Design of an integrated e-Telecom system for improving telecom systems on ships

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Design of an integrated e-Telecom system for improving telecom systems on ships

Jungwoo Kim¹, and Jooyoung Son²

Abstract

The advancement of communication technologies including satellites has been conducive to the ever-evolving ship management. The increasing needs for the accident prevention and the optimized shipping lead to a wide range of methods of ship management using the telecom systems onboard ships. Future ships including smart-ships will be equipped with telecom systems capable of dealing with the ship management and operation in collaboration with land stations. Yet, currently, the development and application of telecom systems onboard ships are nearly at standstill due to the maritime regulations set out decades ago which limit the technological development and translate new technologies as costly investments. Unlike the technological advancement of land-based telecom systems, the existing telecom systems onboard ships have not been integrated until now but installed and operated separately on board ships. Beyond new and/or reinforced features, future ships should consider both scalable and operational aspects. In the future, telecom systems onboard ships will manage all ship-related data and play pivotal roles in controlling ships anywhere in the world. In that respect, it is crucial to integrate the discrete communication systems for stability and efficiency of telecom systems onboard ships. The integration of telecom systems onboard ships will facilitate the availability of futuristic technologies such as unmanned vessels and maritime autonomous surface ships (MASS). This paper proposes a method of designing an e-telecom system integrating the existing telecom systems onboard ships. Despite the proposed e-telecom system's slower performance in latency resulting from additional devices, the results of the present experiment prove that there is no significant difference in its latency in data processing in comparison to the existing telecom system.

Keywords e-Telecom · Communication · Integration · Ship

1 Introduction

Large vessels traveling long distances used to communicate with land stations via satellites and be charged based on the metered data usage. Due to cost burdens, satellite communication has been limited to the transmission and reception of essential data, e.g. emergencies or regular reporting, resulting in the lack of information sharing between ships and land stations. Therefore, it is necessary for ships to deal with all the aspects of ship management on their own. The interpretations of a problem or an issue arising onboard a ship vary with the capabilities of crew members. However, with the increasing availability of VSAT, ships are regarded as the objects that can be managed at land stations.

VSAT is a satellite communication service that ensures a certain transmission speed and unlimited use of data for a monthly flat rate. Also, VSAT leads the advancement of ship management technologies

by helping accumulate and analyze the ship operation data at land stations.

Technological development of telecom systems for ships is the prerequisite for the ship-land communication and data sharing. Telecom systems onboard ships lag decades behind land-based telecom systems, and are far from being optimal for ships. Without radically narrowing the technology gap between land and sea, ships cannot develop into organic and active structures, which will limit the viability of futuristic ships including unmanned vessels and maritime autonomous surface ships.

Information arising onboard ships is transmitted via their telecom systems. In the past, telecom systems onboard ships used to serve as a safety tool for informing the status internally and/or externally in emergencies and as a means of routine communication in usual times. Recently, as the internal status of ships is managed as data, the importance of the telecom systems for ships is increasing. Ships have started to save and manage their data based on their telecom systems, with a range of telecom systems being utilized to share such data with other entities. Unmanned vessels and maritime autonomous surface ships, both of which are being actively explored now, as well as large ships being built have some security features embedded in their telecom systems. To organically integrate various structures and systems onboard a ship, and thus to make the best decisions in any situations, the technological development of telecom systems for ships is an important. However, telecom systems for ships are installed and operated in compliance with the decades-old maritime

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regulations irrelevant to up-to-date technological development. To integrate and apply the telecom systems for ships, the criteria for functions and inter-system stability defined in the maritime regulations should be met [1,2].

Previous research mostly focused on the standardization and the methods of designing the integration of the existing telecom systems. Some studies conducted the experiments on diverse alarms among many other types of data for ships [3,4]. In contrast, this paper experiments on different types of data, e.g. alarm, voice and streaming, to identify the advantages, drawbacks and other aspects that need be reinforced in operating the telecom systems onboard ships.

This paper proposes an e-telecom system integrating the existing telecom systems for ships for the purpose of increasing the onboard user-friendliness and ensuring a seamless communication with land. The proposed integrated e-telecom system addresses the challenges associated with the blind spots of ships. Also, the proposed system is expected to enable the maintenance including troubleshooting and preventive maintenance with the help of land experts and thereby improve the performance and universality of technology. The present experiment proves there is no significant difference in performance between the proposed e-telecom system and the existing telecom system.

