The Intelligent Pelagic Communication System Architecture of the Fleet based on UAV Swarm Relay

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Abstract—**With the development of economy and navigation, more and more ships are sailing to the pelagic, which puts forward more requirements for the communication system of the pelagic. Aiming at the problems of high data transmission delay, low reliability and low transmission rate and high cost in fleet communication in the pelagic, this paper presents the intelligent pelagic communication system architecture of the fleet based on UAV swarm relay, four communication relay modes suitable for the pelagic, and researches on the existing intelligent coverage strategy and routing strategy in the dynamic environment of the pelagic. The communication system supports rapid deployment and can achieve network coverage in a short period. Compared with traditional satellite communication on oceans, it can have higher real-time performance, higher reliability, higher transmission rate, and lower cost of long-term large-scale data transmission.**

Keywords-UAV swarm relay; relay communication; pelagic communication; coverage strategy; routing strategy

I. INTRODUCTION

With the development of the economy and the continuous technological innovation of the manufacturing industry, the maritime industry has developed by leaps and bounds, and indicators such as water transportation, ship construction, fishery output, and the number of crew members are increasing year by year. It can be seen that people are paying more attention to the ocean, which accounts for about 71% of the earth's surface area. From ancient times to the present, human beings have never stopped exploring the ocean. With the development of navigation technology, the ocean areas developed and utilized by people have been continuously expanded, gradually moving towards the deep sea and the far sea. However, the backwardness of communication technology made before the 19th century, the navigators sailed far away from the coastline, basically no news. Until August 1960, the United States used the Delta D carrier rocket to send ECHO 1 into the predetermined orbit, and successfully carried out the first satellite relay communication across the continent in human history. Since then, humans have gradually begun to use artificial satellites to achieve long-distance transmission of letters, numbers, symbols, and digital sound and image information which creates favorable conditions for data transmission when people are sailing in the pelagic [1-4].

During ocean voyages, because the navigation area is far from the coastline, the communication network along the coast cannot be covered, which brings difficulties in information and data exchange for the execution of ocean voyages. Nowadays, satellite data transmission technology, as a powerful means to realize long-distance information transmission and processing on the earth, has been widely used in pelagic communication.

In order to achieve high-quality development of the maritime industry in the future, it is very important to have scientific and efficient intelligent maritime communication service support capabilities. There is a need for local area network communication inside the ocean-going fleet. Affected by the curvature of the earth, normal line-of-sight communication cannot be performed between distant ships inside the fleet, Traditional line-of-sight communication methods cannot support far-sea missions with a wide operating area, and an independent, dedicated, high-speed, and wide-coverage intra-fleet communication method is required.

The usual solution is to use satellites as relay nodes for communication. However, since communication satellites are in orbit around the earth, makes the communication network covered all over the world, but there are also problems such as expensive charges based on data traffic, high data transmission delay, low reliability and low transmission rate caused by the long distance between the sky and the earth.

To solve this problem, we can consider adopting new equipment to replace satellites for relay communication to a certain extent, among which UAVs are a good choice. Nowadays, the airworthiness of UAVs has been significantly improved, and the new generation of UAVs already have the ability to take off and land autonomously under level 5 sea conditions, which can basically meet the daily needs of users. In the case of meteorological conditions where the UAVs cannot be used, the traditional satellite communication method can still be used.

In this paper, the UAV platform is used as the relay node of the pelagic communication, we design the intelligent pelagic communication system architecture of the fleet based on the UAV swarm relay. The communication system can realize the rapid deployment of relay nodes and achieve network coverage in a short time. The communication system can realize the rapid deployment of relay nodes, achieve network coverage in a short time, and the UAV is

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closer to the ship, which can achieve higher real-time performance, higher reliability, higher transmission rate, and lower cost of long-term large-scale data transmission. At the same time, the position of the ship is constantly changing to carry out the mission. In this paper, using the characteristics of easy control of UAV position, the system can adapt to changing terminal node positions in real-time, change the topology of the UAV relay communication network, and realize real-time high-quality communication inside the ocean-going fleet.

