

Research on Issues Related to the Application of wireless Communication Routing Protocols in Maritime Communication

Yan Wang^{1, a *}, Xianyun Qi^{1, a}, and Peizheng Liu^{2, b}

¹ 63879 Unit, Weinan, Shaanxi 714200, China;

² 32399 Unit, Nanjing, Jiangsu 210018, China.

^a 1506625221@qq.com, ^b 872242949@qq.com

Abstract. This paper analyzes the demand characteristics of three-dimensional island-seizure operations for wireless communication networks, conducts analytical research on the network layer routing protocols of existing wireless communication network, proposes optimization suggestions, and verifies the optimization mechanism through simulation to improve the comprehensive support capability of wireless communication networks.

Keywords: Wireless communication; routing protocol; LAR.

1. Introduction

Communication networks are the foundational guarantee for achieving seamless connectivity among communication elements. There are significant differences between the communication environment at sea and that on land, and ad-hoc wireless communication networks are one of the important communication methods for maritime communication. Therefore, it is extremely urgent and meaningful to research and optimize wireless communication network routing protocols to better meet the application needs at sea.

2. Requirements of Wireless Communication Networks for Naval Combat Applications

In naval combat operations, forces must devise and employ strategies and tactics in accordance with the specific mission, battlefield situation, and natural environment. However, regardless of the type of mission being executed, it is essential to account for the operational characteristics of fighting across the sea, with water at one's back, and far from the homeland. Efforts should focus on enhancing the coverage, stability, and water-area access capability of the battlefield communication network, ensuring that combat operations can be precisely initiated, swiftly concluded, and conducted under integrated joint defense and control.

Precise insertion aims to achieve the suddenness of operations, placing extremely high demands on the autonomous networking capability and anytime, anywhere access capability of wireless networks. Taking the covert insertion of special operations as an example, considering that prolonged underwater concealment consumes significant physical energy, an approach involving direct airborne parachute insertion onto the island can be adopted. Utilizing favorable conditions such as adverse weather and under the cover of aircraft, precise parachute landings can be executed onto the target island, or parachuting into nearby waters followed by island infiltration. However, regardless of the method, the precondition is the absence of fixed friendly based providing continuous communication support. Therefore, relying on the autonomous network established by the combat unit to achieve real-time positioning and communication of operational elements is the most practical and feasible approach.

Swift and Decisive Operations, Which emphasize joint coordination among services and arms, impose high demands on the compatibility and real-time transmission capabilities of wireless networks. After a successful island landing, special operations forces and other services must rapidly establish communication links. Other services need to receive the infiltration and reconnaissance results obtained earlier by special forces-such as the locations of key enemy

targents-in a timely manner. Through coordinated efforts, strikes are executed befor enemy reinforcements arrive to achieve the intended operational objectives. During this period, measures such as lelctronic jamming and cyber attacks may also be employed to disrupt the transmission of enemy commands.

Joint Defense and Control emphasizes the defensive nature of operations, placing high demands on the self-adaptability of wireless networks. After achieving the intended objectives in an islan-seizure operation but before withdrawal, the forces on the island must swiftly transition to a defensive posture and prepare for enemy resistance before the arrival of follow-uo landing forces. Given that the occupied island is close to the enemy's homeland, the enemy may attempt infiltration by sea while our fouces are still consolidating their possitions. Therefore, it is essential to strengthen coastal patrols, vigilance and maritime surveillance. The wireless communication network must possess strong self-adaptive access capabilities for various operational information systems, reconnaissance systems, and firepower strike systems, while also effectively handing and mitigating dynamic bandwidth allocation and network congestion.

3. Analysis and Optimization of Wireless Communicati on Network Routing Protocols

Compared to terrestrial communication technologies, research on martime communication technology started later and has been relatively limited. Additionally, the communication environment in maritime military operations deiffers significantly from that on land. If traditional terrestrial wireless network routing protocols are directly applied to maritime wireless networks, the random displacement of nodes and the rapidly changing natural conditons during military operations at sea can lead to high uncertainty in network topology. Changes in topology and communication environment will increase routing overhead, cause network fluctuations, and ultimately degrade communication quality.

3.1 Wireless Mesh Networks and Routing protocols

3.1.1 Wireless Mesh Networks

In maritime military operations, communication nodes are highly mobile, and the network topology changes frequently. As the operational process advances, the number of nodes also fuluctuates. Therefore, wireless cummunication network must support military operations without the need for pre-deployment infrastructure and must be capable of adapting to frequent changes in network topology.

