Dynamic networking and channel access strategies of hybrid communication network for intelligent ship

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Abstract. Based on the architecture of the hybrid maritime communication system, the shipboard hybrid communication network structure is presented for multi-network and multi-mode transmission networking equipment of intelligent ship. The paper briefly introduces the proposed dynamic networking and channel access strategies for the communication system of ship-to-ship and ship-to-shore, as well as the communication data types and priorities, quantitative description for each data and performance of each link. Those strategies make the shipboard communication link will be established automatically and flexibly with many modern communication technologies which will be selected depending on the current conditions of the radio channel and the requirements and preferences of the user. Simulation experiments show that those strategies could achieve the flexible and efficient data transmission with high throughput and low delay, using the advantage of each communication technology.

1. Introduction

As an important development of future marine technology, intelligent vessel incorporate many advanced technologize such as modern communications and artificial intelligence, which improve the vessel performance on security, reliability, energy saving and environmental protection. Compared with traditional vessel, intelligent vessel has intelligent navigation functions including environmental perception, risk identification and aid decision making. The realization of these functions largely depends on data transmission between vessels or between a vessel and a shore-based entity. Traditional methods of communication at sea normally focus on distress alert and business operations services. It relies on satellite and ground communication equipment separately. However, the traditional communication mode might not be sufficient to satisfy the requirements of vessel intelligent navigation and users’ preferences, because separate communication systems must be switched manually according to demand and some systems and technologies that are not usually associated with maritime applications are not applied such as mobile networks, 4G and Wi-Fi with the advantages of high transmission rate and low cost. This work is to develop a maritime hybrid communication network systems and technology which could provide unified management for multiple applications and automatically select optimal communication channel in terms of vessel location and data.

As a part of the EfficienSea 2 project, the architecture of the hybrid communication system for the purpose of maritime applications was proposed in 2017[1]. This architecture is comprised of the
coastal segment, shipboard segment and satellite segment which are connected with each other by different communication modes. Our work concentrates on the shipboard segment under the hybrid communication system architecture. The main idea is that various radio communication systems are integrated into one network. The networking and channel access strategies are designed to let the information and data could be routed by the most feasible or lowest cost one or more communication channels.

Networking strategy provides same underlying principle for communication requirement of different applications. Channel access strategy is used to describe how to process the data queues from various applications in the router. K Bronk[1] defined 9 points and respective weight coefficients which serve as an input to the link selection algorithm, such as data rate, transmission costs and transmission delay. Hu[2] proposed a multi-mode gateway selection algorithm, which selects the gateway comprehensively according to node hops number, round-trip delay of 3G network, packet loss rate and transmission load. Zhang[3] presented a surface vessel formation networking strategy based on distributed dynamic slot allocation. In the hybrid communication system, the router with unified management function needs to play a role in distributing data for packet queue reasonably and orderly.

Furthermore, in this paper, channel access strategy includes the methods of data queue management and channel selection. The operation of the communication system mainly depends on the quality of queue management. Various methods were raised worldwide with and without priority. Drop Tail[4], FIFO (First Input First Output)[5], RED (Random Early Detection)[6] and FQ (Fair Queue)[7] are the classic queue management methods without priority. PQ (Priority Queuing)[8], WFQ (Weighted Fair Queuing)[9], CBQ (Class-Based Queuing)[10] and LLQ (Low Latency Queuing)[11] are the classic queue management methods with priority.

The paper is organized as follows. In section 2, we presents an shipboard network structure is developed based on the intelligent navigation communication architecture. Section 3 describes the types and priority of communication data, dynamic networking and channel access strategies. Simulation experiment of the communication system is demonstrated in section 4. Finally, section 5 concludes the paper.

2. Shipboard hybrid communication network framework

![Figure 1. The architecture of the hybrid communication system.](image)

Figure 1 is the architecture of the hybrid communication system for the purpose of maritime applications which is proposed in EfficienSea 2 project. Based on this architecture, an shipboard hybrid communication network structure is demonstrated as shown in figure 2.

In this network structure, intelligent navigation system, bridge and navigation system could send and receive data by multi-network and multi-mode transmission networking equipment. This equipment supports both satellite and terrestrial communication mode with TCP/UDP/IP protocols.
The satellite communication mainly comprises Inmarsat, VSAT, VDE-SAT (work underway), Iridium, StarLink and other commercial satellite data transmission systems. The terrestrial communication mainly comprises NAVDAT, 3G, 4G, Wi-Fi, VDE-Terrestrial (work underway) et al. Data can select/switch different links under different scenarios, in order to satisfy different users’ preference, such as low delay, high data rate or low transmission cost.

