DESIGN OF AN INTEGRATED TELECOM SYSTEM FOR PERFORMANCE ENHANCEMENT ON SMART SHIPS

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ABSTRACT

Smart ship is a next-generation ship to improve ship operation efficiency and management technology by utilizing big data-based information technology. It will lead to the development of smart ships' remote control and autonomous navigation. Currently, smart ships are equipped with various functions on a differentiated platform to secure competitiveness for each shipyard. Smart ships are expected to bring a lot of changes from the life cycle of ships, from construction to the aftermarket to decommissioning. However, even though a lot of time has passed since the emergence of smart ships, it is still at the level of collecting and analyzing ship data. These factors include low data reliability, unstable communication conditions, and invisible ship-to-shore anxiety. The unstable communication state is analyzed as the biggest cause that hinders the development of smart ships. The unstable communication conditions between the ship and the land as well as on board the ship will transfer trust and responsibility to each other, slowing the development of key functions of smart ships such as real-time monitor and control. Therefore, in order to improve the communication quality of the ship and further improve the performance of the smart ship, the ship's telecom system must be improved and integrated. An integrated telecom system will bring digitalization of smart ships, breaking the boundaries between land and ships, speeding up the shift to autonomous and unmanned vessels. This paper proposes a design method of an integrated telecom system in smart ships and the performance was evaluated in a field environment.

Keywords: *Smart ship, Integrated Telecom System, Data Communication Networks*

1. INTRODUCTION

Smart ship is a next-generation ship technology that applies ICT technology to ships in order to control everything from the states of devices to their operations. Smart ship collects and analyzes status information and alarms for the ship's main engine (M/E), generator engine (G/E), and navigation-related major instruments. It communicates the information necessary for the management and operation of the ship to the crew and land managers. As the technology of smart ships is widespread and advanced, the network of ships becomes more complex for interfaces between devices and systems [1].

Furthermore, as expectations for checking onboard data are rising on land, data transmission technologies using satellites are being developed intensively. Smart ship is breaking the ship's management boundaries and transforming itself into a medium accessible from anywhere in the world. Vessels are no longer fragmented structures that are managed by independent judgment and report results to land. So, the need for cybersecurity is increasing as the need for stabilization of ships' networks and protection of systems increases.

It has been a long time since the concept of the smart ship was created and emerged. Until now, however, the smart ship is still at the level of collecting and analyzing meaningful data from ships. It is difficult to say that the reason is the pace of development of the shipbuilding industry which is relatively slow compared to land. If the development of technologies for smart ships is delayed, it would be very difficult to change the direction toward future ships such as autonomous ships. Factors that hinder the development of smart ships include low trust in data gathered from ships, unstable communication conditions between ships and land, and avoidance of responsibility for technology.

Among them, unstable communication between onboard and land is the biggest reason that hinders

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

the development of smart ship technology. If an error or failure occurs on land while collecting data on a ship, data manipulation and restoration are difficult due to the limitations of communication network speed and maintenance restriction. If the ship fails to collect data needed for smart operations due to internal communication failures, immediate recovery is impossible without the help of experts.

The unstable communication status of ships causes the transfer of responsibility between ships and land, and slows the development of smart ships' technologies such as real-time remote management and control. Smart ship should provide real-time data and analysis results to both the ship itself and land using a stable telecom system. Along with this, both work productivity and convenience should be increased by simplifying the telecom system.

Delivery of voice and data for communication on ships including smart ships is possible by telecom systems. So far, various telecom systems installed on ships are independently configured without interworking. Ship's telecom systems are functionally separated and installed by following maritime regulations, even if the roles are similar or overlapping [2][3]. Data types of the existing telecom systems are largely divided into Serial, I/O (Input / Output), and Ethernet TCP/IP. The Serial data type is used by protocols such as RS-232, RS-422, and RS-485. The I/O data type is used output continuously changing information such as voltage or current. The Ethernet TCP/IP data type is an internet standard protocol to communicate data on systems. Most telecom systems installed on ships are configured to enable an independent communication scheme without considering inter-operability. Compared to land, the conservative ship environment can be interpreted as a yardstick for system verification that older systems represent stability.

