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Research of the New Generation Marine Navigation Security Communication System

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Abstract. With the number of Chinese ships rapidly increasing, the available channels for the Automatic Identification System (AIS) are serious congested. This has led to a sharp rise in collision warnings. The maritime communication System is comprehensively updated from AIS to VHF Data Exchange System (VDES) in order to ensure efficient communication of huge scale, high density maritime ships as well as guarantee marine navigation security. In this paper, the new generation marine navigation security communication system based on VDES is studied. Designing communication systems for ships at sea, shore-based base stations and space-based satellites; The two-way data exchange between huge scale, high density ships-to-ships and ship-to-shore by VHF frequency band in nearshore and port areas can promote the development of maritime navigation technology and maritime economic.

Keywords: VDES; Satellite Communication; Maritime Communication.

1. Introduction

In recent years, the number of Chinese ships increasing rapidly and it may keep continuously increasing trade. In 2001, there were only 210,000 vessels in China. By the end of 2022, the number of Chinese vessels has increased by more than two times to 460,000. In order to realize conveniently maritime communication, the second generation of maritime communication System -- Automatic Identification System (AIS) came into being. With the large-scale use of AIS, AIS can obtain extensive data, which provides important support for ship's navigation such as waterway engineering and water transport management[1-3]. However, with the rapid increase in the number of ships, the need for maritime communication also increases. The network communication rate of traditional AIS is only 9.6kbps, and the channels are increasingly crowded, so AIS is no longer suitable for the specific needs of maritime security navigation. Therefore, the third generation of maritime communication System -- VHF Data Exchange System (VDES) has been proposed and widely studied. Golaya[4] traced the history of maritime communication briefly, and envisaged uses of the VDES system. Lázaro, F.[5] focused on the technical design aspects and challenges of VDES, which uses hybrid communications transmission scheme. Bronk[6] verified that the communication range of VDES system is basically compliant with the theoretical data and confirmed that VDES provides a large coding gain, which significantly improves the performance of data transmission and increases the bit rate compared to the existing maritime radio-communication solutions. Šaf&aacute[7] verified that under the assumed channel conditions, all of the new VDES waveforms provide better ranging performance than the AIS waveform. Zhen Kang[8] proposed a data transmission encryption method for VDES communication system based on Elliptic Curve Cryptography(ECC) encryption algorithm, and verified this method can improve data information encryption. Markus Wirsing[9] proposed a new backup system for maritime navigation, and the experimental results show that system is capable of achieving a 95th-percentile horizontal position error of 22 m, can fully meet The International Association of Marine Aids to Navigation(IALA) accuracy requirements. Besides, VDES includes a satellite component to extend the service coverage also to the high sea. Giovanni Giambene[10] used data taken during a measurement campaign to develop an ON-OFF model for the VDE-SAT downlink channel. Bradbury[11] described the NorSat-2 mission, with an emphasis on the unique and

innovative aspects that are the VDES payload, deployable Yagi antenna, and enhanced S-band uplink. The considerable differences in radio spectrum regulation, propagation delay, mobility, and, possibly, the link budget of satellite communication and their potential impact on the design were highlighted in this paper[12]. Confirmed through extensive research by scholars from various countries, the VDES is more suitable than AIS for future marine navigation, the network rate of VDES is increased from 9.6kbps of AIS to 307.2kbps. However, there is still a huge gap between the communication rate of VDES and land mobile communication system, which often takes Mbps as the unit of measurement. Also, it still cannot meet the transmission demands of pictures and videos. Moreover, even if VDES uses the VHF frequency band for communication, the communication range is only line-of-sight transmission, which cannot realize long-distance transmission across line-of-sight. However, with the increase of ship flow density in offshore waters, ports and inland waters, the primary problem of new generation of maritime communication system is how to ensure the fluent communication between large number of ships-to-ships and ships-to-shores.