3. Dynamic networking and channel access strategies

3.1. Data types and priority

Data communication is the premise and basis for vessel intelligent navigation. Various information needs to be transferred between vessel and shore in order to support the safe navigation, assistance decision, remote-control et al. Even for traditional vessel, small data such as course, position and speed need to be transmitted by satellite or terrestrial communication system to shore. However, for future intelligent vessel, the size and type of transmission of data are larger and more diverse. After analysis of communication needs and their importance, we list the priorities and information types as shown in table 1.

| Priority | Information type             | Data                                                                 |
|----------|------------------------------|----------------------------------------------------------------------|
| Low      | navigation status            | Heading, course, position, speed, ship type et al. target location, speed, intention, image et al. |
| ↓        | environment awareness        | Route planning, collision avoidance decision et al. remote control request, shore-based remote control, control transfer et al. |
| High     | remote control               |                                                                      |

3.2. Quantization description

Quantitative description is beneficial to distinguish transmission requirement of each data and performance of each link. So, it is the basis of queue management and link selection. Every transmission mission is described as:

\[
\text{Mission} = [\text{Priority} \quad \text{Maximum\_delay} \quad \text{Size} \quad \text{Confirm}]
\] (1)

where, Priority shows the information importance and type (see table 1). Maximum\_delay is the request for delay. Size is the amount of data. Confirm shows whether need to reply from destination when data is received.

Furthermore, every link is described as:

\[
\text{Performance} = [\text{Coverage} \quad \text{Signalpower} \quad \text{Rate} \quad \text{Delay} \quad \text{Reliability} \quad \text{Cost}]
\] (2)
where, Coverage determines the available duration of a link. Signalpower reflects the quality of communication. Rate is the transmission efficiency. Delay reflects receiving time of data. Reliability shows the stability of a link in the past time. Cost is communication fee.

3.3. Dynamic networking strategies

Due to the constant change of link available and transmission requirement throughout the voyage, fixed networking strategy cannot meet the requirement of flexible use of resources. For example, when vessel is on the route far away from shore, the transmission could be realized via satellite links which are available almost at all times for all tasks. When vessel is near the shore, cellular networks (3G, 4G) and Wi-Fi could share most of the tasks for high data rate and low cost. So, dynamic networking is based on the data priority and link availability and performance. The dynamic networking strategies are:

(1) Strategy 1 is optimal utilization of link: while data belong with different information types and priorities, one or more preferred links are selected first for high priority data to ensure the reliability and effectiveness of transmission.

(2) Strategy 2 is optimal delivery of transmission task: while data belong with the same priority and small delays are acceptable. In this strategy, every link will be fully utilized which make the best use of transmission resources.

(3) Strategy 3 is lowest transmission cost: while data belong with the same priority and there is no requirement for delay. In this strategy, the link with low cost will be used first.

3.4. Channel access strategy

3.4.1. Queue management

When different priority data need to access channels to be transmitted, the multi-network and multi-mode transmission networking equipment will manage those data packet depending on a strategy which defines the processing sequence, link selection, whether need ACK et al. This strategy is defined as follow:

(1) Depending on the above priority, the higher priority data will be managed faster and access more optimal link.

(2) Access link could be switched to more optimal one if it is unoccupied more than a time threshold or do not exceed link’s maximum capacity.

(3) Lower priority data could be managed over higher one only if the waiting time exceeds allowed threshold.

(4) The transmission of remote control and decision support data need ACK because the cautions should be more exercised for control and decision.

The order of optimal link sequence is confirmed based on the service profile, preferences or polices for each priority data. Thus, for different data the optimal link sequence may different. For example, in normal coastal navigation, 4G and Wi-Fi could be the first choices as the wide bandwidth, low delay and cost. Nevertheless, 4G is the most optional link for remote control data as its high stability. Wi-Fi is the most optional link for environment awareness data as its wider bandwidth then 4G.

3.4.2. Link selection

Generally, link selection is responsible for selecting the optimal channel of transmission in the given time and place on the basis of the information on networks’ availability and performance and then – if required – for switching between various data transmission channels. It should be underlined, due to the availability and quality of transmission link will vary both in time and place, the procedure of link selection or switching will be carried out periodically rather than just once. The link selection will work according to the algorithm depicted in figure 3.

In equation (2), the link performance is defined up by six parameters: Coverage, Signalpower, Rate, Delay, Reliability and Cost. These parameters of available links will serve as an input to the link selection algorithm. The value of them will be obtained empirically during the implementation phase,
and also could be modified by user. When link selection carried out, the available link will be sorted by the value of parameters from big to small according to the parameter which is most critical for a given application. This order expresses the degree of suitability of each link for the application. Then, the algorithm will select the top link.

![Link selection algorithm flowchart.](image)

**Figure 3.** Link selection algorithm flowchart.

### 4. Experiments and results

In order to test the feasibility of multi-network and multi-mode transmission and the performance of networking and channel access strategies, we carried out the simulation experiments using Ns-2. Ns-2 is an open source event simulator targeted at networking research. Ns-2 provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless networks.