It is far-fetched to expect development into future ships, including smart ships, based on telecom systems developed and operated under maritime regulations published decades ago. Technological developments inherent in the two sides of change and decline, especially technologies that induce changes in the ship's environment, such as smart ships, are difficult to complete without changes in the basic environment, such as telecom systems. Therefore, changes to existing telecom systems are essential to improve the management performance of smart ships.

This paper proposes an integrated telecom system that integrates existing telecom systems in ships. The simplification obtained by integrating the existing telecom systems that were individually installed and operated redundantly stabilizes the communication state, increases convenience and provides a variety of communication environments. An integrated telecom system is expected to play many roles in the development of stable technologies for smart ships by breaking the boundaries between ships and land. An integrated telecom system is capable of managing and controlling ships without boundaries between regions and times, beyond the limitations of current smart ships collecting simple data.

Furthermore, it has a cost-saving effect along with preventing safety accidents by eliminating shaded communication areas in ships. Through practical experiments, this paper shows that the integrated telecom system provides the above advantages while maintaining the communication performance compared to the existing telecom systems. This proves that there is little overhead that may occur due to the integration.

2. TELECOM SYSTEM ANALYSIS

The telecom systems deployed in ships are listed up in Table 1. Some telecom systems are not included in both mandatory installation equipment and type approval of IMO (International Maritime Organization). Those may be installed in ships, but the treaty and classification does not reflect them yet. CCTV systems, entertainment systems, wireless systems, and LAN systems, which are rapidly being developed in recent years, are not included in either category.

In Table 1, there are 6 mandatory installation equipment that is 24% of the listed entire equipment, and 8 equipment that need type approval that is 32% of the listed entire equipment. There are clear limitations in defining today's telecom system based on the criteria of treaties and classifications defined in the past. More than 70% of telecom systems listed in Table 1 are reviewed and installed as functions suitable for each purpose. In other words, although it is commonly used in ships, it may not be suitable for use in ships because there is no installation standard and basis. Reflecting this reality, ship telecom systems should be developed and put into effect through joint research by treaty, classification, and manufacturers for system standardization [6].

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Table 1. Telecom systems in ships

Seq. #	Telecom Systems	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

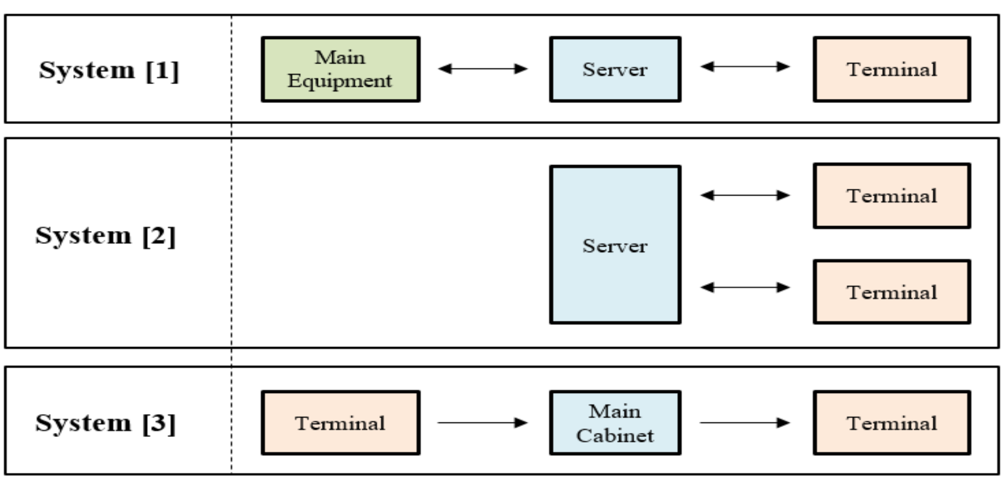

Figure 1. Configurations of the existing telecom systems

In the past, a ship's telecom system was clearly distinguished from other systems as a tool for communication. However, with increasing interest in the management and control of ships, such as smart ship, the ship's devices and systems store and share data with the telecom system. With the development of ship technology, the role and function of the ship's telecom system are becoming more important. However, except for some of the ship's telecom systems, there are no management standards such as marine regulations [4][5].

