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An Efficient Opportunistic Routing Based on Prediction for Nautical Wireless Ad Hoc Networks

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Abstract: Nautical wireless ad hoc networks are becoming increasingly popular in oceans due to their easy deployment and self-curing capability. They may alternate frequently between connected mobile ad hoc networks and partitioned opportunistic networks due to mobility in large spaces. Traditional mobile ad hoc network routing is used to find the shortest route for connected networks. However, for opportunistic networks, routing schemes with a broadcast nature mainly exploit the reduction in message duplication and the local relaying technologies described in the literature, which may lead to unnecessary resource waste and low packet delivery ratios. To solve the problem, we propose an efficient opportunistic routing scheme based on prediction for nautical wireless ad hoc networks. The scheme first develops an effective candidate intermediate region to recognize the unavailability of some apparently qualified intermediate nodes, and then takes into account the packet reception ratio between nodes and relay advancement prediction, to improve packet delivery. The proposed scheme achieves performance improvements regarding packet loss ratio and throughput with a tolerable latency increase, compared to other schemes.

Keywords: opportunistic routing; nautical wireless ad hoc network; packet reception ratio; relay advancement prediction

1. Introduction

The oceans require reliable and stable network services due to rapid marine economy development and continuously growing human activities. The ocean contains more than 71% of the natural resources on Earth’s surface and includes an area of $3.62 \times 10^8$ km$^2$, with an average depth of 3682, 356,000 km of coastline and about 1.3 billion cubic kilometers of saltwater. Compared to terrestrial Internet, which can be conveniently accessed almost anytime and anywhere, these features mean that there are challenges in providing satisfactory services for the oceans. Nautical wireless ad hoc networks (NANETs) are self-organizing and self-healing networks with convenient and quick deployment, using any facilities to perform network functions on the water surface, such as vessels, buoys, ships and floating platforms [1]. They are expected to play an important role in oceans due to their cost-effectiveness.

The NANET is a super-scale dynamic network, and its networking scenarios may alternate frequently between connected mobile ad hoc networks (MANETs) and partitioned opportunistic networks (OppNets), since sparse user distribution and mobility behaviors lead to continuous changes in network topology. The traditional routing protocols designed either for MANETs or OppNets alone cannot adapt well to NANETs. Therefore, in [2], an adaptive strategy switching scheme is designed to adapt to such networking environments. The scheme proposes a corresponding switching strategy based on intelligent network recognition. For MANETs, a utility function is used to find the shortest route as quickly as possible. For OppNets, a forwarding mechanism is introduced based on the broadcast nature of wireless networks. However, blind broadcasting in OppNets leads to unnecessary
packet requests and waste of network resources, and thus low delivery ratios and communication throughputs. Therefore, it is necessary to improve the message transmission efficiency in dynamic nautical wireless ad hoc networks.

The contributions of this paper are summarized as follows:

• Transmission quality prediction. According to the propagation model in oceans, the packet reception ratio (PRR) is evaluated between the sender node and its relay nodes to represent transmission quality.

• Relay advancement prediction. To guarantee the maximum transmission of information, we predict the probability of relay advancement to detect the unavailability of some apparently qualified relay nodes.

• Combining transmission quality and relay advancement prediction, we propose a novel weight-based routing scheme with prediction for OppNets called WRSP, which selects high-priority nodes to forward the packets.

The rest of the paper is organized as follows. Section 2 introduces related work. Section 3 gives a detailed description of the proposed algorithm. The performance evaluation is given in Section 4. Finally, we conclude the paper briefly in Section 5.

2. Related Work

In OppNets, there is no direct route between the source node and destination node, since nodes are moving randomly at any time. Packets are transferred by intermediate nodes adopted by the “store–carry–forward” (SCF) mechanism. In SCF routing, a carrier node buffers the information until the carrier node has a chance to forward the information, and it must be able to buffer the information for a considerable time period, since there may not be an immediately available opportunity for the current carrier node to forward the information [3]. Currently, opportunistic networks are mainly applied in various fields such as wildlife tracking [4], disaster rescue [5] and vehicle-mounted monitoring networks [6]. The maritime opportunistic network introduces the opportunistic network into the marine environment. It has characteristics of both the opportunistic network and the marine environment [7]. In the maritime opportunistic network, vessels are regarded as mobile networking nodes, and packet transmission is dependent on the opportunistic contacts between vessels. Some schemes previously adopted in opportunistic networks are as follows.