2 Telecom systems

As a rule, telecom systems refer to communication-related systems onboard ships. Table 1 shows 25 types of telecom systems used onboard ships including internal communication systems, external communication systems and safety management systems.

The mandatory systems in Table 1 are required to be installed onboard ships as defined in the SOLAS' (International Convention for the Safety of Life at Sea) Life-saving appliances and arrangements, radio communications and safety of navigation [5]. The equipment outlined in Table 1 is required to be certified for its suitability by the competent agencies designated by the European Marine Equipment Directive(MED) for life-saving appliances, navigation equipment and radio communication equipment that are installed on board ships [6].

Approximately 70% of telecom systems shown in Table 1, e.g. CCTV, entertainment, wireless and LAN systems, are neither included in the mandatory equipment nor subject to the certification. The conventions and registers of shipping established in the past are not enough to define the telecom systems used these days. That is, those systems widely in use on board ships may turn out to be inappropriate for ships due to the absence of any standards or grounds for installation. Hence, it is crucial to standardize the telecom systems for ships through joint R&D efforts by conventions, registers of shipping and manufacturers [7].

Table 1 Telecom systems as revised

Seq.	System	Mandatory	Type Approval
1	VSAT system	X	X
2	Satellite communication (C & F)	O	O
3	Electric clock system	X	X
4	Sound powered telephone system	O	O
5	Communal aerial system	X	X
6	MF/HF DSC radio system	O	O
7	VHF DSC radio system	O	O
8	LAN system	X	X
9	VHF radio telephone system	X	X
10	UHF radio system	X	X
11	Auto telephone system (PABX)	X	X
12	Bridge navigational watch alarm system (BNWAS)	O	O
13	Closed circuit television (CCTV)	X	X
14	Entertainment system	X	X
15	Cinema system	X	X
16	Collaboration system	X	X
17	Wireless network system	X	X
18	Public address and general alarm (PAGA) system	O	O
19	Talkback system	X	X
20	Integrated control & monitoring system (ICMS)	X	O
21	Extension Alarm System (EAS)	X	O
22	Elevator alarm system	X	X
23	Ref. chamber alarm system	X	X
24	Hospital calling alarm system	X	X
25	Satellite TV system	X	X

3 Analysis of existing telecom systems

Fig. 1 shows the spots on board a ship, where the existing telecom systems defined in Table 1 are installed. As seen in Fig. 1, different types of telecom systems are concentrated onboard a ship in comparison to land-based facilities.

Fig. 1 Configuration of the existing telecom systems in ships

Excluding the telecom systems such as PAGA and UHF systems that need to be installed onboard ships, installed systems are mostly concentrated in living quarters. PAGA speakers or UHF portable radio sets cannot remove the communication shadow zones onboard large ships. To deal with the communication shadow zones, additional PAGA speakers, UHF antennas and cables need to be installed, which incurs extra costs. Fig. 2 shows the process of installing the existing telecom systems onboard a ship.

Fig. 2 Workflow of the existing telecom system

Non-mandatory existing telecom systems installed onboard ships are determined by the registers of shipping. In general, any system is not installed without the registers' approval or confirmation. To install telecom systems onboard a ship, their integrity must be proved in relation to the mandatory equipment and their stability must be verified by the registers. Lately, wireless network environments for mobile devices are installed onboard ships. Yet, ships heavily rely on the existing telecom systems, and thus wireless networks are used for the convenience of crew members, not for enhancing the management functions. In some cases where it is difficult to install cables, wireless networks are considered but hardly adopted in practice.

The installation of telecom systems onboard ships is focused more on long-term stability than diversity. Thus, the existing systems are rarely replaced by the latest high-performance systems onboard ships. Now, it is necessary to analyze current systems for ships and actively adopt advanced technologies. Should the challenges of current telecom systems not be addressed properly, it would be difficult to bring about the next-generation technologies such as unmanned vessels and maritime autonomous surface ships.