II. UAV RELAY COMMUNICATION SYSTEM COMPOSITION

With the development of the manufacturing industry and the innovation of science and technology, the maturity of UAV manufacturing technology, the increase in output, the decline in manufacturing costs and the diversification of UAV types and loads make UAVs have a wide range of application prospects [5]. In view of the problems mentioned above, this paper adopts the introduction of UAV relay for cooperative transmission, and establishes an over-the-horizon communication link between ships with a long distance inside the fleet to meet the requirements of long-range coverage.

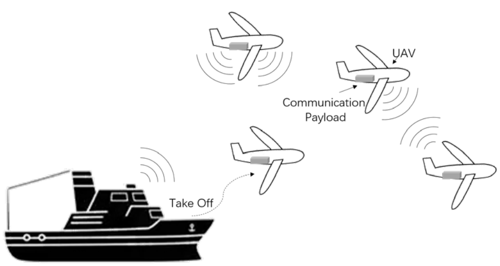

Fig. 1. UAV relay communication system composition

The composition of the UAV relay communication system is shown in Figure 1. Specifically, the UAV relay communication system uses the UAV as a lift-off carrier, carrying airborne communication loads such as micro communication base stations, communication radio stations, etc., and becomes a communication relay site. It receives the data sent by the ship, and after processing and amplifying the received signal, forwards it to the next node. It can extend the communication distance and maintain good communication quality, and can establish communication with nodes on the sea, air and land. In addition, the UAV has the characteristics of easy-to-control aerial position, which can realize real-time adaptation to the network changes caused by the continuous navigation of the ocean-going fleet to make maneuver.

III. UAV RELAY GROUP COMMUNICATION RELAY MODE

In order to adapt to the characteristics of pelagic communication, the communication system in this paper contains four UAV communication relay modes, namely UAV relay group independent networking mode, UAV relay group and island or offshore platform networking mode, UAV relay group and satellite networking mode and Multi-platform hybrid networking mode.

A. UAV relay group independent networking mode

This is a basic networking mode of the communication system in this paper, which can effectively meet the needs of the internal LAN communication of the ocean-going fleet, and provide an independent, dedicated, high-speed, and wide-coverage communication means inside the fleet.

As shown in Figure 2, in the case where normal line-of-sight communication cannot be carried out between ships with a long distance inside the fleet, the UAV group is used for relaying, and a ship as one end of data transmission cannot communicate with the distance through line-of-sight communication means. It can communicate with distant teammates. At this time, it can first send the data to the relay UAV that is closer to it, and then the UAV will forward the received data in the relay group, and finally reach the destination ship.

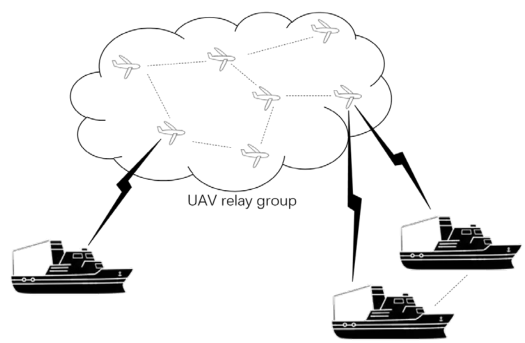

Fig. 2. UAV relay group independent networking mode

This networking method provides a relatively independent dedicated communication LAN for the fleet, which can meet the needs of the internal LAN communication of the ocean-going fleet.

B. UAV relay group and island or offshore platform networking mode

There are many islands scattered in the ocean, some of which have communication equipment and the ability of communication relay, which can be used by the fleet. The fleet can use nearby islands that can provide communication services as communication relay nodes and incorporate them into the UAV relay group network to provide data transmission relay services collaboratively.

As shown in Figure 3, in the independent networking mode of the UAV relay group, the ground stations on the islands that can provide relay services are incorporated into the entire communication network. At the same time, if the island has a submarine optical cable with the mainland, the fleet can also relay business reports and communicate with the higher-level agencies on the ground through the island, return operational data, and access the Internet.