Focus on the trends of e-navigation, surface autonomous navigation ships and intelligent shipping services, this paper researched and established a marine navigation security communication system for Next-generation. The system is based on VDES and consists of three parts: shore-based subsystem, space-based subsystem and maritime vessels. Through the VHF frequency band, the two-way data exchange between large-scale and intensive ships-to-ships and ships-to-shores can be realized in nearshore and port areas. In the broad field of air-sea integrated, the global information broadcasting and two-way data exchange can be realized through the global low-orbit satellite network, which is important to fulfil the demands of the Internet application scenarios of maritime security communication, global three-dimensional observation, energy exploration and environmental monitoring.

2. System Functions

The new generation marine navigation security communication system has got through the key nodes of land-sea-satellite integration, and it's able to make ship, shore and magnitude terminal equipment systematic, standardized and large-scale. This will not only ensure the safety of maritime communications and navigation, but also promote the localization of maritime equipment, support maritime industrial upgrading, improve Chinese Marine science and technology to innovate and realize the common progress of scientific and technological innovation and industrial level. It specifically can be divided into the following four functions:

(1) Information interaction between ships

The new generation of marine navigation security communication system integrates shipborne terminals, shore-based terminals and space-borne terminals, forming an integrated satellite-ship-shore maritime communication system. By adding VDE two-way data interaction channels, the architecture supports more information broadcasting between ships, which can effectively alleviate the problem of ship safety warning information transmission lag caused by AIS channel blocking, and maximize the protection of ship navigation safety. In addition, the space-based subsystem of the architecture can effectively overcome the defects of VDES short distance communication by taking advantage of the global coverage of short messages of the satellite system, and support the implementation of long-distance AIS, ASM and VDE communication applications. It also supports automatic and manual switching of ship data exchange, optional VHF channel on water, idle data synchronization, language independent communication transmission, link-level data integrity monitoring and verification, identity authentication, encryption and other network security control functions.

(2) Information interaction between ship and shore

The new generation of marine navigation security communication system aims to improve navigation supervision and rescue capabilities in distress. Based on VDES, the architecture includes multiple

dimensions such as sea, sky and ground. The VDES system will assist shore-based base stations to automatically update and push all kinds of ship navigation safety information according to the navigation area of the ship. The information includes navigation aid service of coastal waters, safety navigation information service (such as navigation warning, search and rescue, ice conditions, etc.), hydro meteorological service, maritime chart update service, etc, The VDES system will completely solve the problem of timely information exchange between ship and shore, which makes ship can obtain relevant navigation security data quickly, automatically and timely, so as to ensure the navigation safety. Besides, it can also provide application functions such as ship distress alarm, navigation status monitoring, maritime safety information broadcasting, safety emergency command and dispatch, and intelligent shipping shoreline services. At the same time, the collected and processed data can also provide data communication, pooling, sharing, analysis, display and other services for industrial applications, these can lay a foundation for building a general, open, interconnected and comprehensive maritime navigation communication network.

(3) Satellite communication information services

The new generation of marine navigation security communication system can not only meet the requirements of multiple maritime application scenarios, but also provide all-day and all-weather VHF band communication, data acquisition and IoT services for users in sea areas. It can also integrate with other ground communication systems to form the space-integrated-ground satellite internet service system. The system provides basic communication information services for various application scenarios such as global three-dimensional observation, energy exploration and environmental monitoring, promotes VDES satellite Internet industrial chain completely, and drives related industries development collectively.

(4) Establishment of navigation communication standards

The new generation of marine navigation security communication system lays out the international standard system of maritime communication technology. Through conduct technical research deeply, and follow up relevant international organizations actively, to accelerate the related technical standards formulation, for example physical layer, link layer, network layer, intelligent network and etc. A series of industries extended by the standardization of maritime communication system, both conformity assessment and market access have a huge potential market. Meanwhile, the standardization of maritime communication has a very important positive significance for improving the international influence.