The existing telecom systems need to address three challenges. First, the inactivation of communication interrupts the ship management. The existing telecom systems installed onboard ships need to go through multiple steps prior to the intended internal communication. Depending on situations, if any situation arises, crew members call the person on duty, who in turn handles the situation in accordance with the report manual. In case the person on duty is absent or fails to comply with the manual, a delayed response to the situation likely leads to a serious accident. Any maritime incident causes casualties and substantial damage to ships including economic losses.

Second, crew members responsible for the ship operation face difficulties in their daily routines at sea. Crew members who cannot but rely on the existing telecom systems onboard tend to feel frustrated by the limited usage given to each rank, the user-unfriendliness of such systems, and the high cost of communication. Moreover, the existing systems are characterized by the insecure exposure of all conversations including even private ones, poor audio quality, long queues and high costs. Thus, the inefficient operation of the existing telecom systems is one of the most challenging aspects of crew life at sea. The existing telecom systems focused on the safety of ships cause complaints from crew members who are responsible for the safety of ships.

With an increasing number of ships fitted with VSAT, crew members can use messengers or slow video chats on their mobile phones with their land-based families and acquaintances. Yet, the limitations of technologies and the cost burdens prevent them from using the various telecom services they would otherwise use on land.

Third, the limited functionality of the existing telecom systems is not reliable enough to ensure crew members properly report any emergencies. In the expansive and complex structures of large vessels, workers can only use nothing but UHF portable radio sets and wired phones via the two-way communications on the existing telecom systems. Ships have quite a few shadow zones for UHF portable radio sets, and wired phones are partially installed in living quarters and busy working areas. In case a safety accident occurs in any of the communication shadow zones, workers have to move around to find the spots where their UHF portable radio sets work or where wired phones are available, which is impractical and time-consuming. Therefore, any accidents arising onboard ships are prone to delayed initial responses leading to disasters.

This paper proposes an integrated e-telecom system that addresses the challenges arising from the existing telecom systems. The proposed e-telecom system integrates the existing telecom systems, enables the two-way communications, and minimizes the communication shadow zones onboard a ship.

Unlike the existing telecom systems which are functionally sub-divided, the proposed e-telecom system is focused on futuristic components, e.g. scalability to adopt state-of-the-art technologies, immediacy and convenience. Also, the proposed e-telecom system shares the situations onboard a ship with land stations in real time, ensures the continuity of information flow, and helps prevent safety accidents and streamline the ship management.

4 Integrated e-telecom system

The telecom system shown in Table 1 largely comprises three components as in Fig 3. First, the internal communication system is in-

stalled onboard a ship. The internal communication system is subdivided into the wired and wireless communication systems for communication between crew members, and the alarm system for sending crew members cautions, warnings and other notifications.

The wired communication system involves the auto telephone system, talkback system and sound powered telephone system. These systems are like wired phones, with which crew members exchange voice messages.

Seq.	Internal Communication System	Seq.	External Communication System	Seq.	Network System
1	Auto telephone system (PABX)	1	Satellite communication(C & F)	1	LAN system
2	UHF radio system	2	MF/HF DSC radio system	2	Wireless network system
3	PAGA system	3	VHF DSC radio system	3	VSAT system
4	Talkback system	4	VHF radio telephone system	4	Satellite TV system
5	BNWAS			5	Communal aerial system
6	ICMS			6	CCTV system
7	EAS			7	Entertainment system
8	Electric clock system			8	Cinema system
9	Sound powered telephone system			9	Collaboration system
10	Elevator alarm system				
11	Ref. chamber alarm system				
12	Hospital calling alarm system				

Fig. 3 Classification of the existing telecom systems

The wireless communication system involves the UHF system, which is the only wireless communication system onboard a ship. The UHF system enables the wireless communication despite the narrow and complex structures of onboard environment. In compliance with the ITU-R (International Telecommunication Union – Radio Communication Sector) M.1174-2, ships are assigned the UHF bands of 450MHz~470MHz for onboard vessel communications [8]. The UHF system should be installed based on the coverage study that analyzes the UHF antenna performance and removes the shadow zones [9].

The other telecom systems including the PAGA system, BNWAS and ICMS are classified as the alarm systems. The large sizes and complex structures of ships require a range of alarm systems capable of detecting any emergencies and contingencies.