3.1.2 Wireless Mesh Network routing protocols

Based on differences in route establishment methods, wireless mesh network routing protocols can generally be categorized into table-driven routing protocols, on-demand routing protocols, and hybrid routing protocols. Table-driven routing protocols, represented by DSDV, WRP and OLSR, achieve routing by establishing and maintaining complete routing tables that contain various tapyesof information. On-demand routing protocols also establish and maintain routing tables, but these tables contain only information ralated to communication requirements rather than network-wide data. Hybrid routing protocols combine the features of the aforementioned two protocol types, establishing and mantaining routing tables based on communication demands and network topology conditions. Based on comprehensive analysis of the characteristics of the three routing protocols, in the context of maritime military operations where nodes exhibit random mobility and network topology changes frequently, on-demand routing protocols are better suited to reduce network overhead during the route establishment precess in wireless network support. However, when multiple combat unit initiale service requests simultaneously, it can generate significant disturbances, thereby affecting network stability. To address this issue, location-based routing protocols can be employed.

When positioning devices are installed on operational units, location-based routing protocols can utilize acquired information such as position, speed and direction to perform on-demand directional route queries when routing is required. This minimizes unnecessary network overhead, thereby improving routing efficiency and making it more suitable for maritime military operations. Based on whether a route is established before sending data, location-based routing protocols can be categorized into location-aided routing protocols and full location routing protocols. Location-aided routing protocols first utilize location information to assist in establishing a route link before transmitting data, with the LAR protocol being a representative example. Full location routing protocols, on the other hand, do not establish a route link in advance, instead, the forward data directly based on location information. Representative protocols of this type include the DREAM protocol and the GPSP protocol.

3.2 The LAR Protocol

The LAR protocol achieves routing by maintaining and updating routing tables, and organizes routing information into groups, divided into the sending primary routing information group and the receiving primary routing information group. The sending primary routing information includes details such as the position, speed and time of the source node and the destination node, while the receiving group's information includes the position, speed and time of the destination node. Nodes that receive the routing information can extract relevant details about other nodes from these two groups of information, thereby enabling the updating of routing information. The LAR protocol adopts a domain-based management approach to restrict the propagation range of routing information. It can be divided into the original domain and the extended domain.

3.2.1 The Original Domain

Assume the source node is (S) and the destination node is (D). The position of (D) at a past time T_0 , denoted as (X_0, Y_0) and its average speed v are known. The current time is T_1 . The original domain is defined as the possible area where (D) may be located at time T_1 . Given that source node S possesses relevant information about D, the original domain of D at time T_1 is a circle centered at (X_0, Y_0) with a radius of $v \cdot (T_1 - T_0)$. If (S) additionally knows the direction of (D)'s movement, the original domain can be reduced to a semicircle or even a smaller region. If the source node S cannot obtain information about (D), it is impossible to determine the original domain. In extreme cases, the entire network may become the original domain. Therefore, the more information available about the information update, the smaller the determined original domain will be, leading to faster routing. The original domain of the LAR protocol is illustrated in Fig. 1.

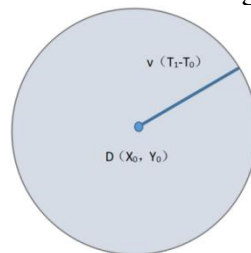


Fig. 1 The original domain of the LAR protocol

3.2.2 The Extended Domain

After determining the original domain, the range can be further narrowed. The specific area where routing request information is sent is called the extended domain. Only nodes within the extended domain can receive the routing information and take corresponding actions, while nodes outside the extended zone directly ignore the routing information. This method reduces network overhead and improves efficiency. The extended domain is defined as the minimum rectangular area that includes both the source node S and the original domain of S for destination node (D). The source node S may lie either inside or outside the extended domain. Therefore, the extended domain

can be categorized into two scenarios, as illustrated in Fig. 2 and Fig. 3 respectively. The size of the extended domain is proportional to the speed of (D), as well as the time interval between the recorded location and the current time.