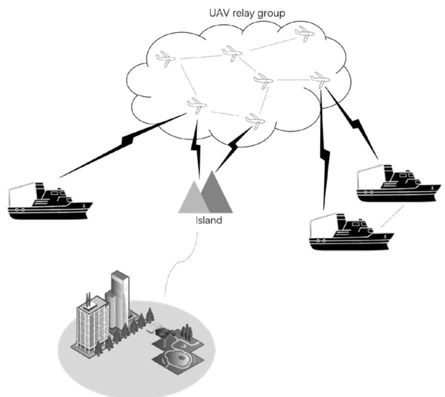

Fig. 3. UAV relay group and island or offshore platform networking mode

In addition, Huawei Technologies Co., Ltd. and Norwegian communication service provider Tampnet developed and built the world's first offshore LTE network offshore platform [6]. The platform communicates with the onshore office area through a submarine optical cable, enabling a maximum distance of 100 kilometers from the onshore office area to the offshore platform coverage. At the same time, the network of the offshore platform can cover the sea area within a radius of 37 kilometers. If the unmanned platform can provide communication relay for ships in the future, in the communication system of this paper, the unmanned platform can be regarded as a man-made "island" node with communication relay capability for wireless communication networking.

C. UAV relay group and satellite networking mode

The communication needs of the fleet are not only the LAN communication inside the fleet, but also the need to communicate with the superior agencies on the shore. There are very few relay islands at sea with the ability to meet this demand. In most cases, satellites are used as relay nodes to communicate with onshore nodes. The environment in the open sea is complex, and the quality of the satellite communication link of individual ships may be poor, or even the satellite communication cannot be established. At this time, you can try to establish a communication link with the satellite through the UAV relay group.

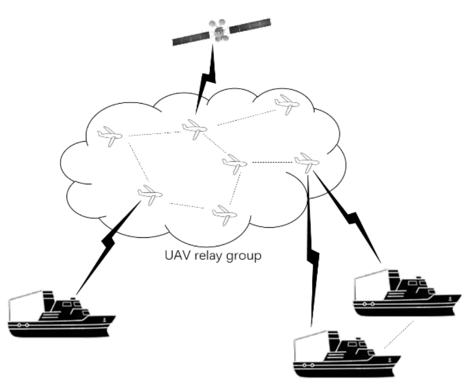

Fig. 4. UAV relay group and satellite networking mode

As shown in Figure 4, in the independent networking mode of the UAV relay group, a ship in the fleet needs to communicate with someone outside the fleet, but its satellite communication is limited, and the data can be sent to the adjacent UAV nodes. The data can be sent to the adjacent UAV nodes, and through the forwarding of the UAV relay group, the data reaches the UAV nodes that can establish a connection with the satellite. Through this node, the data is forwarded to the relay satellite node, and finally the data is sent to someone outside the fleet by the satellite communication network.

D. Multi-platform hybrid networking mode

In order to meet the diverse needs of the fleet, the above modes can be combined to form a multi-platform hybrid network to enrich the communication capabilities of the network.

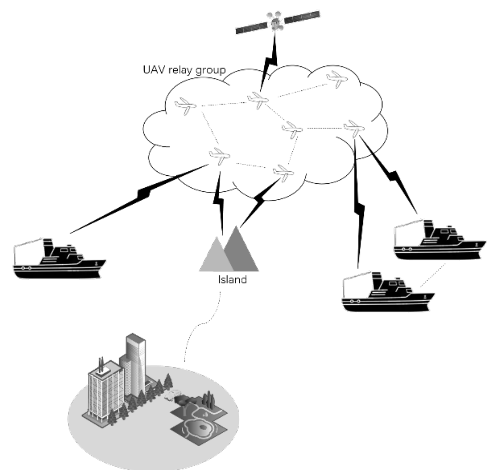

Fig. 5. Multi-platform hybrid networking mode

As shown in Figure 5, the UAV relay group can not only connect the communication satellite nodes, but also use the islands for communication relay. It should be noted that this mode has higher requirements for dynamic networking capabilities, network dynamic planning capabilities, and UAV maneuvering capabilities.

IV. THE INTELLIGENT PELAGIC COMMUNICATION SYSTEM ARCHITECTURE OF THE FLEET BASED ON UAV SWARM RELAY

The fleet remote communication system relayed by UAV mainly relies on the flight management data communication between the UAV and the onboard control terminal to provide high-speed, accurate and reliable two-way communication transmission guarantee between any two ships in the fleet.