Therefore, the communication method of smart ships is interpreted as having no regulations or standards for data. Standardization of data is necessary to develop and implement technologies that meet the requirements of smart ships.

Figure 1 shows diagrams of the existing telecom systems of ships. System [1] is a structure in which data from equipment such as engines and generators are collected from the server of the system and delivered to users through the terminal of the system. Users check the data and control the status of the equipment through the system's terminal.

System [2] is a structure that exchanges information or data between users using system's terminals, such as the telephone system or PCs. System [3] is a structure that is passed to users through the main cabinet by buttons or sensors on terminals of the system. Typically, it is configured in one direction for the purpose of checking status information.

Today's telecom systems being operated in ships have unclear boundaries among them. This means that the definition and scope of the telecom systems are wider and more diverse than in the past. As shown in Table 2, the ship's telecom systems are divided into a variety of onboard telecom systems, outboard telecom systems, and safety and alarm telecom systems.

Table 2. Classification of communication systems in ships

Seq.	Classification	System name
1	Outboard telecom systems	MF/HF DSC radio system
2		VHF DSC radio system
3		VHF radio telephone system
4		Satellite communication (C & F)
5		VSAT system
6	Onboard telecom systems	Auto telephone system (PABX)
7		LAN system
8		Talkback system
9		UHF radio system
10		Wireless network system
11	Safety & alarm telecom systems	Bridge navigational watch alarm system (BNWAS)
12		Integrated control & monitoring system (ICMS)
13		Extension Alarm System (EAS)
14		Public address and general alarm system (PAGA)
15		Closed-circuit television system (CCTV)
16		Ship’s alarm system

Among the systems currently operating on ships, all systems that communicate the situation and share the data with the telecom system were classified as telecom systems. In particular, when ship management technology is activated as in smart ships, the boundaries of the systems according to functions will disappear as it is now.

The outboard telecom systems in Table 2 include long-distance wireless communication and satellite communication systems. Long-distance wireless communication systems are used in emergency situations of ships or when communication between ships is required.

Satellite communication systems are used to exchange essential operational information with land.

With the advent of monthly fixed-rate satellite communications such as VSAT (Very Small Aperture Terminal), management techniques using ship data became full-fledged, and the Internet became available even while sailing.

Onboard telecom systems include automatic telephone systems, wireless network systems, and UHF (Ultra High Frequency) systems for onboard wireless communications. In complex iron structures of ships, wireless communication systems are not often installed in practice due to their low stability and efficiency compared to their high initial cost.

However, as the demand for data collection of ships increases, the number of ships building a wireless network system environment is now growing. This is because, when a specific device needs to be connected on a ship in operation, establishing a wireless network system is more efficient than additionally installing cables.

As a result, LAN systems with Wi-Fi functionality are used together by various devices and systems such as engines, generators, and sensors. The ship's telecom system interfaces most of the instruments and systems and shares their data.

Safety and alarm telecom systems consist of systems for onboard control and alarms. These are essential systems for onboard situation judgment and are responsible for the safe operations of ships. Safety and alarm telecom systems share status information through the LAN systems or deliver data needed for smart ships. The role and importance of ship's telecom systems as media that can bring all of the ship's systems together will increase.

3. NECESSITY OF AN INTEGRATED TELECOM SYSTEM

So far, smart ships have not grown into a technology that enables organic communication with the crew while ensuring the autonomy of ship control. They just try to get real-time data as much as possible to express the ship's status but they do not perform the real-time management and control yet even though those are key components of smart ships. Smart ships did not make organic changes to related systems from the development process.

A new platform requires efficient changes with many systems from the time of being developed to the time of being settled. However, smart ships were implemented separately from existing systems to avoid the ship's conservative tendencies and challenging marine regulations. As a result, smart ships remain at the level of collecting and referencing data.

Systems installed on ships must also be changed to complete technologies of the future ship along with smart ships. Systems on ships have been separately configured and developed to meet purposes of use over the past few decades. Besides, even the same functional systems made by different manufacturers may have different technologies and methods. Simple integrating or making changes to the ship's systems demands a lot of time and cost.