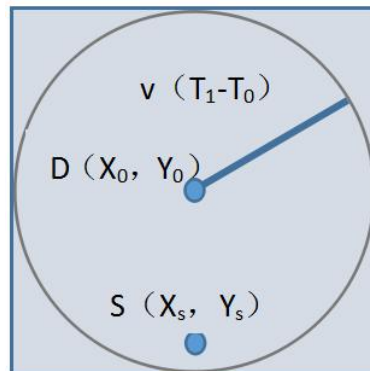


Fig. 2 S is within the extended domain of D

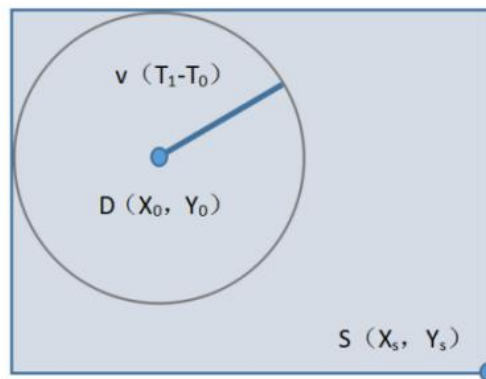


Fig. 3 S is not within the extended domain of D

3.2.3 The DREAM Protocol and GPSR Protocol

The DREAM protocol determines a specific area by calculating the relative positions of the source node and the destination node. Only nodes within this area can receive the routing information from the source node and iteratively propagate in to correctly reach the destination node. The method of searching for the destination node within a defined regional scope is similar in both the DREAM protocol and the LAR protocol. However, the LAR protocol resolves this through route querying, while the DREAM protocol achieves it by forwarding data. The DREAM protocol demonstrates good performance in eliminating routing loops and conserving bandwidth, but it is not suitable for wireless networks with a large number of nodes or high data transmission volumes.

The GPSR protocol is a stateless routing protocol that does not maintain data structures similar to routing tables. Nodes must be aware of the destination's location themselves. Its performance is not affected by the number of nodes in the network, but node mobility increases overhead due to location changes, leading to significant performance degradation. Thus, it is not suitable for wireless networks with dynamic topologies.

3.2.4 The Optimized LAR Protocol

The above routing protocols each have their own characteristics. The LAR protocol controls the scope of packet broadcasting through the request zone and expanded zone, reducing network fluctuations caused by increased communication volume and thereby lowering bandwidth consumption. However, its working principle means that if route discovery fails, the control over the packet broadcasting scope becomes ineffective, and its advantages cannot be realized.

The DREAM protocol avoids the network overhead caused by maintaining large routing tables by using location information to implement its routing algorithm. It is efficient when the network scale is small, but its performance degrades significantly as the network grows larger.

The GPSR protocol's working principle makes it unaffected by the number of network nodes, but when node locations change, its routing overhead increases sharply, leading to performance degradation.

In summary, the LAR protocol is the least affected by the number of nodes and can adapt well to routing changes caused by node mobility. Therefore, this paper selects the LAR protocol as the routing protocol for the wireless Mesh network in three-dimensional island seizure operations, and optimizes it to meet the communication network requirements of combat operations.

The basic idea of the optimized protocol is to improve the request zone of the LAR protocol by introducing a variable factor into its radius to enhance its accuracy. Furthermore, considering the unstable links between combat units in combat communication environments, an automatic repair mechanism is added to improve network reliability.

(1) Optimization of the LAR Original Domain and Extended Domain

The request zone of the LAR protocol described in the previous section is an ideal state. However, in actual maritime wireless Mesh networks, there is a period of route discovery time from the start to the end of the process. The impact of the displacement of combat units during this period on the request zone should be considered. A variable factor (u) is designed, so the radius of the optimized LAR request zone is defined as ($r' = (T_1 - T_0) v + u$) where (u) is determined by the time taken for packet information to travel from (S) to (D), (v) is the speed of (D), (T_1) is the current time, and (T_0) is the time when (D) was last located.

If the distance between combat units (S) and (D) is the maximum signal coverage range, the minimum number of hops is ($H = d/d'$), where (d) is the distance between (S) and (D), and (d') is the maximum communication distance between each combat unit. If the packet processing time per hop is (t), the variable time from (S) to (D) can be calculated as ($t' = tH$). Thus, the variable factor is defined as ($u = 2vt'$). Accordingly, the expanded zone of the optimized LAR protocol is a rectangle that contains both (S) and the optimized request zone of (D). Only nodes within the expanded zone can forward and process packet information, improving the accuracy of route discovery. As shown in Fig. 4.

