A Routing Protocol based on Temporal-awareness Ordered-MPR for Dynamic Wireless Multi-hop Mobile Networks

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Abstract—Dynamic mobile Wireless Network is one important infrastructure for special environment or special applications. High delay and low delivery ratio are its major challenges because of the absence of a complete end-to-end path between source nodes to destination nodes. Although some protocols have been proposed, they usually ignore the action diversity, communication time and duration. In this paper we present a temporal-awareness dynamic routing protocol using order MPR (Multi Point Relays) methods for wireless multi-hop mobile networks. Ordered MPR is the minimum set of nodes that could connect one node’s 2-hop neighbors, in which nodes are ordered by temporal information. Each node has its order MPR and it could update it adaptively with some adaptive rules. When transferring data, the node selects nodes with higher evaluation value from its MPR to relay. Because of the dynamic topology and to avoid the local decision ineffectiveness, we make the node also select one node from non MPR randomly at the same time. Experiments show that our method can not only reduce the average end-to-end delay but also improve the delivery ratio.

Index Terms—wireless multi-hop mobile networks, temporal-awareness opportunistic routing, order MPR, mixture strategy

I. INTRODUCTION

PDAs, cell phones, FRID, wireless mobile sensors and other mobile devices have become increasingly popular in recent years. They form new networks, such as Pocket Switched Network (PSN), Internet of Technology (IoT) or Internet of Vehicle (IoV). In these networks, objects move and the communication relationship is always changing with time. For their mobility every object can get different information and they can transfer information by multi-hops [1]. Thus Dynamic Multi-hop Wireless Networks [2][3][4][5] is needed. Objects’ cooperation could not only improve the effectiveness of intelligent controlling and decision, but also reduce transfer load on backbone.

In dynamic multi-hop wireless networks, node mobility causes network topology changing. Flooding or broadcast is one feasible way to announce new update information. But available bandwidth in wireless network is limited. Flooding will lead a very high network overhead and then cause traffic congestion. Moreover, multi-hop transmission makes delay. So designing novel protocol with low delay and low bandwidth is necessary for dynamic multi-hop wireless networks.

II. RELATED WORK

In dynamic multi-hop wireless networks, communication happens when nodes move closely. This communication method is opportunistic routing. Some opportunistic routing protocols have been proposed. They can be divided into five categories: shortest path based routing protocol, end-to-end iterating, geographic location, network encoding and multi-copies transfer.

ExOR (extremely opportunistic routing) [6] is one protocol based on shortest path. It uses expected transmission count, shortest ETX between nodes as metric, selects candidates and prioritizes them by counting path cost. Due to no feedback, node would receive duplicate packets. SOAR (Simple Opportunistic Adaptive Routing) [7] limits the node selection to those close to the unicast shortest path to avoid routing diverging. It mitigates the effect of reduplicate packets, but it does guarantee forwarding efficiency.

LCOR (the least-cost opportunistic routing) [8] is one protocol based on end-to-end iterative. It enumerates all neighbor nodes to find the best forwarding candidates by cost evaluation. When the average degree of nodes is high, it will cause excessive iteration and larger computation. OAPF (Opportunistic Any-Path Forwarding)
algorithm [9] filters out nodes with lower ETX to destination than source, select nodes that maintain small Expected Any-path Transmission Counts (EAX) iteratively. However, it needs more computation and increases overload.

Base on geographical location, in GeRaF (geographic random forwarding) [10], node decides its preference and priority of forwarding nodes. This reduces the cost of maintaining network topology in routing table. However, geographic distance between nodes does not always truly reflect the performance of routing path and influence the forwarding accurate rate.

We propose an adaptive routing protocol based on temporal-awareness order. In this paper we choose the next hop. And make its decision adaptively. This strategy could reduce overload and increase success delivery rate.

From the above analysis, we can see that dynamic topology and high local computation are the principle problems in present research work. In this paper we propose an adaptive routing protocol based on temporal-awareness order MPR (Multi Point Relays). In this protocol, node chooses next hop nodes from its order MPR based on its ranking and non MPR randomly. When network topology changes, nodes could update its MPR and make its decision adaptively. This strategy could reduce overload and increase success delivery rate.

The main contributions of our paper are the following:

A local network topology model is put forward.