In [8], to control the high overhead caused by unnecessary message transmission or redundant duplication, the authors proposed a message delivery algorithm for opportunistic networks that consists of two routing strategies: cooperative forwarding and store–carry–forward (SCF) forwarding. In the algorithm, communication nodes proactively detect and exploit possible contact opportunities to cooperatively forward messages. When information has never been cooperatively forwarded, SCF forwarding to control the resulting large number of messages is reactive. The adaptive switching of the two routing strategies solves the problem of message duplication. However, it leads to long delivery latency, specifically for messages that remain undelivered.

Considering the dynamic mobility and the characteristics of non-cooperative forwarding of nodes, the authors in [9] studied the influence of social selfish nodes on routing and forwarding. The proposed algorithm takes advantage of the social connection, historical encounter information and cache management to facilitate cooperative forwarding of messages between nodes and ensures the integrity of multimedia communication in partitioned opportunistic networks with social selfish nodes. The results showed that reliable transmission and effective routing communication of intermittently connected opportunistic networks was achieved, compared to other schemes. However, this method ignores the impact of environmental factors on the social relationships between nodes.

A novel opportunistic routing scheme based weight prediction that determines the routing decision of the relay nodes using a forwarding metric was proposed for unpredictable maritime wireless networks in [10]. The proposed method handles the high transmission overhead by collecting the latest-neighbor routing values between nodes and
reducing the resource consumption when keeping these messages. The method achieved higher packet delivery ratios and efficiency compared to other routing schemes.

In [11], the authors proposed an efficient routing algorithm based on node attributes for partitioned opportunistic networks in oceans that exploits the impact of node behaviors on encountering opportunities and the prediction of further relaying nodes. The results improved network performance compared to other schemes. However, the probability related to whether further relay nodes can be used for packet relaying is unknown and should be studied.

In [12], a reliable topology control was proposed, based on an opportunistic routing scheme that takes the message delivery ratio between a carrier node and its candidate relay set into account. In order to improve routing efficiency, the study introduced multi-metric considerations into the variable topologies. The results showed that the performance was greatly improved regarding transmission delay, the energy consumption and the communication throughput compared with other algorithms.

In [13], reliable delegation geographic routing was designed for disruption-/delay-tolerant networks. Delegation forwarding utilizes the time to intercept (TTI) to compare the currently encountered node and a historical node, and takes lifetime and node mobility information into account to overcome the limitation of local maximization, which solves the problem of the message relay decisions of traditional geographic metrics. The method was found to improve routing reliability and transmission efficiency with low transmission overhead.

The algorithms mentioned above mainly focus on optimizing the selection of local relay nodes via controlling local broadcasting to reduce the amount of replicated information to improve packet delivery. However, for partitioned OppNets, only optimizing local relays is not enough, because it is not known whether the currently selected relay node is capable of further forwarding, and this may lead to unnecessary packet requests and resource consumption. Therefore, it is essential to take into account not only the relay selection between the current node and its relay nodes but also the relay advancement prediction.

3. The Proposed Algorithm

3.1. Network Model

In our previous work on NANETs [2], a utility function for the connected MANETs was used to find the shortest route, in order to save network resources. However, for OppNets, a blind forwarding strategy leads to transmission delays and increased routing overhead. Therefore, improving packet routing efficiency for OppNets is our target in this paper.

In this paper, vessels acting as networking nodes are arbitrarily deployed over the sea. Each networking node with a communication function can transmit messages to another when the distance between nodes is within the corresponding communication range. For example, as illustrated in Figure 1, there is a communication requirement from source node $S$ to destination node $D$. The circle denoted by $C(S, R_S)$ represents the transmission range of node $S$, and node $S$ can transmit messages with node $i$ ($i \in \{1, 2, \ldots, N\}$) when $d_{Si} \leq R_S$, where the Euclidean distance $d_{Si}$ is calculated between node $S$ and node $i$, and $R_S$ is the communication radius of node $S$. Similarly, the circle $C(D, R_D)$ denotes the transmission range of node $D$, and $R_D$ is the communication radius of node $D$. If the direct relay node of source node $S$ is destination node $D$, the packets are directly delivered to node $D$ (e.g., $t = t_1$ in Figure 1). Otherwise, the packets are further forwarded by future relay nodes (e.g., $t = t'_1$ in Figure 1) until they reach the destination node. However, not all relay nodes in the communication range can participate in message forwarding; therefore, in order to improve the efficiency of packet relaying, the candidate intermediate region is defined as follows.
Figure 1. An example of packet routing with node mobility.

