An Opportunistic Routing with Improved Node Forwarding Mechanism*

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Abstract - Opportunistic routing protocol is proposed for broadcast and lossy characteristics existing in wireless multi-hop networks. Compared with traditional routing protocols, opportunistic routing protocol can bring higher data transmission abilities. Traditional opportunistic routing protocols have some problems, such as too large forwarding candidates set, too high protocol calculation expense and possible loops in its transmission paths. These problems limit the decrease of protocol calculation expense and the raise of protocol transmission abilities. We improved the selection process of forwarding candidates set (a candidate set of forwarding nodes) and the establishment of forwarding node in the node forwarding mechanism of opportunistic routing, then proposed a novel opportunistic routing protocol with improved node forwarding mechanism named IFOR (Improved Forwarding Opportunistic Routing). Experiments and analysis show that, compared with those opportunistic routing protocols which are based on the traditional node forwarding mechanism, IFOR can reduce protocol computing overhead and raise end-to-end packet delivery ratio in data transmission.

Index Terms - Opportunistic Routing; Wireless Multi-hop Networks; Node Forwarding Mechanism

I. INTRODUCTION

Traditional routing protocols in wireless multi-hop networks are devoted to find an optimal path between the source and the destination before data transmission. Then, data packets are transmitted hop by hop according to the optimal path to achieve data transmission. However, owing to the unreliability of wireless channel, each hop may get failed, which will bring about some problems, such as retransmission times increased and packet delivery ratio decreased. To overcome the above problems, MIT researchers proposed a sort of wireless multi-hop network routing protocol named opportunistic routing [1]. In a traditional wireless multi-hop network routing protocol, those nodes are chosen as forwarders along a fixed route between the source and the destination. Different from traditional wireless routing protocols, opportunistic routing makes use of the selection process of forwarding candidates set to select multiple candidate forwarders per hop. If there is at least one forwarding candidate receiving the packets, the forwarder will be finally selected from these candidates and the packets are forwarded to next hop node. This process goes on until the packets reach the destination. The selection process of forwarding candidates set makes full use of the broadcast nature of wireless multi-hop networks and brings about higher data transmission abilities. Opportunistic routing protocol use the establishment process of forwarding node to select forwarding node from forwarding candidates set. It assigns priority to each candidate forwarder based on some routing metric [2], and nodes with high priority own allocation of long time slots. In each hop packet transmission, one node will be selected as the forwarder only if other nodes with higher priority have not received the packets during one slot time. This mechanism can avoid retransmission and data redundancy.

The node forwarding mechanisms in current traditional opportunistic routing protocols such as ExOR [1] and MORE [3] are simple and easy to implement. On the other hand, the forwarding candidates set is too large and protocol expenses are too high in these classic mechanisms. A classic node forwarding mechanism owns the common forwarding candidates set in each hop data transmission between the source and the destination. This set contains all of the nodes whose routing metric value smaller than the source’s to the destination, but not all nodes in the set are good for data transmission. Too large forwarding candidates set will lead to too much time overhead in the selection process of forwarding candidates set and the establishment process of forwarding node, and also possibly cause loops existing in the selected transmission path, which limits the performance improvement for an opportunistic routing protocol.

Against the shortcomings of classic node forwarding mechanisms, some scholars proposed one kind of node forwarding mechanism we call it limit-candidate-scale node forwarding mechanism, it limits the number of candidate forwarder in each hop data transmission to avoid too large forwarding candidates set, reduces the overhead of the protocol and improves the data transmission abilities. Such as CORMAN [4] proposed by Wang Zehu, TDICOR [5] proposed by Mathias Kurth, CORE [6] proposed by Eric Rozner, etc. However, these routing protocols need to empirically determine the scale or the number of candidate forwarders to ensure the data transmission abilities. Too many candidate forwarders will bring about larger path computing overhead and higher loop appearing possibility in the process of data transmission. On the other hand, too few will lead to

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less broadcast income or end-to-end packet delivery ratio for the opportunistic routing.

In this paper, we learn from the routing protocols with limited candidate scale and develop the node forwarding mechanism in classic opportunistic routing. We use proper restrictions to limit the forwarding candidate scale in each hop data transmission, which can avoid too large scale in classic node forwarding mechanism or its empirical predetermination in limit-candidate-scale node forwarding mechanism. Based on the above assumption, in this paper, we present an Opportunistic Routing with Improved Node Forwarding Mechanism or Improved Forwarding Opportunistic Routing for short(IFOR). Experiments and analysis show that the IFOR can achieve higher end-to-end packet delivery ratio and cost lower runtime than traditional opportunistic routing protocols.