The communication system architecture proposed in this paper includes two parts: the UAV platform system and the shipboard intelligent control system.

As shown in Figure 6, the UAV platform system includes UAV platform, communication payloads, UAV flight control subsystem, UAV navigation subsystem; the shipboard intelligent control system includes shipboard console, UAV intelligent dynamic control subsystem, communication antenna, take-off and landing platform. Among them, the intelligent dynamic control system of the UAV can realize the adaptive network form optimization under the condition that the formation of the ocean-going fleet is constantly changing. Specifically, it includes UAV flight parameter control, UAV intelligent route planning, UAV intelligent routing control, intelligent network coverage algorithm, etc. When the ship sails for a period of time and the node position relationship changes greatly, it can timely and adaptively change the state of the UAV relay group, and continue to provide high-quality communication services.

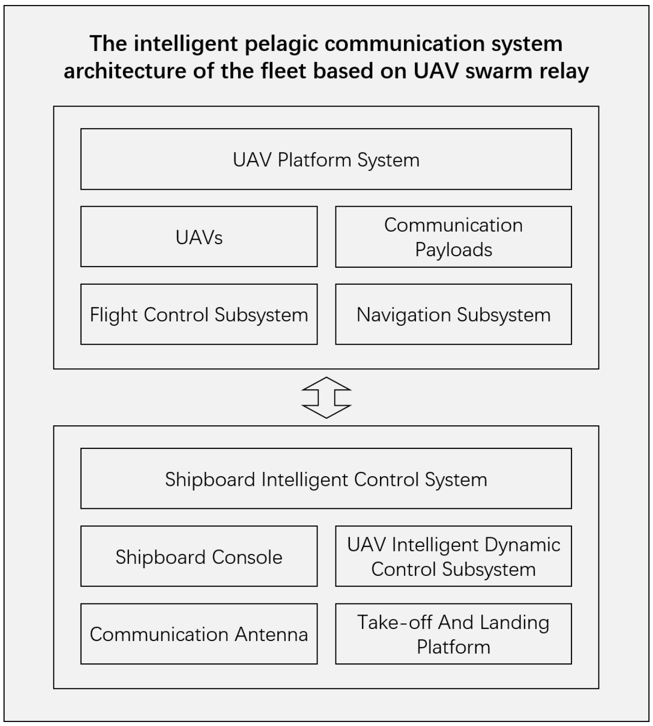

Fig. 6. The intelligent pelagic communication system architecture of the fleet based on UAV swarm relay

The communication between the UAV platform system and the shipboard intelligent control system usually relies on the airborne communication radio and the shipboard communication antenna. The airborne communication radio station is mainly responsible for the UAV's flight information, coordinates, status information and data packet forwarding. The shipborne communication antenna realizes the release of UAV control instructions and the transmission and reception of data packets.

In terms of the selection of UAV platforms, due to the limited space on the hull deck, UAVs that support the vertical take-off and landing can be selected, such as multi-rotor UAVs, hybrid-wing UAVs, etc. At the same time, for the consideration of storage and transportation of the UAV, a UAV with a folded wing design can be used. The fuselage of the UAV is generally made of lightweight aviation aluminum and carbon fiber, which can not only ensure the structural strength, but also reduce the weight of the UAV itself and improve the load-carrying capacity of the mission. In terms of energy and power, kerosene or battery power can be selected for safety reasons.

In terms of the intelligent network coverage algorithm, since the communication system in this paper is a dedicated network for the fleet of pelagic, its topology will continue to change with the position of the ship. Therefore, it is necessary to perform network coverage calculation based on the real-time position information of the ship, and adjust the position of the UAV relay node in time according to the calculation result.

The coverage modes of the network are mainly point coverage and area coverage.