Second, the external communication system is used for ship-to-ship communications and short-distance communications with land stations. The external communication system is sub-classified into the communication system used in an emergency for rescue like the satellite communication and the general communication system. The communication system for rescue includes Inmarsat-C, MF/HF DSC radio system (Medium Frequency/High Frequency Digital Selective Calling Radio System) and VHF DSC radio system (Very High Frequency Digital Selective Calling Radio System). The general communication system includes Inmarsat-F and VHF radio telephone system.

Third, the network system includes the operational technology network, business network and crew network.

The operational technology network manages the systems installed onboard a ship, and comprises the management servers and relevant systems. Each server for the internal and external communication systems and the network system in Fig. 3 is mostly included in and run as part of the operational technology network.

The business network comprises the client terminals that can access the operational technology network for data transmission and reception. Controlling the key information of a ship, the operational technology and business networks are underpinned by security in response to troubleshooting, viruses and hacking. The crew network is excluded from the operational technology and business networks but involves the internet accessed via personal devices, e.g. laptops and smart phones. The crew network is a discrete network for the stability of network systems. Unauthorized users or personal devices cannot connect to the crew network. Just as the land communication technology has developed based on fast and stable networks, the network systems need to lay the foundation for the integration of systems onboard ships.

4.1 Integrated e-telecom system structure

Fig. 4 shows the configuration of the existing telecom system installed onboard a ship. It is a general structure comprising individual systems, where the capacity of the main equipment is determined by the number of terminals and hardly scalable.

As seen in Fig. 4, the configuration of terminals varies and is complex across the systems. The complexity of configuration causes the design and test errors in ship building, and incurs extra indirect costs. When data need to be shared between telecom systems, separate cables are installed between main units. As the applicable range increases and the boundaries blur between telecom systems, the interfaces are increasing. As in Fig. 4, the existing telecom system has the terminals for a few different telecom systems at a location. An efficient use of different terminals requires the skillfulness of users.

Fig. 4 Configuration of the existing telecom system

The existing telecom systems cause such extra material expenses for installing additional terminals and cables at a specific location. Particularly, since it is nearly impossible to add new systems at sea, they minimize the installation or live with the inconvenience.

Fig. 5 shows the proposed e-telecom system configuration, comprising the e-main unit, the e-terminal and the existing telecom system's main unit.

Fig. 5 Configuration of the e-Telecom system

In Fig. 5, the existing discrete telecom systems shown in Fig. 4 are integrated into the proposed e-telecom system. Notably, a single e-terminal unit (e-T #1, e-T #2, ... e-T #N) replaces multiple units of

the existing telecom terminals (T #1, T #2, ... T #N). The e-terminal includes all the features of the existing telecom terminals and interacts with the existing telecom system's main unit. The e-telecom system has the e-gateway installed as the interface between the e-main unit and the existing telecom system's main unit. The e-telecom system configuration ensures convenience, scalability and minimal maintenance and installation costs. On the e-telecom system, it is easy to add new systems via the interface between the e-main unit and the existing main unit.

Fig. 6 shows the process of installing the e-telecom system onboard a ship, which is simple in comparison to the process illustrated in Fig. 2, where each telecom system is installed separately. The e-terminal encompasses all the features of individual terminals on the existing telecom system. The e-terminal enhances the differential accessibility through the authorization for each rank, system and function.

Fig. 6 Workflow of the e-Telecom system

4.2 Strengths of integrated e-telecom system

4.1.1 Scalability

The e-telecom system is scalable. To add any telecom system to the e-telecom system, the existing terminal features can be implemented in the interface between the e-main unit and the existing main unit and the e-terminal using S/W. The features of the telecom system can be added to or deleted from the e-terminal settings. The e-terminal's PoE (Power over Ethernet), where one Ethernet cable covers both data and power supplies, requires no additional cable installation. The e-terminal installation ensures the availability of diverse systems, saving the trouble of installing the cables and terminals.

The e-telecom system involves the internal and external communication systems and the network-related system features in Fig. 3. That is, the e-terminal involves all the features of the existing telecom

system terminals. The e-terminal supports the two-way communication and controls each telecom system.