3. System Composition

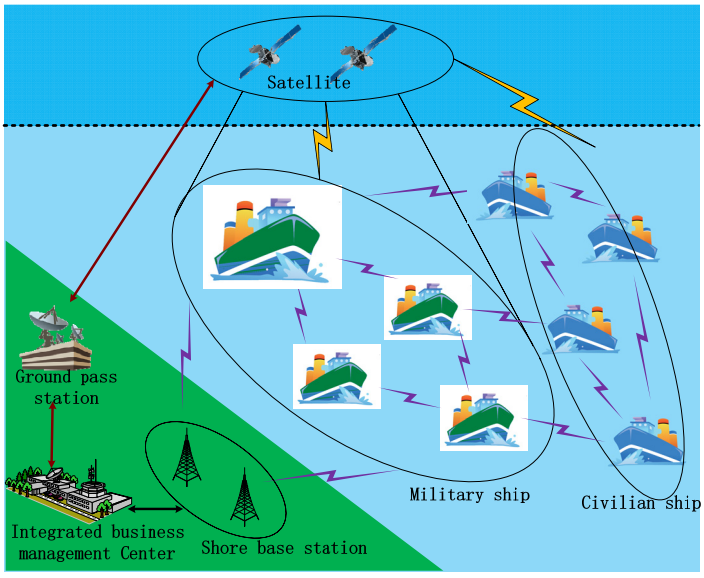

Figure 1. Composition of the new generation of marine navigation security communication system

The new generation of marine navigation security communication system provides guarantee for safe navigation and reliable communication of ships, and builds a communication network with large bandwidth, high speed, anti-interference and high security between maritime ships, shore-based base stations and space-based satellites. The new generation of marine navigation security communication system consists of an integrated business management center, a ground-based subsystem and a space-based subsystem. The composition of system is shown in Figure 1.

The functions and structure of each sub-system are as follows:

(1) Integrated Business Management Center

The integrated business management center of the new generation marine navigation security communication system has the function of communication, service, network management and early warning.

A. Communication function: Through ground wired network, the battle command center and satellite ground station can achieve information exchange;

B. Business service functions: supporting electronic navigational charts, safety information and other maritime business information services required for the safe navigation of civil vessels and naval vessels;

C. Network management functions: It can manage wireless networks and terrestrial wired networks among Marine ships, shore-based base stations, space-based satellites;

D. Early warning function: It can monitor the running status of the system and alarm the abnormal situation.

The integrated business management center is operated by the central server, data storage server and man-machine management server. Man-machine management computer conducts man-machine interaction, satellite timing device, network equipment and ground communication network provide system support. Figure 2 shows the composition of the integrated service management center.