II. PROBLEM DESCRIPTION

In this section, we give such definitions with directed graph theory for opportunistic routing protocols to facilitate the subsequent descriptions:

Definition 1 (wireless multi hop network): A wireless multi-hop network is a directed graph, or set of nodes connected by edges, where the edges have a direction associated with them. Assuming the total number of the nodes is n, this network can be denoted by a pair of G=(V,E) of:

A set \( V = (v_1,v_2,\ldots,v_n) \), whose elements \( v_1,v_2,\ldots,v_n \) are called vertices or nodes.

A set \( E = \{e(v_i,v_j) \mid v_i,v_j \in V, v_i \neq v_j \} \), called ordered pairs of vertices or directed edges or links. Each \( e(v_i,v_j) \) expresses a directed link from any \( v_i \) to \( v_j \).

Definition 2 (path): A directed path (or “path” in this paper) is a sequence of edges which connect a sequence of vertices, with the added restriction that the edges all be directed in the same direction. The path from node \( v_i \) to node \( v_j \) in data transmission is denoted by \( p(v_i,v_j) \), where \( p(v_i,v_j) \subseteq E \).

Definition 3 (packet reception ratio, or PRR for short): Packet reception ratio means the probability of the packet successfully transmitted to a receiver through a directed link \( e(v_i,v_j) \), which is denoted by \( prr(v_i,v_j) \).

Definition 4 (neighbor node): If \( prr(v_i,v_j) > 0 \), then node \( v_j \) is one of \( v_i \)'s neighbor nodes.

Definition 5 (neighbor nodes set): The set of any node \( x \)'s neighbor nodes is denoted by \( R^x \).

Definition 6 (packet delivery ratio): Packet delivery ratio means the probability of the packet successfully transmitted from the source to the destination.

Definition 7 (forwarding candidates set): Forwarding candidates set is the set of the nodes which are allowed to receive packet of per hop transmission, any node in the set has the opportunity to be a real forwarder. If a sender is denoted by \( x \), then \( x \)'s forwarding candidates set is denoted by \( F^x \).

Definition 8 (candidate forwarder): A node in the forwarding candidates set.

In a classic node forwarding mechanism, not all the nodes in the forwarding candidates set are in favor of data transmission. A forwarding candidates set with too many nodes will cause the following problems:

A. Increasing the computing overhead

In current node forwarding mechanisms, the selection process of forwarding candidates set requires a routing metric to evaluate the quality of each link in the network. We need calculate each routing metric value then choose the nodes whose routing metric value are smaller than the source’s as candidate forwarders. Firstly, the calculating of all nodes’ routing metric values will bring high computing overhead. Secondly, the nodes in the forwarding candidates set may be far away from the sender in each hop (means routing metric value is high), which will also lead to unsuccessful forwarding and high cost selecting.

B. Increasing the time cost

When a node transmits data packets to its candidate forwarders in each hop data transmission, classic node forwarding mechanisms assign different priority to different candidate forwarder, each candidate forwarder will wait some time if it has received packets exactly. The higher the priority, the shorter the waiting time is, so as to avoid duplication of forwarding packets. The bigger forwarding candidates set will bring the higher time cost of selecting the forwarder in the forwarding candidates set.

C. Reducing the data transmission abilities

An actual path may generate loops. Fig. 1 shows a simple network model. Node A is the source node and node D is the destination. The percentages in Fig. 1 represent the PRR of corresponding links (Assuming that the forward link and the reverse link have the same PRR). The numbers and the directed lines represent the order and the direction in data transmission. Use ETX [2] as the routing metric. Node A sends the data packet to B and C, then ETX(B,D)=1.43 and ETX(C,D)=2. The routing selects B as the forwarder because its ETX value is smaller than C’s. Furthermore, node B forwards the packet to its candidate forwarders C and D. C succeeds in receiving the data packet but D fails to do that. Then, node B becomes forwarder again and forwards the packet according to the node forwarding mechanism until the packet finally reaches the destination. The loop between B and C appears in the data transmission and it will increase the unnecessary or redundant transmission.

In addition, in an opportunistic routing protocol with limited-candidate-scale node forwarding mechanism, we need to empirically predetermine the number of candidate forwards to ensure its data transmission abilities. This mechanism is not convenient to implement in wireless multi-hop networks.
III. THE DESIGN OF IFOR PROTOCOL

A. The Improved Node Forwarding Mechanism

Same as other node forwarding mechanisms in opportunistic routing, the Improved Node Forwarding Mechanism in IFOR consists of three parts. They are the update of routing information, the selection of forwarding candidates set and the establishment of forwarding node.