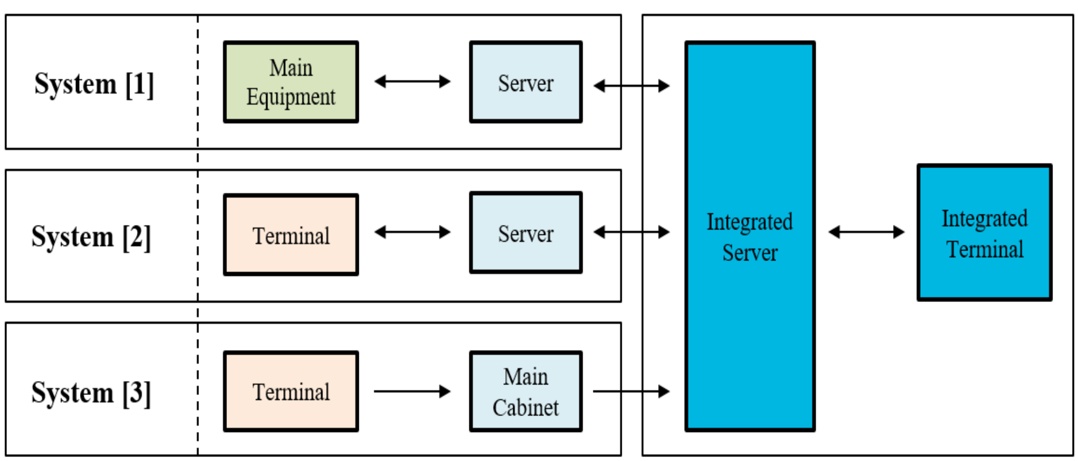

Figure 2. Configuration of the proposed integrated telecom system

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Therefore, a new platform and an intermediate medium that can integrate and control systems for stable engagement with ship's systems are needed. They increase the stability among ship's systems, and allow various solutions to be provided in case of failure.

Since stable communication states are closely related to the technological advancement and performance improvement of smart ships, changes to telecom systems should be preceded. In addition, as all data on ships is transmitted and shared through the telecom systems, a specialized system is needed for the integrated control of the telecom systems. Seamless data sharing of smart ships can increase trust between ships and land, and secure a sense of stability in technologies.

This paper proposes a design method for an integrated telecom system that integrates the existing telecom systems to improve the telecommunication environment on smart ships. Figure 2 is a configuration diagram for the proposed integrated telecom system.

Existing telecom systems have the same structure except that the system-specific terminals shown in Figure 1 have been removed. The integrated telecom system shown in the rectangle on the right hand side of Figure 2 is interfaced with the server and the main cabinet of the existing telecom system through the integrated server. Integrated terminals in the integrated telecom system provide integrated functions of each terminal in the existing telecom systems.

The advantages of the integrated telecom system can ensure the safety of efficient network operations and external intrusions such as viruses and hacking, by making the data compressible and controllable. The integrated telecom system expects to increase the performance and utilization of smart ships by providing a stable communication environment.

This paper demonstrates that the proposed integrated telecom system has little performance overhead in terms of processing time compared with the existing telecom system through experiments. This proves the overhead that may occur due to the integration is negligible. That means that there are much better reasons why the integrated telecom system is readily acceptable when considering advantages of the integrated telecom system.

4. PERFORMANCE EVALUATION

4.1 Experiment environment

The ship's existing telecom systems have been installed and operated independently and they were not standardized on the data [6]. The existing telecom systems are not data compatible yet if the manufacturers of them are different. If data needs to be shared with other systems, another common type of data needed for exchange should be developed in consultation with each other.

This paper classifies the existing telecom systems as shown in Table 2 according to the representative network types. The telecom systems can also be classified as shown in Table 2 according to the data types that the telecom systems are using to send and receive data. Data types shown in Table 3 are defined following the data packet formats used in the network types.