4.1.2 Economic feasibility

The proposed e-telecom system saves costs and is economically feasible compared to the existing telecom system. The ship-building costs include the direct costs e.g. equipment and cables, and the indirect costs, e.g. installation and testing. The existing telecom system has the 1:1 installation of cables between the main unit and the terminal. The proposed e-telecom system's e-terminal allows the easy addition/removal of the existing telecom system features.

This paper analyzes the cost saving effects of the existing telecom system installed onboard a 14,500 TEU (Twenty-foot Equivalent Unit) container ship. Given the indirect costs including the labor, testing and commissioning costs vary across countries, shipyards and workers' skills, the indirect costs are excluded from the analysis.

The analysis of the cost saving effects is focused on the existing telecom system features widely installed onboard ships, particularly automatic telephone system, PAGA system, electric clock system, and communal aerial system. The proposed e-telecom system exerts the cost saving effects in comparison to the existing telecom system in terms of three aspects.

First, it saves the equipment cost. The analyzed existing telecom system terminals, which are mostly installed in one area, are replaced by a single e-terminal. The existing auto telephone terminals, which are replaced by the e-terminal, include IP and analog phones. The existing PAGA system includes speakers and panels. The existing electric clock and communal aerial systems can be replaced by the distributor and integrated outlet. Based on the analysis, the proposed e-telecom system configuration costs 41.9% as much as the existing telecom system equipment as shown in Fig. 7. The proposed e-telecom system saves the equipment cost by 58.1% compared with the existing telecom system.

Fig. 7 Material cost reduction rate comparison between existing Telecom system and e-Telecom system

Second, the proposed system saves the cabling. Each existing terminal requires a cable installation, whereas the proposed e-terminal requires only an Ethernet cable. The more cables are installed onboard a ship, the harder the maintenance gets and the higher the cost increases. Tens or even hundreds of thousands of kilometers of cables are installed onboard a ship, depending on the types and

complexity of ships. The cable installation onboard is accompanied by the installation of the cable trays and other parts that are installed in the cableways.

As shown in Fig. 8 and Fig. 9, the analysis indicates the proposed e-telecom system saves the cable by 5,473m or 35.5%, compared to the existing telecom system analyzed. Given the differences in the types and costs of the cables installed in the existing telecom system, the saving effects in terms of the sums of cables are excluded from the analysis.

Fig. 8 Cable length reduction comparison between existing Telecom system and e-Telecom system

Fig. 9 Cable reduction rate comparison between existing Telecom system and e-Telecom system

Third, the proposed system reduces the weights of ships. The weights of ships are closely related to their economic feasibility. The ship weight exerts effects on the performance of ships and shipping environment. As the difference in ship weights leads to the competitiveness of ships, each shipyard makes persistent R&D efforts to reduce the ship weights.

Fig. 10 and Fig. 11 show the analysis of the effects of the proposed e-telecom system on the reduction of ship weights versus the existing telecom system. The existing telecom system weighs 7,126 Kg, whereas the proposed e-telecom system weighs 4,031.6 Kg. That is, the proposed e-telecom system weighs less than the existing system by approx. 3.1 tons, or 43.4%.

Fig. 10 Weight reduction comparison between existing Telecom system and e-Telecom system

Fig. 11 Weight reduction rate comparison between existing Telecom system and e-Telecom system

The saving effects would increase further if the existing 25 telecom systems in Table 1 are included in the analysis of the cost and weight of the equipment.

4.1.3 Other effects

Table 2 Classification of existing telecom systems by data types

Seq.	System	Serial (RS-232, RS422, RS485)	Voice	I/O (AO/DO)	Ethernet (TCP/IP, VoIP)
1	VSAT system	√			√
2	Satellite communication (C & F)	√	√		√
3	Electric clock system	√		√	√
4	Sound powered telephone system		√	√	
5	Communal aerial system	√	√		√
6	MF/HF DSC radio system	√	√		
7	VHF DSC radio system	√	√		
8	LAN system				√
9	VHF radio telephone system	√	√		
10	UHF radio system	√	√		√
11	Auto telephone system (PABX)	√	√		√
12	Bridge navigational watch alarm system (BNWAS)	√		√	√
13	Closed circuit television (CCTV)	√		√	√
14	Entertainment system			√	√
15	Cinema system			√	√
16	Collaboration system	√		√	√
17	Wireless network system				√