Definition 1. The intersection region of two communication circles with radii $R_S$ and $R_D$ centered on node $S$ and node $D$ of $C(S, R_S)$ and $C(D, R_D)$, respectively, is defined as the candidate intermediate region of node $S$ for sending a message to destination node $D$, as illustrated in Figure 2 (sector SAB).

Figure 2. The network model for opportunistic routing.

Only a node in the candidate intermediate region is likely to be selected as a relay, and therefore the node degree of the carrier node is defined as the number in the transmission range of the carrier node. However, it is noted that not all the candidate intermediate nodes
can forward data messages in WRSP; thus, the intermediate node degree of carrier node is defined as follows.

**Definition 2.** Assume the node \( i \) has an initial location \((X_i, Y_i)\) and is moving with speed \( V_i \) and direction \( \theta_i \) at time \( t_{cur} \). The speed and direction vary by random variables \( V_i \) and \( \theta_i \) in a time interval \( \Delta t \). In addition, \( V_i \in [0, 10 \text{ km/h}] \) and \( \theta_i \in [-30^\circ, 30^\circ] \). The position of the node \( i \) after time interval \( \Delta t \) is expressed as:

\[
\begin{align*}
X_p^i &= X_i + (V_i + \text{randi}(V_i)) \cos(\theta_i + \text{randi}(\theta_i)) \Delta t \\
Y_p^i &= Y_i + (V_i + \text{randi}(V_i)) \sin(\theta_i + \text{randi}(\theta_i)) \Delta t
\end{align*}
\]

(1)

where \( X_p^i \) and \( Y_p^i \) are the predicted coordinates.

The candidate intermediate region of node \( S \) is defined as \( CR_{S \to D}(S, d_{DS}) \), which is given by:

\[
CR_{S \to D}(S, d_{DS}) = \{1, 2, \ldots, i, \ldots, N | d_{Di} \leq d_{DS}\}
\]

where \( d_{Di} \) is the Euclidean distance between node \( D \) and node \( i \). Moreover, the next time interval of neighbors should meet the criterion \( \{d_{pDi} \leq d_{Di}\} \), where \( d_{pDi} \) is the predicted Euclidean distance between node \( D \) and next predicted location of node \( i \). As an example, in Figure 2, the intermediate nodes of node \( S \) are neighbor 1 to neighbor 6. However, in the light of Definition 2, only neighbor 3, neighbor 4 and neighbor 6 in the candidate intermediate region (the red area) are selected as the intermediate nodes to forward messages.

**Definition 3.** We define the intermediate node degree as the number of intermediate nodes in the candidate set whose distances and predicted distances to the next hop nodes are less than the current nodes and corresponding intermediate nodes, denoted by \( \eta_{rel} \).

For instance, Figure 2 shows that the neighbor degree of node \( S \) is 6; however, the intermediate node degree is 3, according to Definition 3.

### 3.2. The Description of WRSP

#### 3.2.1. Transmission Quality Prediction

In dynamic nautical wireless ad hoc networks, the distances between communication nodes are constantly changing as the nodes move. According to the marine wireless propagation model introduced in [14], the signal strength of the receiver is also changing. Furthermore, ambient noise also makes the received signal strength change frequently, even if the distance between communication nodes is the same. The signal power at the receiver can be calculated by:

\[
Pr(d) = P_{tr} - P_{pl}(d_0) - 10\phi \log_{10}(\frac{d}{d_0}) - \gamma
\]

(2)

where \( P_{tr} \) is the transmitting power, \( P_{pl}(d_0) \) denotes the average path loss at a reference distance \( d_0 \), \( \phi \) is the path loss constant, and \( \gamma \) is the Gaussian white noise, with \( \gamma \sim (\mu, \delta^2) \).