Table 3. Classification Of The Existing Telecom Systems By Data Types

Data Types	Telecom Systems
Serial	MF/HF DSC radio system VHF DSC radio system VHF radio telephone system Talkback system UHF radio system BNWAS ICMS EAS PAGA system
A/O	Ship's alarm system
Ethernet TCP/IP	Satellite communication (C & F) VSAT system Auto telephone system (PABX) LAN system Wireless network system CCTV system

Data types of the existing telecom systems are largely divided into Serial, A/O (Analog Output), and Ethernet TCP/IP. The Serial data type is mainly used by protocols such as RS-232, RS-422, and RS-485 serial communication network protocols and is used to communicate or control the state of the systems. The A/O data type is used in various alarm systems on ships. Finally, the Ethernet TCP/IP data type is used to exchange data among the systems, deliver voice and control the systems as well.

The Ethernet TCP/IP data type is defined as a default data type in the integrated telecom system because it is most commonly used in configuring a ship's network nowadays.

Table 4. Telecom Systems For Data Types For The Experiments

Data Types	Telecom Systems
RS-422 Serial	ICMS
A/O	Ship's alarm system
Ethernet TCP/IP	Onboard telephone system
	Integrated telecom system

For the performance comparison experiments between the existing telecom systems and the integrated telecom system, the telecom system corresponding to each data type is defined as shown in Table 4. Among the existing telecom systems listed in Table 3, it is selected as a representative system by each data type.

The ICMS (Integrated Control and Monitoring System) is a system that collects data from instruments related to the ship engine and manages them, accounting for more than 60% of the data on smart ships. The ship's alarm system is a collective name for various alarm systems to which alarms are automatically propagated by the ship's major systems or manually propagated by the crew at a particular location. Smart ships monitor various alarm systems in real-time to make decisions according to the conditions of them. The onboard telephone system is configured with a LAN system. It should be managed essentially in the operation of smart ships for onboard control and communication between ships and land.

This paper compares the processing time for each data type shown in Table 4 by building the existing systems and the proposed integrated telecom system as depicted in Figure 3 and analyzes the results of the experiments.

For the experiments, the ICMS uses an alarm generator to generate data of the temperature of the main engine and deliver them to an ICMS server by using the RS-422 serial communication method. For the existing telecom system case, the time is measured from when a temperature data starts to be transmitted from the alarm generator in the main engine to the moment it is finally transmitted to an ICMS PC through the ICMS server. For the integrated telecom system case, the time is measured from when a temperature data is transmitted from the alarm generator in the main engine to the moment it is finally transmitted to an integrated terminal through the ICMS server and an integrated server.

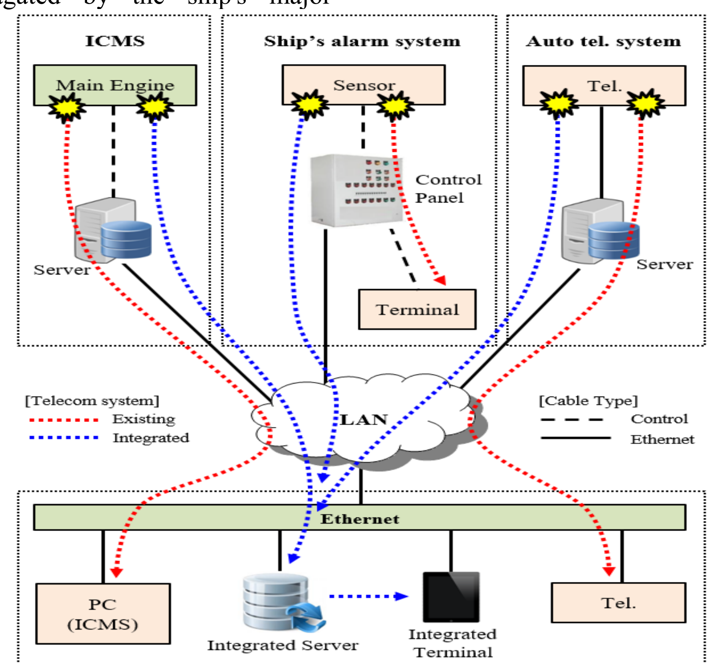

Figure 3. Test-Bed Diagram For The Existing Telecom System And The Integrated Telecom System

For the ship's alarm system, ON/OFF signals of a sensor are repeatedly generated. The signals are passed to a control panel. For the existing telecom system case, the time is measured from when a signal data starts to be transmitted from the sensor to a terminal through the control panel. For the integrated telecom system case, the time is measured from when a signal data starts to be transmitted from the sensor to the integrated terminal through the control panel and the integrated server. In the control panel, the process of changing A/O (Analog Output) data type to the Ethernet TCP/IP data type to deliver the signal data to the integrated server.