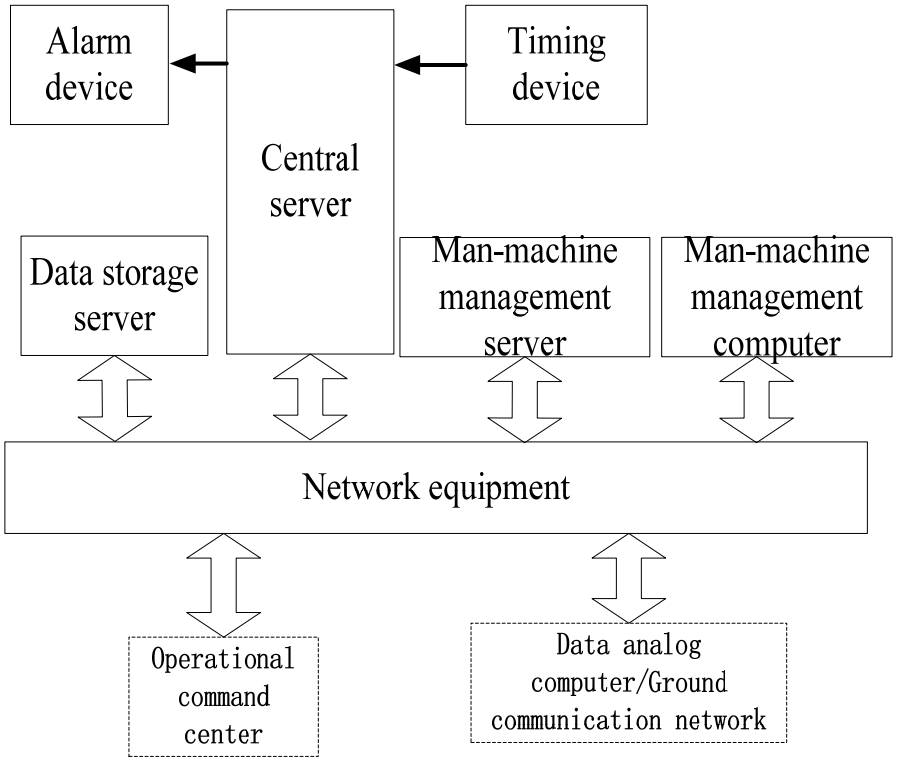

Figure 2. Block diagram of integrated Business Management Center

Except for the direct connection between the timing device, the alarm device and the central server, other parts are connected through the network device.

A. The central server is the business center of the whole system, running four software: business service software, system status duty and alarm service software, shore station management service software, and system timing service software;

B. The data storage server is the data storage center of the whole system and runs the data storage system service software;

C. Man-machine management server is the man-machine interaction center of the whole system, running system display and control service software;

D. Man-machine management computer provides man-machine interaction interface for system administrators;

E. Beidou timing equipment provides time reference for the central server;

F. Network equipment provides network infrastructure between devices in the sub-system;

G. Ground communication network is available for telecommunication between the Integrated Business Management Centre and shore-based base stations and satellite ground stations;

