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Heuristic Routing Protocol Research On Opportunistic Networks

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Abstract—**Opportunistic network is a kind of ad hoc networks which exploits the nodes' meeting opportunities to transmit messages. Routing protocols have a great impact on the efficiency of data transmitting in opportunistic networks, but common routing protocols are usually not adaptable to different opportunistic networks due to the complex and unstable network topology. First introduce formal definitions of the opportunistic networks characteristics, and then propose a serious heuristic rules for data forwarding. Experimental result shows that the heuristic rules have better performance than dissemination based routing protocol and PROPHET protocol.**

Keywords-opportunistic networks; heuristic; routing protocol

I. INTRODUCTION

Connected topology is a basic request in classical networks, which means when the messages transmit from the source node to the destination node, an end-to-end path exists between them. However, as the mobile ad hoc networks are developing rapidly, the structure of networks has become much complex and unstable. In some situation, the network connectivity can not be guaranteed, but the moving nodes have the opportunity to meet other nodes, and then the messages may be transmitted from the source node to the destination node by taking advantage of the meeting opportunities. Therefore, a new type of network is described as: "The nodes of the network exploit the meeting opportunities with others to transmit messages while the topology of the network is disconnected.", and this type of network is called "opportunistic networks"[1].

Due to the diversity of the network form, there are numerous applications of opportunistic networks, such as ZebraNet[2] (for tracking Zebras), SWIM[3] (for tracking whales), PSN[4](for pocket wireless devices), CarTel[5](for in-vehicle devices), etc. Thus, opportunistic network is a valuable and potential research field.

In opportunistic networks, routing and data forwarding proceed at the same time: a node forwards a message to another node while the forwarding becomes a hop of routing. So "data forwarding schemes" and "routing protocols" are the same meaning in opportunistic networks. Routing protocols have a great impact on the efficiency of data transmitting in opportunistic networks, so researching on routing protocols is very important.

Usually, a certain protocol can not adapt various opportunistic networks, and has quite different performance among them (e.g. "Spray and Wait" scheme performs badly when nodes move slowly or mainly in a small space[6]). There are plenty of routing protocols proposed recently to improve the efficiency of data forwarding, such as PPSW (Position Prediction-based Spray and Wait)[6], PreS(Predict and Spread)[7], TBR(TTL Based Routing)[8], CiPRO(Context information prediction for social-based routing technique in OppNets)[9] and PROPHET(Probabilistic ROuting Protocol using History of Encounters and Transitivity)[10].

In this paper, we propose a series of heuristic routing protocols for the complex and unstable network topology, and then evaluate the efficiency by simulation experiment.

II. RELATED WORK

A. Definitions of opportunistic networks

In our earlier works[11,12], we have given out formal definitions of the opportunistic networks characteristics, and the definitions related to this paper are simply listed below, including some newly added definitions:

Definition 1: node of opportunistic network

$$N = \{X_1, X_2, X_3, ...\} \tag{1}$$

N is an opportunistic network and $X_i (i = 1,2,3...)$ is the nodes in N.

Definition 2: message of opportunistic network

$$M = \{m_1, m_2, m_3, ...\} \tag{2}$$

M is the set of all messages transmitted in opportunistic network N. $m_j (j = 1,2,3...)$ is a single message. If node X_d is the destination of message m_k, there is $dest(m_k) = X_d$.

Definition 3: utility of message transmitting

u_{X_a, X_d} is denoted as the utility from node X_a to node X_d. Assume message m_k is carried by node X_a, when X_a meets X_b, if $u_{X_a, dest(m_k)} < u_{X_b, dest(m_k)}$, then X_a

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transmits m_k to X_b , since X_b has higher utility to the destination node.

Definition 4: FRL(Frequently Reached Location)

For network *N*, the FRL is defined as

$$F_N = \bigcup_{X \in N} F_X \tag{3}$$

where:

$$F_X = \{(L_k, p_k) | p_k > \alpha\} \tag{4}$$

L_k is a FRL of node *X*, p_k is the arriving probability at L_k of node *X* in unit time, α is a predetermined threshold.

Definition 5: Terminal of Movement

We can define a function $ToM(X)$ to estimate whether node X has reached its terminal. A feasible form of $ToM(X)$ may be:

$$ToM(X) = ToM(L_X, \mathrm{TP}_X) = 1 - \frac{|L_X - TL_X|}{D\max} \cdot \frac{TP_X}{T\max} \tag{5}$$

TL_X is the location of space terminal of node *X*, L_X is the current location of *X*, $D_{\max}$ is the length of geographic diameter of the opportunistic network. TP_X is the remaining power supply time of *X*, $T_{\max}$ is the maximum power supply time of *X*.