The proposed e-telecom system increases such intangible effects as the efficiency of ship operation. The proposed e-telecom system integrating the individually managed existing telecom systems provides the real-time system status information to facilitate the maintenance and preventive measures. Also, the proposed system enables the simultaneous use of different telecom systems, supporting such services as remote maintenance in case of ship failures. Also, the proposed e-telecom system helps reduce the ship weights, the fuel consumptions and the electrical loads.

So far, ships have been operated for intended purposes with most side effects or pitfalls having been diluted. The proposed e-telecom system enables the reconfiguration of the existing telecom systems onboard a ship and thereby contributes to the improvement of crew satisfaction with their work life at sea and the future development of the shipping industry. The following chapter experimentally proves there is no significant difference in data processing performance, i.e. latency, between the proposed e-telecom system and the existing telecom system.

5 Performance evaluation

5.1 Experimental environment and method

The types of data used on the existing telecom system vary across systems onboard ships. The existing telecom system does not support the compatibility between different systems and manufacturers. When the interface between the existing telecom systems is required, either side is designed to fit the data type given. Table 2 outlines the typical data types used on the existing telecom system shown in Table 1. The existing telecom system mostly uses several data types for the interfaces or modes.

18	Public address and general alarm (PAGA) system	✓	✓	✓	
19	Talkback system	✓	✓	✓	
20	Integrated control & monitoring system (ICMS)	✓		✓	✓
21	Extension Alarm System (EAS)	✓		✓	✓
22	Elevator alarm system	✓		✓	
23	Ref. chamber alarm system	✓		✓	
24	Hospital calling alarm system	✓		✓	
25	Satellite TV system	✓		✓	✓

For the experiment, Table 3 defines the data type for each sub-system of the existing telecom system shown in Table 2.

Table 3 Representative telecom systems by data type for experimentation

System	Data Type	Function
PAGA system	RS-485, Voice	Alarm, Paging
UHF System	RS-422, Voice	PTT, Transmit/Receive
Auto telephone system	VoIP, Voice	Calling
Elevator alarm system	AO	Alarm
CCTV system	TCP/IP	Streaming

The PAGA system uses RS-485 and voice data. RS-485 is used to transmit and receive the status information to and from other systems or send alarms through speakers or beacons. Voice data are used for paging through speakers using the microphones on the control panel.

The UHF system uses RS-422 and voice data. RS-422 is used for the PTT(Push to Talk) mode, a 1: M communication method widely used in portable radio sets. Voice is used for voice reception and transmission in microphones or portable radio sets.

The auto telephone system uses the VoIP of IP phones and the voice of analog phones. The VoIP and voice interconnect the IP and analog phones via a PABX(Private Automatic Branch Exchange). The elevator alarm system uses the AO data. AO is used to ring alarms with a buzzer or lamp installed on a console in a bridge or engine room. The CCTV system uses Ethernet or TCP/IP data. TCP/IP is used for streaming videos, controlling cameras and sending system status.

The e-telecom system's e-terminal includes all features of the telecom systems shown in Table 3. The e-terminal should work with the switchboard of the auto telephone system to enable the voice talk between IP and analog phones. Also, the e-terminal should support the data sharing and simultaneous control through the interface between telecom systems. The proposed e-telecom system converts all data types for the telecom systems in Table 3 into the Ethernet TCP/IP at the e-gateway.

As illustrated in Fig. 12 and Fig. 13, the latency is compared between the existing telecom system in Table 3 and the proposed system. The structures in Fig. 12 are largely classified into three types, depending on the characteristics of the existing telecom systems in Table 3. First, system #A is the structure where the main unit and the terminal are connected 1:1 using the control cable. The system #A

includes the PAGA system, auto telephone system and elevator alarm system in Table 3. The experiment on the existing telecom system in the system #A was conducted as follows.