H. Analyze and process navigational safety information through data fusion and inversion methods.

(2) Ground-based station subsystem

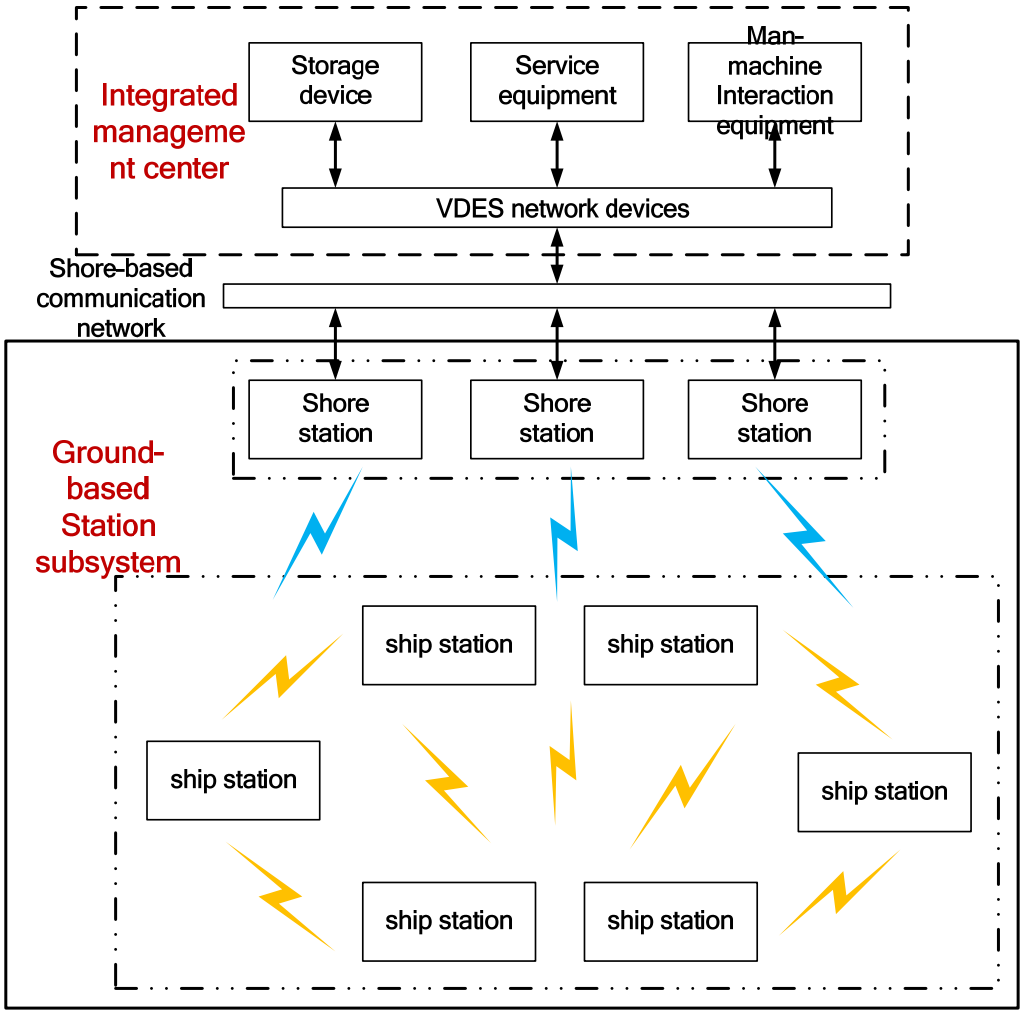

Figure 3. The composition diagram of Ground-based station subsystem

The ground-based station subsystem of Next-generation marine navigation security communication system has the function of communication, routing and monitoring.

A. Communication function: can provide networking communication function among Marine ships, shore-based base stations and space-based satellites;

B. Routing function: It has wireless network routing function to realize network transmission based on information categories;

C. Monitoring function: It has function of monitoring the working mode, communication link status, and running status.

The subsystem includes ship station and shore station, and its composition is shown in Figure 3.

A. The ship station consists of shipborne terminal, VHF shipborne antenna and GNSS shipborne antenna, which are compatible with relevant IMO, ITU-R and IEC standards and regulations. Ship stations use Ad-hoc network topology structure to realize the certain range network communication between ship-to-ship and shore-to-ship and satellite-to-ship.

B. The shore station consists of shore-based station, VHF shore antenna and GNSS shore antenna, which are compatible with relevant IMO, ITU-R and IEC standards and regulations. Through VHF wireless communication link, shore stations uses star topology structure to realize the certain range communication with the ship stations. It's worth noting that there is no direct interface between each shore station. The information exchange and sharing between each shore station is realized by integrated management center.