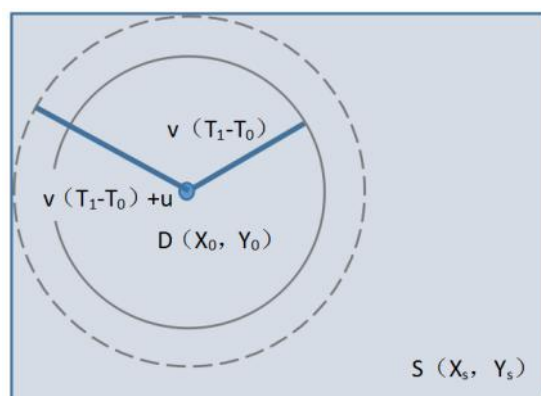


Fig. 4 Optimized request zone and expanded zone of the LAR protocol

(2) Automatic Repair Mechanism in the Optimized LAR Protocol

Antenna sway caused by wave motion and uncertain movement of combat units can lead to communication link interruptions, resulting in data loss and increased delay. An automatic repair mechanism is designed in the optimized LAR protocol to find alternative routes to the destination unit when a link fails, minimizing packet loss rate and delay.

The basic principle is as follows: When source node (S) intends to communicate with destination node (D), if an intermediate node (C) detects that its adjacent node (E) is disconnected, (C) holds

the data packet and activates the automatic repair mechanism to find another path to communicate with (D). The mechanism adopts a distance-based forwarding strategy, selecting an adjacent node (E) close to (C) as the next hop. If communication is possible, the packet is forwarded, and the unreachable link is replaced with a new one. If communication is not possible, node (J) reports the link error information to (S), and (S) restarts the route discovery process. The working principle of the automatic repair mechanism is shown in Fig 5.

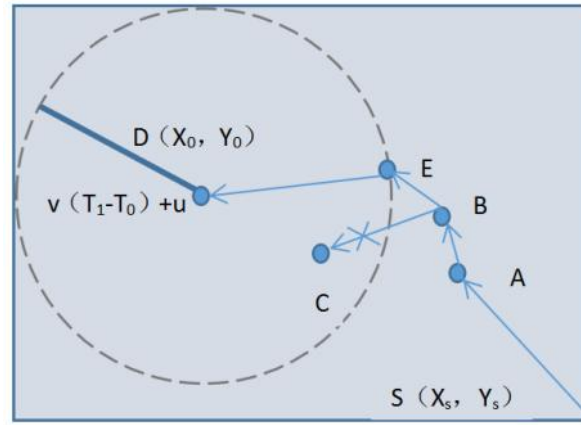


Fig. 5 Automatic repair mechanism of the optimized LAR protocol

4. Simulation Verification

This section simulates the performance of the optimized LAR protocol in a wireless Mesh network model using OPNET software, and conducts a comparative analysis with the AODV protocol and the original LAR protocol, which are commonly used in maritime wireless communication networks.

4.1 Scenario Setup

The simulation scenario is defined as a rectangular area of (M, N) (where both (M) and (N) are less than 100Km). The mobility model of the combat units is built based on AIS data provided by the Maritime and Port Authority of Singapore. Considering that the receiver in maritime wireless communication receives not only line-of-sight signals but also sea-surface reflected signals, the received signal is assumed to follow a Rice distribution.

4.2 Result Analysis

4.2.1 Packet Loss Rate

The simulation counts the packet loss rates of the optimized LAR protocol, the original LAR protocol, and the AODV protocol when communication links are broken with different numbers of combat units. A lower packet loss rate indicates higher reliability of the network routing protocol.

The variation of the packet loss rates of the three protocols with the number of interrupted nodes is shown in Fig. 6. It can be observed that the packet loss rates of all three protocols are positively correlated with the number of broken nodes. The optimized LAR protocol exhibits a significantly lower packet loss rate than the other two protocols, with a more gradual upward trend overall. This is because the optimized LAR protocol controls the packet loss rate by adopting an automatic repair mechanism.

4.2.2 Routing Overhead

The simulation results are presented in Fig. 7. The results show that the routing overhead of the optimized LAR protocol is far lower than that of the AODV protocol and slightly lower than that of the original LAR protocol. This is because both the optimized LAR protocol and the original LAR protocol adopt certain measures to limit the scope of packet broadcasting. In contrast, the AODV

protocol, when facing topology changes, traverses all neighboring nodes indiscriminately to discover new available routes.