Node X has reached its terminal when $ToM(X)=1$, while node X do not have movement terminals if $ToM(X) \equiv 0$.

Definition 6: community of nodes

Some nodes in opportunistic network may have similar behavior, such nodes can be classified as a community. We can define the set of communities of opportunistic network N as

$$C_N = \{C_1, C_2, C_3, \ldots\} \tag{6}$$

where $n_{C_N} = |C_N|$ is the amount of communities in the network.

Every community C_i is a vector like:

$$C_i = (a_1, a_2, a_3, \ldots, a_n) \tag{7}$$

where $a_j (j = 1,2,\ldots,n)$ is an attribute of C_i. a_j can be a behavior, such as the FRL of nodes, et al.

Specific but not unique, we have:

$$C_i = (s_{id}, N_C, L_{FR}, TL_C) \tag{8}$$

where:

s_{id} is the identifier of the community,

N_C is the set of nodes belong to the community,

L_{FR} is the frequently reached location set of N,

TL_C is the terminals of the nodes in the community,

If node X_k belongs to community C_i, we denote this as $X_k \xrightarrow{belongs} C_i$.

We use the definitions above to describe the heuristic rules in Section III.

B. Description of PROPHET protocol

The PROPHET protocol[10] can be described as below, using the definitions above.

The nodes initialize their utility $u_{X,Y}$ to u_0.When two nodes meet each other, they update the utility $u_{X,Y}$ to $u'_{X,Y}$:

$$u'_{X,Y} = u_{X,Y} + (1 - u_{X,Y}) \times u_0 \tag{9}$$

The utility will decrease with time, which is called "aging", while a aging constant $\gamma \in [0,1)$ is given:

$$u'_{X,Y} = u_{X,Y} \times \gamma^k \tag{10}$$

The utility of node is transtiv, while a factor $\beta \in [0,1]$ is given:

$$u'_{X,Z} = u_{X,Z} + (1 - u_{X,Z}) \times u_{X,Y} \times u_{Y,Z} \times \beta \tag{11}$$

We take the PROPHET protocol as comparison in Section IV.

III. HEURISTIC RULES OF ROUTING PROTOCOL

We are looking for routing protocols which can adapt various opportunistic networks. A serious of heuristic rules proposed in this section may indicate different routing behaviors according to different characteristics of opportunistic networks.

A. Rule 1: transmit data near FRL

Describe: when a node *X* carrying message *m* can not find a node *Y* whose $u_{Y,dest(m)} > u_K$ for some time, *X* should not lower the threshold u_K, but wait to reach at a FRL and then try to find *Y* again. If *X* can not find such a node *Y* after reaching at FRLs *l* times, then lower the threshold u_K.

Explain: a node usually have higher probability to meet other nodes near FRL, so it might find a proper node for data transmitting at a FRL.

B. Rule 2: transmit data to strangers near FRL

Describe: when a node X carrying message m meets a node Y and $u_{X,Y} < u_K$, then node X copies the message m to Y.

Explain: u_K is a small threshold. $u_{X,Y}$ indicates the encounter probability of node X and Y. $u_{X,Y} < u_K$ means node X and Y are strangers, then Y is supposed to have different moving behavior from node X and meet different nodes from the ones X meets. So Y might meet the destination node of message m.

C. Rule 3: refuse to relay message if approaching terminal

Describe: when a node X meets node Y carrying message m and $ToM(X) > \alpha$, then node Y transmit m to node X (= node X relays m for Y) only if $u_{X,dest(m)} > \max(u_K, u_{Y,dest(m)})$

Explain: u_K is a high threshold. A node will stop transmitting data after reaching its terminal, so it should refuse to relay message for others while approaching terminal except it has very high utility of transmitting the message to destination.

D. Rule 4: deliver message to others if approaching terminal

Describe: when a node X carrying message m meets node Y and $ToM(X) > \alpha$, then node X transmit m to node Y (which means node Y relays m for X) if $u_{Y,dest(m)} > \min(u_K, u_{X,dest(m)})$

Explain: u_K is a small threshold. A node will stop transmitting data after reaching its terminal, so it should deliver the messages to others before reaching its terminal in order to avoid loss of data.

E. Rule 5: unlimited nodes should relay messages for limited nodes

Describe: when a node X meets node Y carrying message m, $ToM(X) \equiv 0$ and $ToM(Y) > 0$, then node Y copies m to X (= node X relays m for Y) if $u_{X,dest(m)} > \min(u_K, u_{Y,dest(m)})$

Explain: u_K is a small threshold. An unlimited node will work in network forever while a limited node will reach its terminal and exit the network. So unlimited nodes will have high probability to meet the message destinations and should relay messages for the limited nodes.