(3) Space-based subsystem

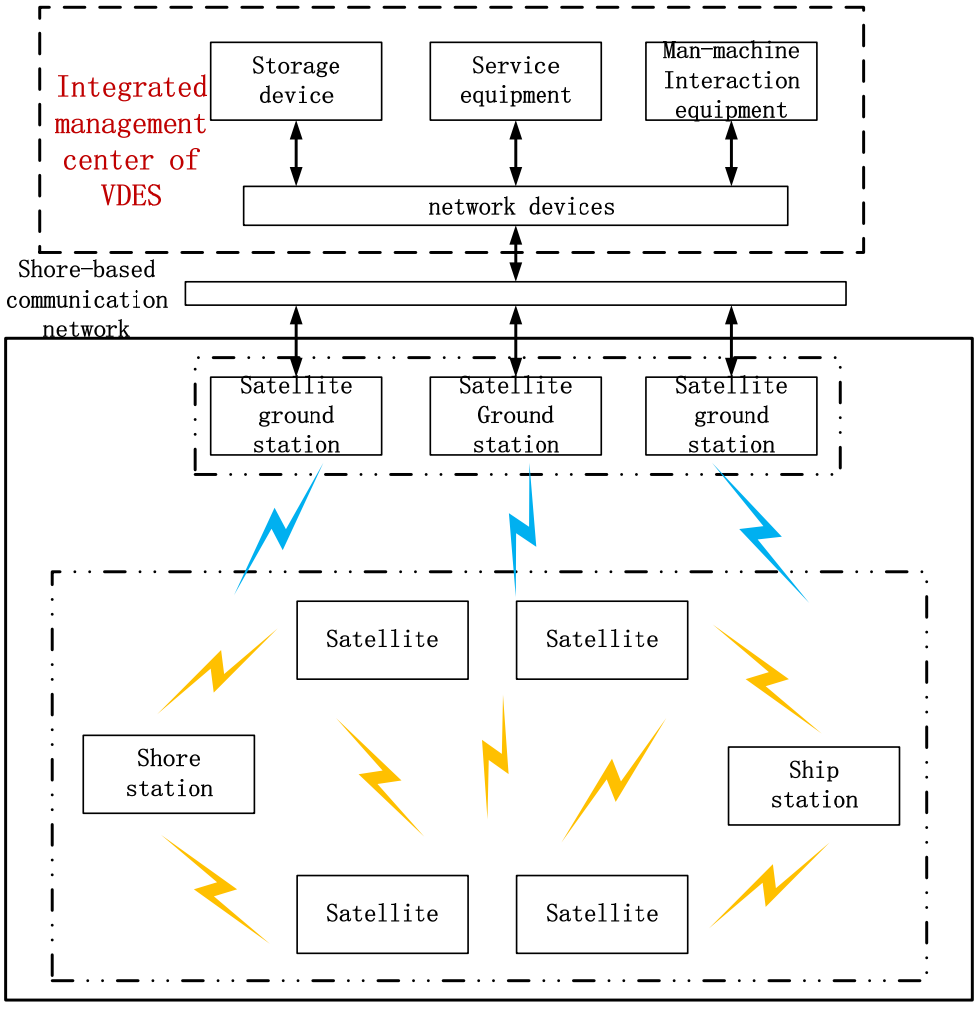

Figure 4. Composition diagram of satellite-based system

The space-based station subsystem of Next-generation marine navigation security communication system has the function of communication, routing and monitoring.

A. Communication function: It has the network communication function between maritime ships, shore-based base stations and space-based satellites, and the information interaction function with the integrated business management center;

B. Routing function: It has the function of inter-satellite routing, which can realize the quick distribution and landing of information.

C. Monitoring function: It has function of monitoring the working mode, communication link status, and running status.

The space-based subsystem includes satellite and satellite ground station, and its composition is shown in Figure 4.

A. The satellite consists of payloads and satellite platform. The payload includes on-board satellite terminal (hereinafter referred to as the on-board satellite terminal) and a VHF on-board satellite antenna. The satellite platform includes a measurement and control terminal, a power supply and distribution unit and a measurement and control antenna. The AD-hoc network can be built between the payloads and the ship stations or the shore stations. The measurement and control terminal and the measurement and control antenna of the satellite platform are used to establish the measurement and control link between the satellite and the ground station. The power supply and distribution unit is used to supply power to payloads and measurement and control terminal.

B. The satellite ground station consists of management equipment, measurement and control equipment and antenna. The measurement and control equipment and antenna are used to establish measurement and control links with the satellite. The information exchange between ground station management equipment and integrated management center is realized by shore-based communication network.

4. Communication Architecture

According to the open system interconnection model, the marine navigation security communication system can be designed as a four-layer model, which consists of the physical layer, link layer, network layer and transport layer. The upper layer of conversation layer, presentation layer and application layer are not involved. The architecture of this communication system is shown in Figure 5 below.