B We build a temporal-awareness order MPR model and its creation algorithm.

One routing protocol is proposed that based on order MPR and random strategy.

The rest of this paper is organized as the following. Next section we propose a routing protocol based on temporal-awareness order MPR. In section 4, the performance of our protocol is evaluated by some experiments, and section 5 some conclusions are given.

III. A TEMPORAL-AWARENESS ROUTING PROTOCOL BASED ON ORDER MPR

A. Basic Definitions and Models

Firstly we build the communication network model that includes global network model and local network model.

1 Global network model

Definition 1: The global network model for wireless mobile network is a network sequence with timestamps, that is \( G = \{G_1, G_2, \ldots, G_m\} \), \( G_i \) is the \( i \)-th network topology. The model for \( G_i \) is

\[
G_i = (V_i, E_i) \quad V_i \cup D = V
\]

\( V \) is the node set at the \( t \)-th time window. In mobile communication environment there are mobile nodes and stable nodes. Stable nodes usually are Accept Points and in different times we can think they are same, so we term them as \( D \) or \( D' \). Observed networks in different times consists of different mobile nodes and we term them as \( V' \). \( E' \) is the meeting frequency sum of \( V' \) at \( t \)-th time.

2 Local network model

In mobile networks each node cannot observe the global network topology. It only has its local view about the network and the view will continually change with time. Because of limited storage capability and limited decision requirement, we build local network model without timestamps. But that does not mean we abandon the historical information. We just design some mechanism using new view updating old view and then local network topology is always the newest topology view.

Definition 2: local network model (LNM)

Local network model is a model describing the network information one node can get. In wireless mobile network, nodes get information by communication and the local network model consists of the communication history. That is the node and its 1-hop neighbor nodes.

We give the definition of 1-hop neighbor set and 2-hop neighbor set for node \( A \).

\[ A_{1-hop} = \{a | a \in V', E'(A,a) \neq 0\} \]

\[ A_{2-hop} = \{a | a \in V \land A_{1-hop} \} \]

Definition 3: the profile of node is the following vector:

\[ \text{profile} = (\text{ID}, \text{meetF}_{[1-hop])} \]

\( \text{ID} \) is the node identifier, \( \text{meetF} \) is the meeting time between this node and any destination node in set \( D_{\{1-hop\}} \) is the set of the node’s 1-hop neighbors. Taking node \( A \) as an example,

\[ \text{profile}_A = (\text{A.ID}, \text{meetF}_{A,D}, A_{1-hop}) \]

For each node in set \( \{1-hop\} \), it has the following structure:

\( \text{ID}, \text{meetF}_{[1-hop,ID]}, \text{neighN}, \text{meetD}, \text{max Dur} \)

\( \text{ID} \) is the node’s identifier, \( \text{meetF} \) is the meeting time.
between the owner node and this neighbor, \(1-hop.ID\) is the ID set of this node’s 1-hop neighbors, neighN is the size of \(1-hop.ID\), meetD is the meeting frequency between this node and destination, maxDur is the max meeting duration between the owner node and this node. For example, there is one node \(a\) that is the direct neighbor of \(A\), \(a \in A\_hop\), its information in local network model is:
\[
a = (a.ID, meetF_{A.a}, \{a\_hop.ID\}, \text{neighN}, \text{meetD}, \text{maxDur})
\]

Fig1 is one instance of local network model for node \(A\).
According to node’s 1-hop neighbor set, nodes can share their communication history and from \(LNM\) we can draw the node neighbors within 2 hops. We give the formal definition of \(LNM\) as definition4.

**Definition 4:** Formal model of \(LNM\)
\[
g_{A} = (V, E)
\]
\[
A \cup A_{-hop} \cup A_{2-hop} = V
\]
\[
E_{i,j} \cup E_{i,j}^{'} = E
\]
\[
E_{ij}^{'} = \text{meetF}_{A_{ij}}^{'}\quad E_{ij}^{'} = 1
\]

- **Temporal-awareness order MPR**

In dynamic mobile multi-hop wireless network, node mobility leads network topology changing. Nodes need broadcast their updated relationship to others. That updated information broadcasts quickly will help node make correct routing decision. However, excessive broadcasting will waste available bandwidth in wireless network. The opportunistic routing protocol we present can reduce the flooding impact and works well in dynamic networks. We base on MPR [14] and propose ordered MPR model.