#### 4.1. Simulation network topology

There are four class data in this shipboard hybrid communication, and ten alternative transmission links. So, the simulation network topology is shown in figure 4. In this topology, four nodes on left side express the data generator for the four class, and right side ten links from node ④ express the ten transmission modes which presented beside the nodes. The arrows are directors of data transmission. Additionally, the data generation frequencies are 0.5 Hz, 15 Hz, 2 Hz and 2 Hz and the start time are 0.1 s, 0.5 s, 5 s and 10 s. Total test time is 60 s. Bandwidth and delay are also set for these links according to table 2.

![Simulation network topology.](image)

**Figure 4.** Simulation network topology.
4.2. Test scenarios

Below, we test the above strategies in three typical scenarios, including berthing and departing, ocean navigation and coasting. The details of them are shown in table 3.

| Scenarios | Recommended communication modes | Details |
|-----------|---------------------------------|---------|
| Scenarios 1: berthing and departing | public networks | Four types of information are transmitted including navigation status, environment awareness, decision support and remote control |
| Scenarios 2: ocean navigation | satellite communications | Three types of information are transmitted including remote control, decision support and environment awareness. |
| Scenarios 3: coasting | terrestrial networks | Four types of information are transmitted including navigation status, environment awareness, decision support and remote control |

4.3. Test results and analysis

The simulation tests for above three scenarios are carried out after programming and setting up parameters. Then, communication modes and statistics of throughput and delay are counted, which are shown in table 4, figure 5 and figure 6.

Comparatively, environment awareness data includes basic information which needs more stable communication mode with high signal power while environment awareness data need wider bandwidth as its large volume of data. Compared with decision support data, remote control data needs more stable communication mode. In table 4, for example, the data of navigation status and remote control select 4G while data of environment awareness and decision support select Wi-Fi in scenario 1. As it is near the shore, public networks are available in the area with low delay and wide bandwidth. In addition, 4G is more stable and Wi-Fi has wider bandwidth.

| Scenarios | Scenario 1 | Scenario 2 | Scenario 3 |
|-----------|------------|------------|------------|
| Navigation status | 4G | Inmarsat FBB | ASM |
| Environment awareness | Wi-Fi | Iridium | VDE-TER |
| Decision support | Wi-Fi | Iridium | VDE-TER |
| Remote control | 4G | —— | VDE-TER |

Data generation frequencies are low except for environment awareness data. The performance of selected links can meet the requirements concerned. See figure 5, under the ideal simulation environment, the throughputs of all data soon stabilise without loss.

The transfer delay is shown under each scenario in figure 6. We can see that delay time is largely determined by link delay which is set on table 2. To compare the delay of three scenarios, the smallest one is in scenario 1 and biggest one is in scenario 2. This is consistent with the fact that satellite delays are greater than public networks and terrestrial networks are in the middle. Otherwise, in scenario 3, although decision support and remote control data are transmitted by the same link, the sizes and frequencies of both data are not beyond the capabilities of this link. Especially, the first data packet

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Table 2. Bandwidth and delay for each link.

|            | Inmarsat FBB | Inmarsat C | Iridium | VSAT | VDE-SAT | VDE-TER | ASM | NAVDAT | Wi-Fi | 4G |
|------------|--------------|------------|---------|------|---------|---------|-----|--------|-------|----|
| Bandwidth  | 432kb        | 600bb      | 1.5Mb   | 1Mb  | 307.2kb | 307.2kb | 9.6kb | 20kb   | 150Mb | 50Mb|
| Delay      | 300ms        | 300ms      | 200ms   | 240ms| 240ms   | 200ms   | 150ms| 80ms   | 60ms  |    |
The delay of decision support and remote control in every scenario is lower than other packets. This is because the first data packets for them are ACK related information with very small size to make sure the link is available. The packet delay of ACK is small then others.

In generally, appropriate links are selected depend on the networking and channel access strategies. Experiments results show that proposed communicate system and method have excellent performance in delay and throughput.

![Figure 5](image1.png)  ![Figure 6](image2.png)

**Figure 5.** Statistics of throughput in three test scenarios.

**Figure 6.** Statistics of delay in three test scenarios.
5. Conclusions
Based on the maritime hybrid communication system, a shipboard hybrid communication network structure was proposed in this paper and further concentrates on dynamic networking and channel access strategies, which could be a significant improvement of ship-to-ship and ship-to-shore connectivity.

The approaches of those strategies for this hybrid communication system have several advantages:

(1) Four priorities of transmission data are defined: remote control, decision support, environment awareness, navigation status, which is provided differential service for improving the rational allocation of channel resources.

(2) Quantization description of the task to transmit and link performance as the basis of those strategies could understand the data and available links clearly for multi-network and multi-mode transmission networking equipment.

(3) Hybrid communication mode could support more options. Multi-network and multi-mode transmission networking equipment can select or switch optional link flexibly according to the ship's geographical location, network status, data priority and transmission requirements. Tests results show that this way could have low delay than only use satellite communications at all time.

In future work, the proposed strategies will be conducted both in laboratory as well as in real conditions (at sea), in order to verify the implemented algorithms and identify the areas for improvement.

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