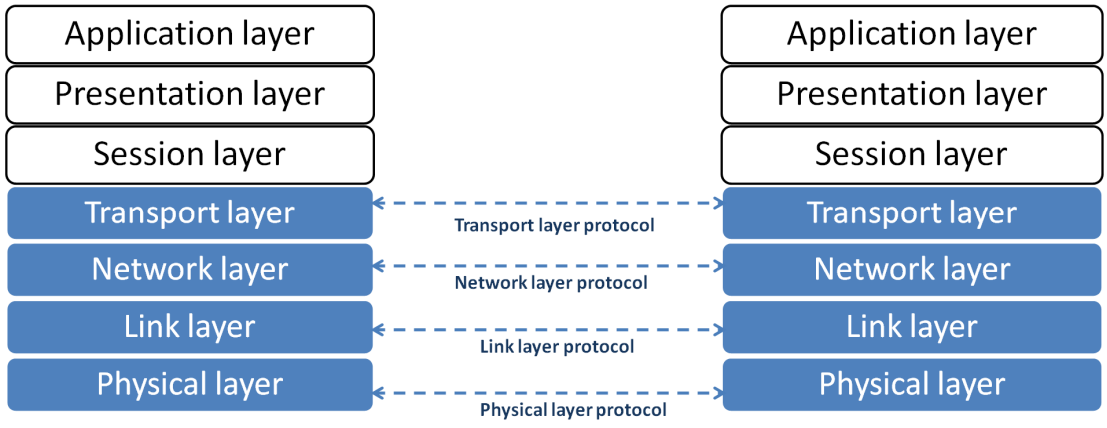

Figure 5. Architecture diagram of the marine navigation security communication system

(1) Physical layer

The physical layer is a physical entity, which responsible for data transmission directly. In order to ensure reliable transmission of marine communication system, it creates, maintains, and removes physical links for data transmission, provides transmission functions and standardized features. Specifically, the physical layer of marine navigation security communication system mainly

completes the processing of encoding and decoding, modulation and demodulation, frame setting/frame dismantling, digital-to-analog/analog-digital conversion, power amplification and so on, it also provides services for the link layer.

(2) Link layer

The link layer provides the ability to transfer data between two entities in the network as well as the ability to correct errors that occur at the physical layer. Specifically, the link layer of the marine navigation security communication system mainly completes the functions of message encapsulation, media access control, activation and release of the data link, error detection and correction etc., it also provides services for the network layer.

(3) Network layer

Network layer is to realize the data transparent transmission between two network nodes, and provide the function of addressing and routing selection, connection establishment, retention and termination. Specifically, the network layer of marine navigation security communication system mainly provides the ability to establish and maintain network links, information management, priority allocation, data relay, the resolution of data link congestion and other functions, it also provides services for the transport layer.