The received signal power has a direct influence on the packet reception ratio (PRR) for the receiver. We utilized the PRR to evaluate the transmission quality between two networking nodes. The PRR given by a theoretical model [15] is:

\[
P_{prr} = (1 - \frac{1}{2} \exp^{-\frac{Pr(d) - P_0}{2C_f}})^{8C_f}
\]

(3)

where \( Pr(d) \) denotes the signal power at the receiver for a distance \( d \), and \( P_0 \) and \( C_f \) are the noise power and carrier frequency, respectively.
3.2.2. Relay Advancement Prediction

The packet is transmitted from the carrier node to its intermediate nodes based on the packet reception ratio, and the packet must be broadcast further. Therefore, the relay advancement prediction is introduced. The definition of the intermediate node degree was given in Definition 3. When the nodes are deployed in the relay region, the probability for a carrier node that the number of relay nodes is \( n_{\text{rel}} \) is given by [12]:

\[
P_{\text{rel}}(n_{\text{rel}}) = \left( \rho \Omega \right)^{n_{\text{rel}}} / n_{\text{rel}}! e^{-\rho \Omega}
\]

where \( \rho \) is the node density and \( \Omega \) denotes the coverage region of node \( S \) and can be described as: \( \Omega = \pi R^2_S \). However, not all coverage regions of the carrier node are considered to participate in the node selections of the candidate relay set. Therefore, the calculation of \( \Omega \) is not reasonable, and it must be recalculated.

As shown in Figure 2, according to Definitions 2 and 3, the coverage region \( \Omega \) is recalculated by:

\[
\Omega = S_a + S_b + S_c
\]

where \( S_a \) denotes the area of sector \( SDB \), and \( S_b \) and \( S_c \) are the areas of sector \( SCD \) and the shadow area, respectively.

Figure 2 shows the intersection region of the two circles \( C(S, R_S) \) and \( C(D, d_{DS}) \) (red line), where \( R_S \) and \( d_{DS} \) are the communication ranges of node \( S \) and the Euclidean distance between node \( D \) and node \( S \), respectively. Hence, the length of the line \( DB \) is equal to \( d_{DS} \). Thus, for the isosceles triangle \( SDB \), the angle \( \theta_{SDB} \) is expressed as:

\[
\theta_{SDB} = \arccos \left( \frac{R_S}{2d_{DS}} \right)
\]

Therefore, the area of \( S_a \) is calculated by:

\[
S_a = \frac{1}{2} R^2_S \arccos \left( \frac{R_S}{2d_{DS}} \right)
\]

Similarly, for calculation of angle \( SDB \), angle \( S13 \) and angle \( DS3 \) are:

\[
\theta_{S13} = \arccos \left( \frac{d_{1S}^2 + d_{3S}^2 - d_{13}^2}{2d_{1S}d_{3S}} \right)
\]

\[
\theta_{DS3} = \arccos \left( \frac{d_{3S}^2 + d_{DS}^2 - d_{DS3}^2}{2d_{3S}d_{DS}} \right)
\]

Therefore, the area of \( S_b \) is the area of sector \( SCE \), which is calculated as follows:

\[
S_b = \frac{1}{2} R^2_S \left\{ \arccos \left( \frac{d_{1S}^2 + d_{3S}^2 - d_{13}^2}{2d_{1S}d_{3S}} \right) \right\} + \arccos \left( \frac{d_{3S}^2 + d_{DS}^2 - d_{DS3}^2}{2d_{3S}d_{DS}} \right)
\]

The area of \( S_c \) is the area of sector \( SDB \) minus the area of isosceles triangle \( SDB \), which is described as:

\[
S_c = \frac{1}{2} R^2_S \left\{ \pi - 2\arccos \left( \frac{R_S}{2d_{DS}} \right) \right\} - \sin \left\{ \pi - 2\arccos \left( \frac{R_S}{2d_{DS}} \right) \right\}
\]
Hence, the value $\Omega$ of the intermediate node region is expressed as:

$$\Omega = \frac{1}{2} R_S^2 \left\{ \arccos \left( \frac{R_S}{2d_{DS}} \right) + \arccos \left( \frac{d_{1S}^2 + d_{3S}^2 - d_{13}^2}{2d_{1S}d_{3S}} \right) + \arccos \left( \frac{d_{2S}^2 + d_{DS}^2 - d_{23}^2}{2d_{2S}d_{DS}} \right) + \left( \pi - 2\arccos \frac{R_S}{2d_{DS}} \right) - \sin \left( \pi - 2\arccos \frac{R_S}{2d_{DS}} \right) \right\}$$