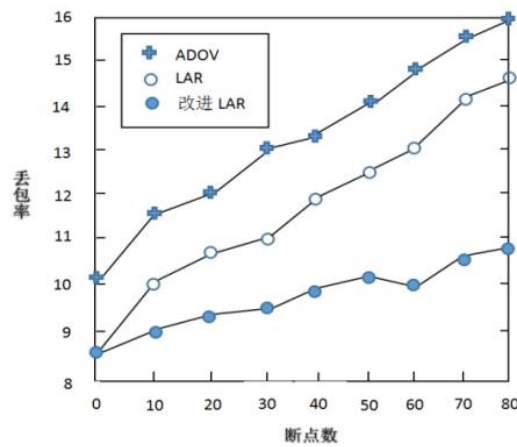


Fig. 6 Packet Loss Rate

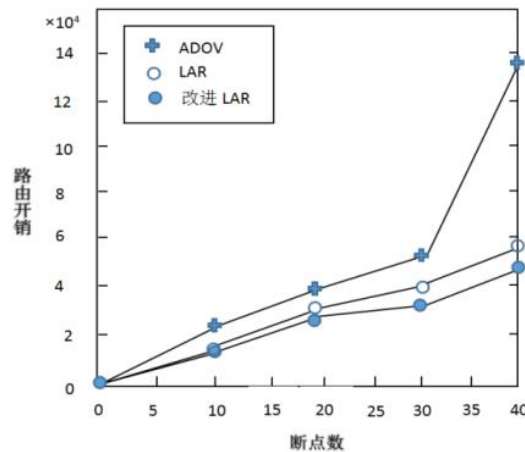


Fig. 7 Routing Overhead

4.2.3 Data Delay

The simulation results of node speed versus data packet delay are shown in Fig. 8. The results indicate that the packet delay of the optimized LAR protocol is lower than that of both the original LAR protocol and the AODV protocol, with a more gradual growth trend. This is because the optimized LAR protocol incorporates an automatic repair mechanism, which enables it to quickly utilize alternative routes after a link failure.

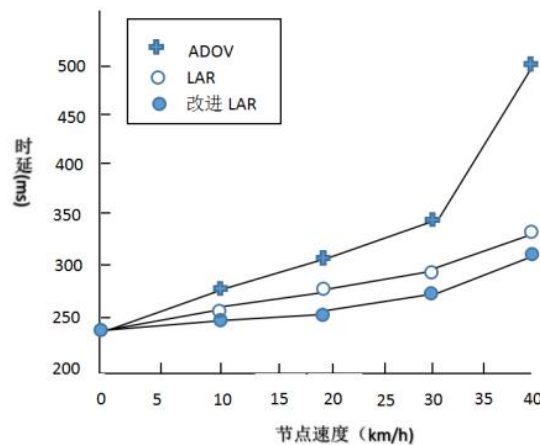


Fig. 8 Data Delay

5. Conclusion

In maritime military operations, combat units exhibit high mobility with unpredictable changes in direction and speed. They may move beyond the predetermined communication range, resulting in network disconnection. Therefore, the selected wireless routing protocol must possess robust capabilities to effectively address the aforementioned challenges.

Acknowledgements

This paper is supported by the fund project LJ20191C080686 (Research on Key Technologies for Constructing the Simulated Company Test Environment of Command and Communication Equipment for the Army Combined Arms Brigade).

References

- [1] Yang S. Research on Routing Protocols for maritime Mobile Ad-Hoc Network[D]. Dalian:Dalian Maritime University, 2011.
- [2] Zhong X, Ge D. Application of Mesh Networking in Wireless Cities[J]. Communication world,2012, (38) :32.
- [3] Chen X F. Research on Wireless Mesh Network Routing Protocols[D]. Xi'an:Xidian University, 2010.
- [4] Zhang Y, Mao Z Y, Liu X G. Research on Classic Link Data Link Channel Transmission Models and Characteristics[J]. Modern Electronics Technique, 2023,46(3):21-24.
- [5] Li W. Research on Jamming Techniques for Link 16 Data Link[D]. Xian:Xidian University, 2018: 2-3.
- [6] Du B Z, Bai H, Xue Q. Research on Test and Evaluation Methods for Performance Metrics of Measurement and Control Data Links[J]. Journal of Microwaves, 2023,39(4):95-100.