For the existing telecom system case of the onboard telephone system, the time of each call is measured from an outgoing phone to a receiving phone via a PABX server. For the integrated telecom system case, the time of each call from the outgoing phone to the integrated terminal through the PABX and the integrated server.

Table 5 is the detailed specification of the equipment used in the test-bed environment, and both of the existing and the integrated telecom systems were tested under the same condition.

Experiments have been repeatedly performed 1,000 times each for the existing and the integrated telecom systems, respectively.

Table 5. Specification Of Equipment Used In The Test-Bed Environment

Equipment	Specification
Integrated Server	CPU : Intel Core i7-10700F
	Memory : DDR4 8GB
	Storage : 2TB
	OS : Microsoft Windows 10
	Database : MS-SQL Server 2012 Express
Integrated Terminal	CPU : Qualcomm Snapdragon 450
	Memory : 4GB
	Storage : 64GB
	OS : Android Oreo 8.1
Alarm Generator	CPU : Intel Core i3-9100F
	Memory : DDR4 8GB
	Storage : 1TB
	OS : Microsoft Windows 10
Switch	Cisco WS-C2960-24-S

4.2 Results of the experiments

Figure 4 is the result of measuring the average processing times of the existing telecom system and the integrated telecom system for the ICMS.

The integrated telecom system for the ICMS took additional 268.8ms processing time on average compared to the existing telecom system. That means the average processing time for the ICMS data type (the Serial data type) by the integrated telecom system is 36.2% longer than by the existing telecom system. It was analyzed that changing the data types from the RS-422 Serial to the Ethernet TCP/IP on the ICMS server took relatively longer processing time on average.

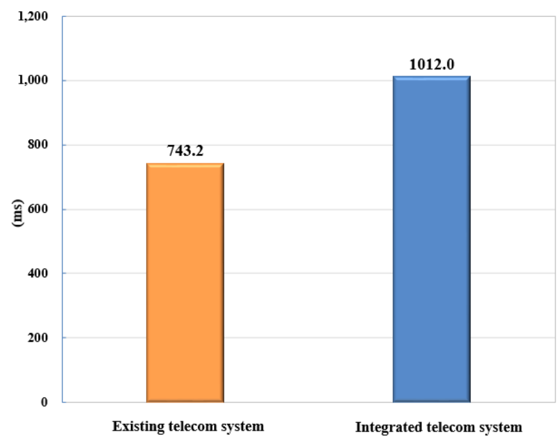

Figure 4. Average Times Of The Existing Telecom System And The Integrated Telecom System For The ICMS

Figure 5 shows the comparison result of the average processing times of the existing telecom system and the integrated telecom system for the ship's alarm system.

The integrated telecom system took an average of 552.6ms more processing time than the existing telecom system. The average processing time for the data type of the ship's alarm system by the integrated telecom system is 98.0% longer than by the existing telecom system. The integrated telecom system took very longer processing time in changing data types from the A/O to the Ethernet TCP/IP in the control panel.

The ship's alarm system adds a process of changing the data types in the control panel in the same way as the integrated telecom system to deliver signal data to the smart ship.

Finally, figure 6 is the comparison result of the average processing times of the existing telecom system and the integrated telecom system for the onboard telephone system.