**Definition 5:** MPR (Multi Point Relays) is the node set for one node, which is its minimum 1-hop set covering its whole 2-hop neighbors.

**Definition 6:** order MPR is a node sequence ordered by some standards in MPR.

Take node \(A\) as example,
\[
\text{AMPRI} = \arg \min \{d_{a}, d_{a}, \cdots, d_{a} | d_{a} \in A_{-hop}, \bigcup_{i} d_{a} \supseteq A_{2-hop}\}
\]
\[
\text{Aorder \_MPRI} = \{d_{a}, d_{a}, \cdots, d_{a} | d_{a} \in AXPR\&a \succ a^{i}, i = 1, 2, \cdots, n\}
\]

MPR aims at reducing bandwidth overload by offering effective transfer nodes. But in mobile multi-hop wireless network, neighbor nodes continue changing, such as new nodes enter and old nodes escape. To get more communication covering ratio, action diversity is another important factor. In our \(LNM\) we recode the meeting frequency and meeting duration time between nodes. These elements can uncover nodes’ action diversity. Based on these observations we improve MPR model and build a new Temporal-awareness ordered MPR (ToMPR).

There are two important algorithms in our ToMPR, which are Neighbor area un-overlapping Ratio(abbr. \(\text{NuoR}\)) and Diversity evaluation(abbr. \(De\) ) t. Neighbor area un-overlapping ratio \(c\) is to evaluate the covering ratio and we set it as \(c = |a_{-hop} - A_{-hop}|\). Diversity evaluation is based on the meeting frequency and max meeting duration time between nodes.
\[
De() = \text{meetF} \times \frac{\text{maxDur} / \text{ID}}{\text{ID}}
\]

We design the sorting rule \(>\) is the following:
\[
f((a' .c > a'.c) \& (a'.t < a'.t & & a'.c == a'.c))
\]
\[
\text{then} a' > a'
\]
\[
\text{else} a' < a'
\]

In detail, we set Neighbor area un-overlapping ratio priority and then meeting times and meeting duration second. That is, nodes with short meeting time and large NuoR have precedence over that with short meeting time and small NuoR, nodes with short meeting time and small NuoR have precedence over that with long meeting time and small NuoR.

The following is the node \(A\)’s ordered MPR information.

<table>
<thead>
<tr>
<th>ID</th>
<th>(\text{meetF})</th>
<th>(\text{maxDur}) (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>{E,F,G}</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>{D,N}</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>{Y,H,E,C}</td>
<td>3</td>
</tr>
<tr>
<td>E</td>
<td>{B,D,J}</td>
<td>3</td>
</tr>
</tbody>
</table>

**Table.1. The ordered MPR of node A**

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B. An Opportunistic Routing based on Ordered MPR

Based on these definitions we design an opportunistic routing protocol for Multi-hop network and term it as TAMOP. The two important parts in it are building ordered MPR and selection the forwarding nodes.

- Building order ToMPR

The general method for getting MPR is greedy
algorithm. But it is a NP-hard problem. Some improved studies have been done. In open real world, nodes set and node relationship are not fixed. MPR is then not fixed. So it will be a better optimal to get MPR using greedy method based on observed latest communication events.

We design the algorithm of building MPR for one node based on greedy method. The detailed procedure is shown as Fig. 2.

### Building order MPR for node A

**Input**: An arbitrary node.

1. Neighbor[]: Hop neighbor set of node A.
2. \( \text{N} \) represents the hop node x connects node y.
3. \( \text{meetF(x)} \) represents the meeting times between node i and j.
4. \( \text{Dur}(x) \) represents the max duration time between node i and j.

**Output**: MPR set [M].

**Procedure**:

1. **Step 1**: finding MPR
   - \( M \rightarrow \text{null} \)
   - Sort ANeighbor[] based on the hop neighbor set of ANeighbor[J] - N and the descendant.
2. i = 1; \( k = 0; \)
3. While N2 = null && \( i = n \)
4. \( m[k] \rightarrow \text{AnMei}[] \)
5. \( N2 \rightarrow \text{the hop neighbor of ANeighbor[J]} ; \)
6. i = i + 1;

**Step 2**: sort MPR

Sort [M], based on \( \text{Dur}(x) = \text{meetF(x)} \times \text{maxDur}(x) / \text{ra} \).

