For these reasons, this paper presents WiMedia wireless gateway between shipboard control network and instrument network. With this concept, integrated network architecture of the SAN with wireless gateway is proposed as shown in Figure 2.

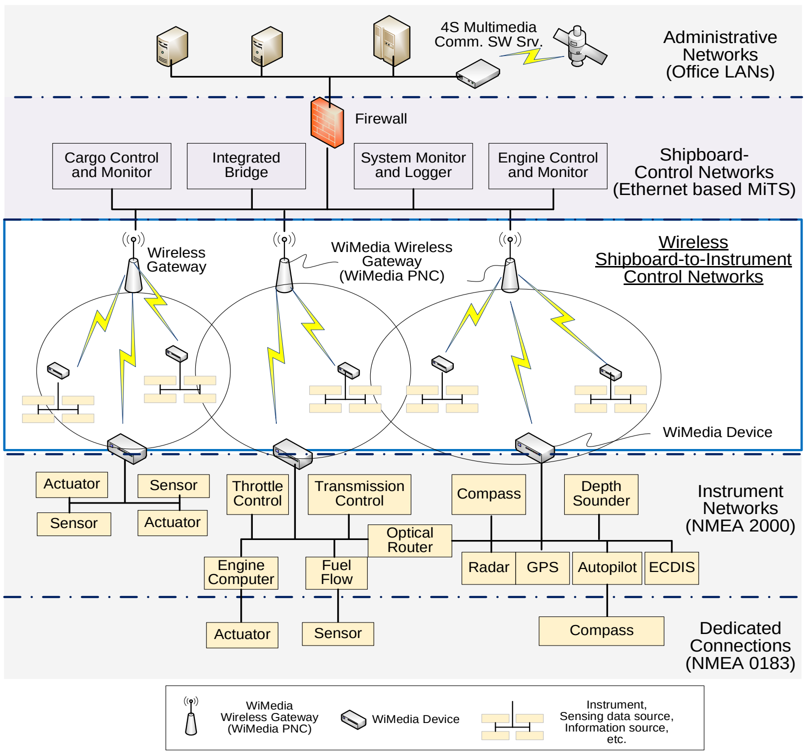

Fig. 2. The proposed architecture of SAN with WiMedia wireless gateways.

In the proposed architecture, a WiMedia piconet network coordinator (PNC) plays as a WiMedia wireless gateway and each WiMedia device is a wireless transceiver connected to each navigational instrument. Thus, a wireless shipboard-to-instrument control network is comprised as shown in Figure 2, wherein wireless WiMedia transmission technique gives a degree of freedom in *A* deploying infra-nodes and reliable networking with each device. A WiMedia device connected to instrument(s) can collect information from the sensor(s)'s measurement data, navigation, and a number of control devices. For this, it is noted that a WiMedia wireless gateway should be capable of supporting high-speed and multimedia data transmission with high quality, energy efficiency and transmission reliability. Thus, the proposed WiMedia wireless gateway should apply a relay cooperative transmission scheme base on WiMedia-distributed cooperative MAC, which is to overcome wireless channel variation and increase communication reliability.

2.3. WiMedia Cooperative MAC Protocol for WiMedia Wireless Gateway

In a distributed MAC of WiMedia operation, the Distributed Reservation Protocol (DRP) enables devices to reserve one or more Medium Access Slot (MAS) blocks and to communicate with one or more neighbors by announcing its reservations by including DPR Information Elements (IEs) in their beacons. With the Link Feedback IE, each device can collect data rate information and transmit the power level of neighboring nodes. There are ideal PHY data rate and information from the transmission power in Link Feedback IE, and they are transferred to the transmission device from the receiving device [3].

In this paper, we will use three transmission schemes: direct transmission (DT), relay transmission (RT), and cooperative transmission (CT) [5], which is based on relay DRP supported in WiMedia D-MAC [4, 7]. The selection algorithm of relay transmission applied in this paper is shown in Figure 3. Based on the Reason code and Relay Node Table (RNT) of WiMedia devices, wireless gateway can choose a transport transmission path to support a minimum delay and maximum data rate with the negotiating process of a new cooperative relay DRP. After getting information from the neighboring devices, it is necessary to determine the optimum device for providing the smallest relay transmission time by calculating the transmission time in the available links. With this selection algorithm, WiMedia wireless gateway can select transmission paths among three methods, and thus guarantee channel quality and a required QoS.

Step 1: Selection of one among three relay transmission methods

IF (Good link quality b.w. a source node S1 and a destination node D1) THEN
- Case 1: ***Select DT(direct) TX***

ELSE (Bad link quality b.w. S1 and D1, and
Good link quality b.w. S1 and Relay node R1)
THEN
- Case 2: Select relay node as R1 → ***Select RT TX***

ELSE (Bad link quality b.w. S1 and D1, and
Good link quality b.w. S1 and adjacent nodes of R11 and R12) THEN
- Case 3: Select relay nodes as R11 and R12 → ***Select CT TX***

Step 2: Calculation of total required transmission time

Source node calculates total required transmission time to transmit a data frame to a destination node.