F. Rule 6: nodes should not deliver message to another node belonging to the same community, unless that node is "excellent".

Describe: when a node X carrying message m meets node Y, where $X \xrightarrow{belongs} C_p$ and $Y \xrightarrow{belongs} C_p$, then X will not deliver m to Y, unless $u_{Y,dest(m)} > \max(u_{X,dest(m)}, u_K)$.

Explain: u_K is a high threshold. The nodes have similar behavior if they belong to the same community, so they may have similar meeting probability to other nodes. Thus, a node should not deliver messages within its community, unless it meets an "excellent" node – the node has very high utility to the destination node.

G. Rule 7: nodes have high priority to deliver message outside its community, especially to the destination's community.

Describe: when a node X carrying message m meets node Y, where $X \xrightarrow{belongs} C_u$, $dest(m) \xrightarrow{belongs} C_v$ ($C_u \neq C_v$) and $Y \xrightarrow{belongs} C_w$, if $C_u \neq C_w$, then X deliver m to Y with probability p_K; if , $C_v = C_w$ then X deliver m to Y with probability 1.

Explain: p_K is a high threshold. X and Y belong to different communities, so Y may meet different nodes from which X meets, thus X should deliver message m to Y with a high probability. Especially if Y belongs to the same community as the destination's , X should deliver message m to Y because Y may meet the destination with very high probability.

The heuristic rules above have involved different characteristics of opportunistic networks. The parameters in the rules can be determined by experience or simulation results. The expansible rules and adjustable parameters will make the routing protocols adapt different opportunistic networks well. We have the experimental result in Section IV.

IV. EXPERIMENTAL RESULT

A. Background and settings

We evaluate the efficiency of the heuristic routing protocol in a simulation experiment. The background of the experiment is a series of mountain sports[12]. We have tracked 100 nodes in the sport, so the simulating network is consist of these nodes.

Table I shows the values of heuristic routing protocol parameters in the experiment.

We compare the efficiency of data transmitting of the heuristic routing with dissemination based routing and PROPHET routing.

Table II shows the parameter values of the other two routing protocols in experiment.

B. Result

In the experiment, we apply the seven heuristic rules separately in data forwarding, and calculate the ratio of successfully transmitted message. Fig. 1 shows the results of the three routing protocols:

TABLE I. PARAMETERS IN HEURISTIC RULES

Rule	parameter	value
Rule 1	u_K	0.8
	l	2
Rule 2	u_K	0.2
Rule 3	α	0.75
	u_K	0.9
Rule 4	α	0.6
	u_K	0.8
	k	4
Rule 5	u_K	0.4
Rule 6	u_K	0.8
Rule 7	p_K	0.6

TABLE II. PARAMETERS IN OTHER PROTOCOLS

parameter	value
copies of message in dissemination based routing	4
PROPHET u_o	0.75
PROPHET β	0.25
PROPHET γ	0.98

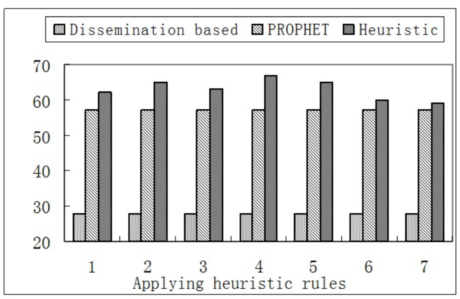

Figure 1. ratio of message transmitted.

The experimental result shows that the dissemination based routing protocol can not adapt this opportunistic network environment, while the other two have much better performance. Applying heuristic rules can make further improvement of data forwarding than PROPHET protocol.

Especially when applying Rule 4, the transmitting ratio is higher than other rules, because in the experiment the nodes' power supply are limited and Rule 4 makes the nodes deliver the messages out before power off.

When applying Rule 6 & 7, the ratio is less than other rules (but higher than the other protocols). This is because there are too many communities and only 4-8 nodes in every community in this experiment.

V. CONCLUSION

Now the applications of opportunistic networks have extensive prospects. The research on opportunistic networks has prospective significance. The common routing protocols are usually not adaptable to different opportunistic networks due to different nodes' behavior and the complex and unstable network topology.

In this paper, we introduce formal definitions of the opportunistic networks characteristics, and then propose a serious heuristic rules for data forwarding in opportunistic networks. Experimental result shows that the heuristic rules have better performance in data transmitting than dissemination based routing protocol and PROPHET protocol. The heuristic rules are open and extendable. So we can adjust the parameters according to different applications of opportunistic networks. Appropriate adjusting will make the heuristic rules adaptable for different occasion.

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