As the PAGA system's latency in alarm processing, the amount of time it takes for the alarm to get to the speaker through the main unit is measured, once the alarm button is selected on the control panel. As the latency in paging, the amount of time it takes for the voice to get to the speaker via the main unit is measured, once the paging button is selected on the control panel. As the latency in calling on the automatic phone system, the amount of time it takes for the voice to get to the IP phone via the PABX is measured, once the analog phone sends a signal. As the latency in alarm processing on the elevator alarm system, the amount of time it takes for the alarm to get to the alarm panel via the main unit is measured, once the alarm button is selected.

Second, system #B is the structure where the main unit and the terminal use the wireless frequency for communication. The system #B includes the UHF system in Table 3.

Figure 12: Test-bed diagram for interface in existing telecom systems

As the latency in the PTT processing on the UHF system, the amount of time it takes for the request for the voice transmission mode to get to the base station via the antenna is measured, once the PTT button on the walky-talky is selected. For the Transmit/Receive, the time for the voice to get to the base station via the antenna is measure, once the voice transmission mode is established on the walky-talky.

Third, system #C is the structure where the main unit and the terminal are connected 1:M using the Ethernet cable. The system #C includes the CCTV system shown in Table 3. As the latency in streaming on the CCTV system, the amount of time it takes for the

Division	Specification
e-Main	CPU : Intel® Core™ Xeon Memory : Max. 512GB RAM Storage : 4TB

	OS : Microsoft Windows Server 2019 Std.
	Database : MS-SQL Server 2012 Express
e-Gateway	CPU : ARM cortex A9 Quad core
	Memory : DDR3 2GB
	Storage : eMMC 8GB
	OS : Android 5.1
e-Terminal	CPU : ARM cortex A9 Quad core
	Memory : 4GB DDR3
	Storage : eMMC 8GB
	OS : Android 5.1
S/W	Netgear GS510TPP (PoE+)
Router	Cisco 1921 / K9

Based on the experimental settings for the existing telecom system in Fig. 12 and the proposed e-telecom system in Fig. 13, the latency in each feature of the telecom system shown in Table 3 is comparatively analyzed.

5.2 Results

Fig. 16 and Fig. 17 show the latency measurements of the PAGA system on the existing telecom system and the proposed e-telecom system.

Fig. 16 Comparison of alarm test of PAGA system for existing telecom and e-Telecom

In Fig. 16, the latency in alarm processing of the PAGA system on the existing telecom system ranges from 150ms min. to 250ms max., with a max difference being 100ms. On the proposed e-telecom system, the latency ranges from 270ms min. to 750ms max., with a max difference being 480ms. Unlike the existing telecom system, the proposed e-telecom system goes through an additional process of converting the alarms from the Ethernet TCP/IP to serial data through the e-gateway, which is why the latency in alarm processing on the e-telecom system is higher than that on the existing telecom system.

Fig. 17 Comparison of paging test of PAGA system for existing telecom and e-Telecom

In Fig. 17, the latency in paging of the PAGA system on the existing telecom system ranges from 350ms min. to 410ms max., with a max difference being 60ms. The latency on the e-telecom system ranges from 590ms min. to 720ms max., with a max difference being 170ms. The proposed e-telecom system goes through the additional process of converting the Ethernet TCP/IP to voice data, which leads to the higher latency in paging than that on the existing telecom system.

Fig. 18 and Fig. 19 show the latency measurements for the UHF system features on the existing telecom system versus the proposed e-telecom system. In Fig. 18, the latency in the PTT of the UHF system on the existing telecom system ranges from 62ms min. to 126ms max., with a max difference being 64ms. On the proposed e-telecom system, the latency ranges from 172ms min. to 540ms max., with a max difference being 368ms. The higher latency measurements in the PTT processing on the e-telecom system are attributable to the additional process of converting the data types.

Fig. 18 Comparison of PTT test of UHF system for existing telecom and e-Telecom

In Fig. 19, the latency in the Transmit/Receive of the UHF system on the existing telecom system ranges from 220ms min. and 290ms max., with a max difference being 70ms. On the proposed e-telecom system, the latency in the Transmit/Receive of the UHF system ranges from 630ms min. to 750ms max., with a max difference being 90ms.