IF (TDT <= max(TCT, TRT) : DX TX time is shorter than that of either RT TX or CT TX)
THEN
- Case 1: ***Select DT TX***

ELSE (TDT > max(TCT, TRT) : DX TX time is larger than that of either RT TX or CT TX)
THEN
{ IF (TCT >= TRT) THEN
- Case 2: ***Select RT TX***

ELSE ((TCT < TRT) THEN
- Case 3: ***Select CT TX***

}

Step 3: After the selection of a transmission method, the source node starts negotiating the DRP reservation.

Fig. 3. Selection algorithm of the relay-based cooperative transmission techniques.

3. Simulation Results and Discussion

As a simulation platform, we use ns-2 simulation tools for the performance evaluation of the proposed architecture of SAN with WiMedia wireless gateway applying cooperative relay transmission techniques. It is assumed that randomly distributed devices connect shipboard instruments within 10m x10m. Without loss of generality, this is assumed as a model of engine room or control room. The size of the packet forwarding considered is 2,048 bytes, which is assumed as a bunch of various instruments' data [8].

Figure 4 shows the change of throughput performance according to the number of WiMedia nodes. Simulation shows that the relay cooperative transmission with DRP outperforms direct transmission because the overlapping probability of device clusters increases as the number of devices increases. This deteriorates the transmission performance of the direct transmission without the help of relays. Figure 5 shows the throughput performance comparison according to various channel statuses with 20 nodes, where bit error rate (BER) represents channel status. It is expected that as channel status worsens, performance decreases. However, the performance of the relay cooperative transmission is sustainable compared to the direct transmission scheme. It is noticed that the cooperative relay transmission can maintain acceptable performance degradation level in BER 10^{-4} to 10^{-3}, compared with other direct transmission methods. Thus, the proposed WiMedia wireless gateway with cooperative relay transmission with distributed MAC DRP can guarantee a reliable channel quality for a ship area integrated network environment.

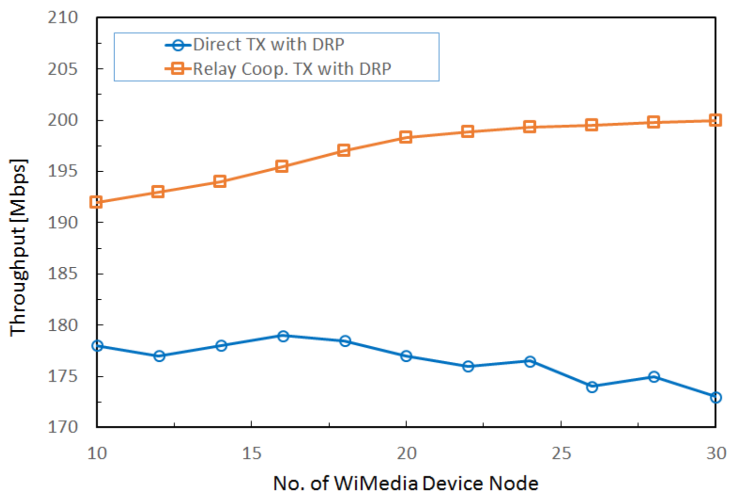

Fig. 4. Throughput performance comparison of a direct transmission with DRP (Direct TX with DRP) and a relay cooperative transmission with DRP (Relay Coop. TX with DRP).

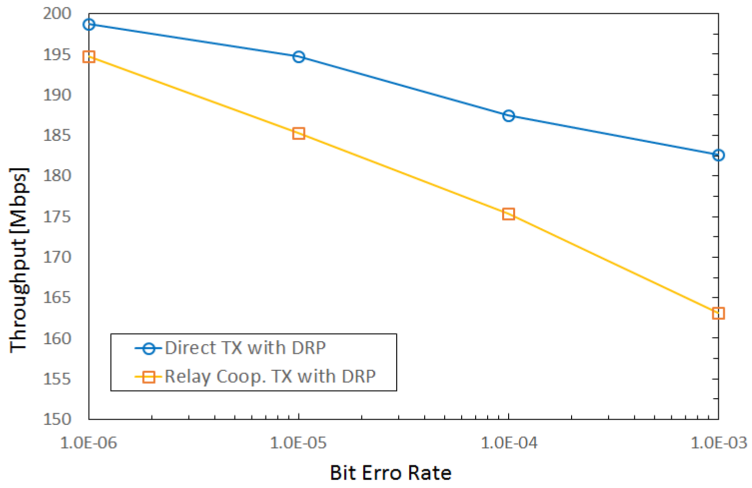

Fig. 5. Throughput performance comparison according to various channel statuses represented by bit error rate.

4. Conclusions

In this paper, we proposed the architecture of WiMedia wireless gateway using relay cooperative transmission scheme for an integrated SAN environment. The proposed WiMedia wireless gateway can support a high data throughput and increase communication reliability by applying cooperative relay transmission with distributed cooperative MAC DRP protocol. It was confirmed that the proposed architecture applying WiMedia wireless gateway improved throughput performance upon supporting high speed and multimedia data services even under severe channel conditions. The proposed architecture and techniques are meaningful for implementing an e-Navigation system.

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