(4) Transport layer

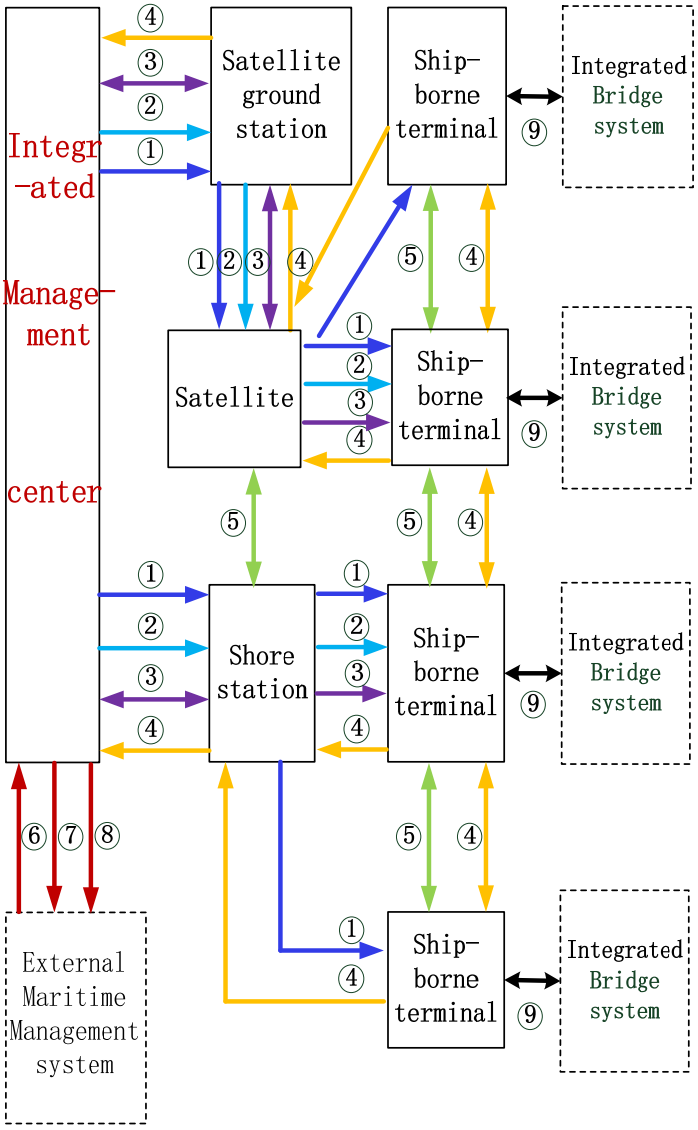

Figure 6. Main information flow diagram of maritime navigation safety guarantee communication system

The transport layer is to realize the flow control on a given link, segmentation/reorganization, and error control. Specifically, the transmission layer of marine navigation security communication system is mainly providing the ability to segmentation, confirmation and reuse of data segments for reliable transmission. The transport layer needs closely coordinated with network layer and link layer to implement functions, which needs to be closely coordinated with the network layer and link layer.

The main business flow of marine navigation security communication system is shown in Figure 6.

1) Distribute information about broadcast service: electronic navigational charts (ENC), maritime safety information (including binary broadcast information, text broadcast information), search and rescue information, military information;

2) Distribute information about addressing service: electronic navigational charts (ENC), maritime safety information (including binary broadcast information, text addressing information), military information;

3) Status monitoring information: Monitoring the communication network status of shore-based station, managing the status of VDL link, monitoring the information interaction situation between connected ship stations, monitoring the status and the information interaction situation between connected shore station and satellite;

4) Ship report broadcast information: ship static information, ship dynamic information, voyage information and military information;

5) Ship addressing service information: inquiry service, maritime safety information (including binary addressing and text addressing information), telemetry information of ship system and military information;

6) Data information about maritime service application: electronic navigational charts (ENC), maritime safety information (including binary addressing or broadcast information, text addressing or broadcast information), search and rescue information, military information;

7) Technical service information: ship static information, ship dynamic information, voyage information, ship system telemetry information, military information;

8) Maritime auxiliary information: maritime auxiliary information, maritime telemedicine auxiliary information, local port service information, maritime safety information, ice navigation information, real-time hydrologic environment information, meteorological information, navigation publications information, pilotage information, tugboat information, military information;

9) Shipboard communication and navigation interactive information: all kinds of communication, navigation and control data between the station and the integrated bridge system.

5. Summarize

This paper designed and built a new generation marine navigation security communication system, which is modular, low-cost, micro-service and autonomous interconnection. Based on VDES, this paper comprehensively designed a communication system for maritime ships, shore-based base stations and space-based satellites. By analyzing the communication business process as well as the communication architecture of the physical layer, link layer and network layer to effectively realize the comprehensive coordination of ship-borne terminals, shore-based terminals and space-borne terminals. The system provides various services such as navigation AIDS in coastal waters and safe navigation information for civil ships' daily activities, which can improve the production capacity of civil ships and support the rapid development of Marine economy.

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