(11)

To effectively reflect the relay possibility of the carrier nodes forwarding data messages to the destination, we define a new metric $P_{FD}$, which can be given as follows:

$$P_{FD} = \alpha P_{prr} + \beta P_{rel}$$

(12)

where $\alpha$ and $\beta$ are the weight factors of the packet reception ratio and the relay advancement prediction of the relay possibility of the node, respectively. The larger the value of $P_{FD}$, the more likely it is that the node will be selected to participate in relaying messages.

### 3.3. Routing Decision Scheme

During packet delivery, an efficient routing scheme can improve the success delivery ratio of message forwarding. In the scheme below, we utilize $F_{N_n}$ to denote the neighbor sets of node $N_n$, where $F_{N_n}^m$ indicates the message sets carried by node $N_n$. In Algorithm 1, when a link does not exist in the networks, the sender or carrier node $N_S$ will broadcast routing messages. If node $N_l$ ($N_l$ is the relay node of node $N_S$, and $N_l \in N_n$) is the destination node $N_D$, the messages are directly transferred from node $N_l$ to the destination node $N_D$ (Algorithm 1: line 5). If the intermediate node $N_l$ still needs to broadcast messages, relay advancement prediction to the destination node is introduced. Equation (12) is further used to make decisions on relay node selection (Algorithm 1: line 9). Otherwise, the link between node $N_l$ and its next hop is available, and the routing strategy is switched to the MANETs routing described in [2] to select the appropriate relay node (Algorithm 1: line 11). Finally, the messages are delivered hop by hop until the destination node is close and eventually to the destination node itself.

**Algorithm 1: WRSP routing algorithm**

Begin

1. for each message $m \in F_{N_n}^m$ do
2. \hspace{1em} for each node $N_l \in F_{N_n}$ do
3. \hspace{2em} for sender $S$ broadcasts messages to its neighbors do
4. \hspace{3em} if $N_l = N_D$ then
5. \hspace{4em} $N_l$ transmits directly messages $m$ to $N_D$
6. \hspace{3em} else
7. \hspace{4em} while $P_{prr}(N_S(m), N_l(m)) > 0$ do
8. \hspace{5em} if node $N_l$ still needs to broadcast messages to its neighbors then
9. \hspace{6em} Equation (12) is used to make decision on relay node selection
10. \hspace{5em} else
11. \hspace{6em} the routing strategy is switched to the MANETs routing in [2] to select the relay nodes
12. \hspace{4em} end if
13. \hspace{3em} end while
14. \hspace{2em} end if
15. \hspace{1em} end for
16. \hspace{1em} end for
17. \hspace{1em} end for

End
4. Performance Evaluation

The simulations are executed for the source node, and the destination node can be randomly designated. The nodes participating in the message forwarding do not have malicious functions. In the experiments, the proposed scheme introduces the movement of nodes and a propagation model into marine networking communication for transmitting data packets. The network simulator ns-3 was used to perform the experimental analysis, combining the proposed routing scheme and the characteristics of nautical wireless ad hoc networks. The deployment region was $1000 \times 1000$ km, and the initial communication range of the nodes was $100$ km. The packet size was 2048 bytes, and the message rate was $150$ kbps. The traffic source type was constant-bit-rate traffic, and the packets were generated at a fixed interval rate with a simulation time of $100$ s.

To validate the effectiveness of our proposed scheme (WRSP), we conducted comparative experiments with ad hoc on-demand distance vector (AODV) [16] and PASS (only broadcast packets for OppNets) [2] methods. The evaluation and experimental analysis are described as follows.

4.1. WRSP Parameters

As shown in Equation (12), the parameters $\alpha$ and $\beta$ have a direct influence on routing decisions. We defined 10 combinations with different values, as shown in Table 1.