Journal of Theoretical and Applied Information Technology
15th October 2021. Vol.99. No 19

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

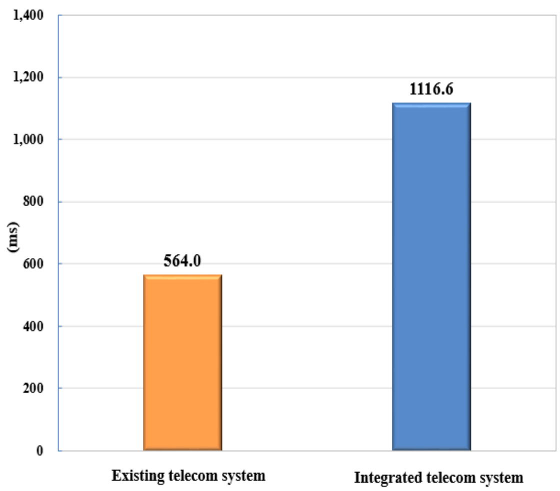

Figure 5. Average Times Of The Existing Telecom System And The Integrated Telecom System For The Ship's Alarm System

The integrated telecom system took an average of 14.3ms of processing time more than the existing telecom system. The average processing time for data type of the onboard telephone system by the integrated telecom system is 13.3% longer than by the existing telecom system.

The difference of the processing times between the existing telecom system and the integrated telecom system for the onboard telephone system is much smaller than those for the ICMS and the ship's alarm system. The reason is from the fact that the change of data types is not necessary as both systems already have the same data type of the Ethernet TCP/IP.

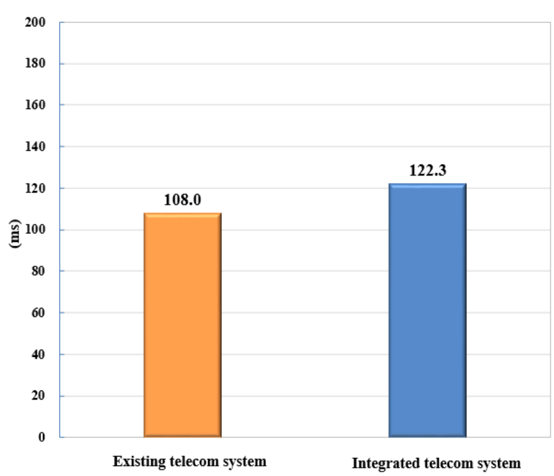

Figure 6. Average Times Of The Existing Telecom System And The Integrated Telecom System For The Onboard Telephone System

4.3 Analysis Of The Experiment Results

The experiment results show that the average processing times by the integrated telecom system are commonly longer than those by the existing telecom systems.

However, According to the relevant regulations and application guidelines of the Korean Register, the delay time limit for processing and transmission of data in computer-based systems is stipulated as 2 seconds [7]. Therefore, the fact that the average processing time in the ICMS and the alarm system increased to 1,012ms and 1,117ms, respectively, still satisfies the general data processing delay time upper limits on ships.

And even in the case of the onboard telephone system, if it is within the delay time limit of 400ms defined in the case of Class C, which is the standard for the Internet telephony (VoIP Voice over the Internet Protocol), there is no problem in terms of quality of telephony service.

Therefore, the performance of the integrated telecom system is suitable for services such as data processing, alarms, and telephone calls on ships.

It can be seen that it is very advantageous to adopt the integrated telecom system when considering the seamless data sharing feature, and advantages in design, installation and maintenance acquired by the integrated telecom system.

Based on the experiment results, deployment of the integrated telecom system to smart ships can ensure a stable communication state for the ship's telecom system. The integrated telecom system proposed in this paper has been proven to be superior in terms of performance and convenience for smart ships.

5. CONCLUSION

This paper proposes a novel integrated telecom system by analyzing existing telecom systems to solve unstable states and improve the performance of communications on smart ships. The telecom system is not just a means of communication but an important system that requires change for the technological development of future ships.

This paper demonstrates that even though the integrated telecom system proposed takes more time compared to the existing telecom system, the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

performance difference is acceptable for the integrated telecom systems on ships to work properly. Proposed integrated telecom system in this paper will bring light weight, cost saving and convenience in the ship systems.

Currently, more than 70% of the data needed by smart ships are collected from telecom systems on ships, and the utilization of telecom systems will increase rapidly in the future. Based on this paper, it is planning to study an integrated network system that can implement IoT (Internet of Things) of ships in the future. It is expected that the proposed integrated telecom system will serve as an opportunity to take smart ships from the analysis stage to the control stage.

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