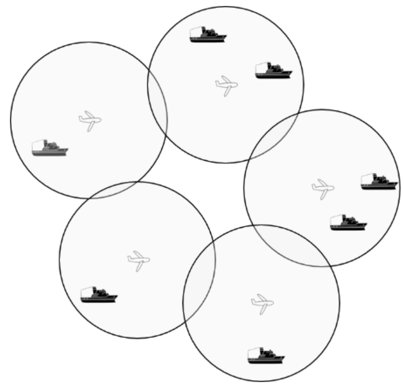

Fig. 7. The point coverage diagram

Specifically, the point coverage method is to complete the coverage of all target points in the target area. As shown in Figure 7, under the condition of network connectivity, all the target ships in the fleet only need to be covered.

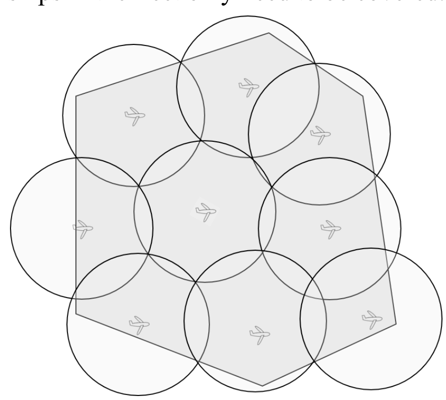

Fig. 8. The area coverage diagram

Another coverage method is regional coverage, which mainly completes the coverage of the entire target area. As shown in Figure 8, under the condition that the UAV relay nodes are connected to each other, full coverage of the designated area network is achieved.

The coverage problem has attracted many researchers to conduct theoretical and applied research, and related methods can be introduced into the architecture of this communication system to solve the network coverage problem of UAV relay groups. Ling Ding et al. [7] presented an approximation algorithm for the target coverage problem of constant approximation. Zhou proposed a coverage optimization algorithm based on the signal irregularity model. The coverage model only uses the signal strength value received by the sensor nodes to construct a virtual force coverage model, which solves the problem of irregular signal transmission range [8].

In the intelligent routing scheme, due to the dynamic change of the network topology, the traditional routing algorithm cannot well adapt to the networking requirements of the UAV relay cluster [9]. This communication system can introduce a routing scheme that has the ability to adapt to the highly dynamic network topology changes. Chen et al. proposed the optimal relay selection based on location prediction for unmanned aerial vehicle networks. The algorithm predicts the position of the UAV at the next moment according to the Kalman algorithm, judges the quality of the link, and calculates the optimal relay selection by the greedy algorithm [10]. In 2017, Mao et al. proposed a considered system model of the deep belief network-based routing protocol [11]. At the same time, some researchers have tried to design intelligent routing algorithms based on machine learning methods [12-14].

It can be seen from the above that it is feasible to use UAVs to replace traditional maritime satellites for pelagic communication to a certain extent. The following will compare the two methods from three aspects. In terms of communication cost, the cost of maritime satellite communication is expensive, and the cost is mainly calculated according to the data traffic. When the monthly cost per ship is large, it can reach tens of thousands of RMB. Using the UAV relay communication system in this paper, although a large one-time investment is required in the initial stage for UAVs, communication terminals and other equipment, but the later period is mainly for the cost of UAV use, which has a strong price advantage for scenarios with long-term use and large data transmission. In terms of real-time performance, satellite communication has a long transmission distance between the sky and the earth, resulting in a transmission delay of more than 500 milliseconds. The transmission distance of UAVs relay is relatively short, so that the transmission delay can be significantly reduced. In terms of the reliability, because the data of satellite communication needs to pass through the atmosphere and the transmission distance between the sky and earth is far, the bit error rate increases, and the transmission speed decreases. The UAV relay communication method adopted in this paper has enhanced reliability due to the advantages of transmission distance. In addition, communication satellites are public resources, and there are security and reliability risks in the transmission of classified information. The UAV relay communication method can be constructed as an internal private network, and such risks are relatively low.

V. Conclusion

This paper presents the intelligent pelagic communication system architecture of the fleet based on UAV swarm relay which contains four communication relay modes suitable for the pelagic, and researches on the existing intelligent coverage strategy and routing strategy in the dynamic environment of the pelagic. Through the high real-time, high reliability, high transmission rate, and low-cost communication system of this paper, the communication of the ocean-going fleet will be more convenient and support the fleet to complete the ocean-going mission better.

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