<table>
<thead>
<tr>
<th>Combination #</th>
<th>$\alpha$</th>
<th>$\beta$</th>
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<tbody>
<tr>
<td>1</td>
<td>0.1</td>
<td>0.9</td>
</tr>
<tr>
<td>2</td>
<td>0.2</td>
<td>0.8</td>
</tr>
<tr>
<td>3</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>0.4</td>
<td>0.6</td>
</tr>
<tr>
<td>5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>6</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>7</td>
<td>0.7</td>
<td>0.3</td>
</tr>
<tr>
<td>8</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>9</td>
<td>0.9</td>
<td>0.1</td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
<td>0</td>
</tr>
</tbody>
</table>

From Figure 3, we can see that the packet loss ratio performance and throughput of combination #10 was the worst. This is because it gives all the weight to the packet reception ratio, i.e., the relay node with the largest value of the reception ratio is always selected without considering any other information. This is not sufficient to evaluate whether the packet can continue to be forwarded, since it does not take into account the prediction of future relay nodes. Thus, it leads to high packet loss ratios and low throughput. We can observe that performance improves significantly when relay advancement prediction is considered ($\beta \neq 0$), since the link may be available for a very short time owing to the dynamic movement of nodes. Furthermore, the best packet loss ratio performance and throughput is reached when the values of $\alpha$ and $\beta$ are those in combination #4. These values were used in the experiment by default, unless specifically mentioned.
4.2. Performance Comparison with AODV and PASS

In this section, we compare the WRSP routing scheme with AODV and PASS schemes under different node densities. The results and analysis are shown as follows.

Figure 4a shows the comparison results for the packet loss ratio. As expected, the packet loss ratio of all schemes improves as the node density increases, since more nodes means more chances of forwarding, and thus a lower packet loss ratio. However, compared to the blind flooding strategies with redundant replications of AODV and PASS, the proposed routing scheme predicts the transmission quality between nodes and the relay advancement to jointly reduce the number of aborted messages for apparently qualified relay nodes. Thus, the WRSP has the lowest packet loss ratio.

From Figure 4b, we can see that AODV and PASS have lower throughput than WRSP routing. This is because the WRSP makes decisions on relay node selection by combining transmission quality evaluation and the probabilistic prediction of a relay node forwarding packets to the destination node. In contrast to blind broadcasting to its neighbors, as in AODV and PASS when a link is unavailable between nodes, WRSP not only avoids the unnecessary packet requests of senders but also predicts when the relay advancement indicates the packet cannot be forwarded further. Therefore, the proposed scheme has higher throughput than other routing schemes.

As shown in Figure 4c, the average latency of the three schemes improves as the node density increases, because the existence of more nodes implies more intermediate nodes for selection, and thus higher average latency. Since the proposed scheme always tries to find a good forwarder with respect to each hop, it checks the ability of the forwarder to reach the destination node; thus, the average latency is the highest. However, in addition to an 18.92% and 10.12% increase in latency, the proposed scheme achieved 32.0% and 21.14% lower packet loss ratios and 31.79% and 20.85% more throughput than AODV and PASS routing schemes, during data transmissions. We feel that tolerating a delay that improves packets delivery greatly is a good trade-off.
Figure 4. Comparison of different schemes. (a) Packet loss ratio vs. node density. (b) Throughput vs. node density. (c) Average latency vs. node density.

5. Conclusions

In this paper, we developed an efficient opportunistic routing based on prediction for nautical wireless ad hoc networks for the first time, to the best of the authors’ knowledge. For unavailable links of opportunistic networks, the proposed scheme takes into consideration transmission quality evaluation and relay advancement prediction to improve message forwarding. The results demonstrated that the proposed scheme achieved performance improvements with respect to packet loss ratio and throughput compared to other schemes. Due to the sparse distribution of nodes and the complexity of marine environments, the selections of intermediate nodes are easily affected during message transmission, and therefore the average latency becomes longer. However, we feel that the additional delay in a scheme that greatly improves routing performance is a good trade-off. In future work, intelligent routing strategies will be further explored to reduce latency as much as possible, while ensuring routing efficiency.

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**References**

11. Ge, L.; Jiang, S. An Efficient Routing Scheme Based on Node Attributes for Opportunistic Networks in Oceans. *Entropy* 2022, 24, 607. [CrossRef] [PubMed]