End

### IV. EXPERIMENTS AND ANALYSIS

We conducted several simulation experiments in two groups to study performance of the proposed algorithm. In the first group of our experiments, we investigate the effectiveness of the TAmOP in terms of the nodes set size as compared with the AODV algorithm. In the second group, we measure the performance of the TAmOP in terms of the speed of nodes mobility, and compare the obtained results with those of AODV algorithm.

We use NS2 to evaluate the performance of TAmOP and present the results. In simulations, the assumptions and parameters are as follows. (1) The simulation area is 1200m * 1200m. (2) Nodes are uniformly distributed in the simulation area. (3) The simulation time lasts 400s. In the same simulating scenario, comparing with AODV algorithm, we compare the two algorithms on its average delay, delivery ratio, packet losing ratio and route load.

#### A. The impact of the network size

In this scenario, we evaluate the performance of TAmOP and AODV when the number of nodes increases from 20 to 200 and node mobility speed is 30m/s. The average delay and delivery ratio are shown as following.

- **Average delay**
  
  Average delay is the duration of packet from source to destination. Fig. 3 offers an insight into the average delay of TAmOP and AODV with alterable nodes size. In fig. 3, it is clear that the average delay of AODV protocol is slightly higher than that of TAmOP. That is because TAmOP calculates the ordered MPR quickly. Since TAmOP utilizes nodes local information to select forwarding nodes, the average delay is relatively stable with the node number increasing. Because AODV works basing on network information, the average delay of AODV increases with the number of nodes increment.

- **The delivery ratio**
  
  The delivery ratio equals to the value of the number of data packet reception dividing the number of data packet transmission. We give the delivery ratio comparisons of TAmOP and AODV in Fig. 4. As shown in Fig. 4, the two

![Fig. 3 the average delay for different size of the nodes set](image-url)
algorithms decline with the increment of the number of nodes. It is observed that the more the number of nodes is, the lower the delivery ratio is. Overall, TAmOP is better than AODV in the packet transmission. Because of selecting the forwarding nodes, TAmOP can utilize the MPR nodes and rank these nodes, and ensure a precise route. That is, TAmOP can calculate route according to the local information of each node, however AODV need the network information to ensure route, it is no doubt that AODV expends much higher cost of routing, so the performance of TAmOP is superior to AODV protocol on the delivery ratio.

![Fig. 4 the delivery ratio for different size of the nodes set](image)

**B. Impact of the Speed of Nodes Mobility**

For this scenario, the speed of nodes mobility is increased from 5 m/s to 25 m/s, and the number of nodes is 50. The simulation results are as following:

- **The average delay**

  Fig.5 shows the average delay of all the packets in simulation, under different maximum mobility speed of nodes. As shown in Fig. 5, the average delays of the two algorithms increase with the speed of nodes mobility increasing, that is due to the increasing of speed of nodes strengthen the dynamic of the network, the route need to be frequently reconstructed during the nodes communication, so the average delay increases. But the average delay of TAmOP algorithm is lower than that of AODV. Because in TAmOP algorithm, nodes can select the best forwarding node in a shorter time by ranking the MPR nodes, and reduce the time of the route reconstruction, eventually, reduce the average delay from end to end.

![Fig. 5 the average delay for different speed of nodes](image)

- **The packet losing ratio**

  The packet losing ratio reflects the reliability of routing protocol. The smaller the value is, the more reliable routing protocol is. Fig.6 shows the relationship between losing ratio and nodes mobility.

![Fig. 6 the packet losing ratio for different speed of nodes](image)

V. **CONCLUSIONS**

In this paper we presents a dynamic routing protocol based on ordered MPR for redundant transmitting in Dynamic Multi-hop Wireless Network. Selecting the forwarding nodes in temporal-awareness ordered MPR or non-MPR, both strategies complement each other in order to increase the transmission ratio in a shorter time. Our simulation experiments show that the routing protocol we proposed has a better performance with the number of nodes increment and modifying the speed of nodes mobility.

In future, we will improve our TAmOP to reduce routing load and discovering social information to design new protocols.

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