Fig. 19 Comparison of transmit / receive test of UHF system for existing telecom and e-Telecom

Unlike PTT, the Transmit/Receive shows stability on both systems. The higher latency in the Transmit/Receive on the proposed system is attributable to the additional process of converting Ethernet TCP/IP to voice data.

Fig. 20 shows the latency measurements in the auto telephone system (calling) on the existing telecom system versus the proposed e-telecom system. In Fig. 20, the existing telecom system measures 79ms min. and 119ms max., with a max difference being 40ms. The proposed e-telecom system measures 118ms min. and 139ms max., with a max difference being 21ms.

Fig. 20 Comparison of calling test of Auto telephone system for existing telecom and e-Telecom

The PABX on the existing telecom system converts voice into VoIP data, whereas the proposed e-telecom system does not. The conversion of data types by the PABX on the existing telecom system seems to explain the bigger difference in the latency. The calling latency measurements of the auto telephone system hardly differ between the existing telecom system and the proposed e-telecom system. Since the PABX on the existing telecom system supports both voice and VoIP, the latency seems to be relatively low.

Fig. 21 shows the latency measurements in alarms of the elevator alarm system on the existing telecom system versus the proposed e-telecom system.

Fig. 21 Comparison of alarm test of Elevator alarm system for existing telecom and e-Telecom

In Fig. 21, the latency measurements are comparable and unstable between the existing telecom system and the proposed e-telecom system. On the existing telecom system, the max difference between the min (501ms) and max (1494ms) latency measurements is 993ms. On the proposed e-telecom system, the max difference between the min (994ms) and max (1900ms) latency measurements is 996ms. There is little difference in the latency between the existing telecom system and the e-telecom system. The e-gateway on the e-telecom system converts the alarm data from TCP/IP into I/O, which explains the slightly higher latency in alarms on the proposed system than that on the existing system.

Fig. 22 shows the latency measurements in the streaming of the CCTV system on the existing telecom system versus the proposed e-telecom system.

Fig. 22 Comparison of streaming test of CCTV system for existing telecom and e-Telecom

In Fig. 22, the max difference between the min (260ms) and the max (390ms) latency is 130ms on the existing telecom system. On the proposed e-telecom system, the max difference between the min (251ms) and the max (946ms) latency is 695ms. Neither the existing system nor the proposed e-telecom system converts the data types here. Yet, the proposed e-telecom system is designed to maintain the interface with the CCTV system to minimize the system and network loads. Thus, in the experiment, the e-terminal undergoes the authentication each time it sends a request for streaming to the CCTV main

unit. The latency in the streaming on the e-telecom system seems attributable to the time-consuming authentication in the main unit of the CCTV system. Therefore, it is crucial to upgrade the systems and network environments onboard ships, so that the interface between the e-telecom and CCTV systems is maintained with a single authentication. Should such a design upgrade be implemented, the latency will disappear between the existing telecom system and the proposed e-telecom system.

The experimental results highlight the lower performance in latency on the proposed e-telecom system, which is attributable to the additional equipment and data conversion. Still, based on the experimental results, the performance in terms of latency on the proposed integrated e-telecom system is not significantly different from that on the existing system.

6 Conclusion

This paper analyzes and experimentally proves the improvement of telecom systems onboard ships is essential to the enhancement of competitiveness of ships. Telecom systems are to play pivotal roles in the advancement of control technologies in futuristic ships including unmanned vessels and maritime autonomous surface ships. Therefore, it is necessary to adopt an integrated telecom system such as the proposed e-telecom system, which can efficiently integrate a wide range of discrete legacy telecom systems in use today.

This paper proposes an e-telecom system, where the existing telecom system features remain while the terminals are integrated into one terminal. The proposed e-telecom system can serve as the center for the management and operation of all systems onboard a ship including the existing telecom system. The analysis findings suggest the scalability, convenience and economic feasibility of integrating the existing telecom system into the proposed e-telecom system. Taken together, the present experiment demonstrates no substantial difference in the performance, i.e. latency, on the proposed integrated e-telecom system compared with the existing telecom system.

Hence, the findings in this paper warrant the need to analyze all the systems operated onboard ships, in the sense that the integration of systems onboard ships will bring an opportunity to turn ships into the subjects of management rather than the objects of simple operation.

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