Part 1. Update of Routing Information

Update of Routing Information periodically is the basis of protocol execution, and here the Routing information is indicated by PRR. The improved node forwarding mechanism needs to get each link's PRR in network to calculate each link’s ETX value. Each node periodically broadcasts Hello message [7] to its own one-hop-distance nodes, and those who received Hello message will record its PRR in the period of time. Then, each node broadcasts its known links’ PRR, until every node knows all links’ PRR in network.

Part 2. Selection of Forwarding Candidates Set

For each hop data transmission, the improved mechanism needs select multiple nodes to generate each forwarding candidates set based on ETX value. If the sender in each hop transmission denoted by x, \( R^x \) will be x’s neighbor nodes set, and \( F^x \) will be x’s forwarding candidates set. This mechanism requires \( F^x \) must be the subset of \( R^x \). In addition, one node named n added to \( F^x \) must satisfy the selection conditions of a candidate forwarder:

\[
ETX(n, d) \cdot hop(n, d) < ETX(x, d) \cdot hop(x, d). \quad (1)
\]

Here n is one of x’s neighbor nodes, d is the destination node. ETX(n,d) and ETX(x,d) represents the ETX value from n to d and the ETX value from x to d, respectively. hop(n,d) represents the hops of the path when ETX value is ETX(n,d), hop(x,d) is similarly available.

ETX value and hop count can be calculated by the shortest path algorithm. Our improved mechanism doesn’t need to calculate all nodes’ ETX values, only need to calculate the ETX values from a part of nodes in the network to the destination, which will reduce the computing overhead, exclude those nodes far away from the sender and avoid transmission loops.

The ETX value \( \text{ETX}(v_i, v_j) \) and hop count \( \text{hop}(v_i, v_j) \) from \( v_i \) to \( v_j (v_i, v_j \in V, v_i \neq v_j) \) are calculated by:

\[
\text{ETX}(v_i, v_j) = \min \sum_{k=1}^{\text{hop}} \text{ETX}(v_k, v_{k+1}).
\]

Here \( P(v_i, v_j) \) represents the path from \( v_i \) to \( v_j \), and \( v_k, k \in [1, \text{hop}] \) is one node on \( P(v_i, v_j) \) with any hop count \( hop \). The result of \( \text{ETX}(v_i, v_j) \) corresponds to \( \text{hop}(v_i, v_j) \).

Part 3. Establishment of Forwarding Node

In this process, our mechanism chooses the forwarding node in the candidate forwards. Before each hop data transmission, it assigns priority to each node in one forwarding candidates set. The smaller value of \( ETX(n, d) \cdot hop(n, d) \) corresponds to the higher priority of node n. In each hop data transmission, select the node with the highest priority in the candidate forwards as the final forwarder. Forwarder then sends the ACK message to the packet sender its successful reception and stops the lower priority node to forward. Each candidate forwarder will wait for a time if it has received packet correctly. The higher priority node needs shorter waiting time, so as to avoid duplication of forwarding packets.

B. IFOR Protocol Description

In this protocol, assume that s is the source, d is the destination, and x is the sender in each hop transmission. IFOR protocol executes steps as follows:

Step 1: Set initial sender x as s, and \( R^s, F^s \) as empty set;

Step 2: Add all x’s neighbor nodes to \( R^s \), suppose node n belong to \( R^s(n \in R^s) \) ,then calculate the ETX(n,d) and hop(n,d) using (2);

Step 3: Add any node n to \( F^s \) who satisfies (1), except the source node and those who have been allocated to existing forwarding candidates sets;

Step 4: Node x send the packet to its candidate forwarders, \( F^s \). If the packet reaches the destination, finish the protocol. Else, turn to next step;

Step 5: If the nodes in \( F^s \) haven’t received the packet, sender x will retransmit the packet (The number of retransmissions must be less than the maximum number of retransmissions, otherwise turn to the end). If there exists at least one node receives the packet, then set \( R^s, F^s \) as empty set and the receiving node with the highest priority becomes the new sender x, then turn to step 2;

Step 6: End.

Algorithm 1. IFOR protocol.

1: \( x = s, R^s = \emptyset, F^s = \emptyset \)
2: \while \( d \in F^s \)
3: \forall \( n \in R^s \)
4: \quad \text{calculate ETX(n,d) and hop(n,d) using (2)}
5: \quad \text{if } ETX(n, d) \cdot hop(n, d) <= ETX(x, d) \cdot hop(x, d)
6: \quad \quad \quad \text_style{F^s = F^s \cup \{n\}}
7: \quad \text_style{end if}
8: \end for
9: \text{packet is transmitted from} x \text{to the nodes in} F^s
10: \text{update} x
11: \( R^s = \emptyset, F^s = \emptyset \)
12: \end while
Following the steps above, the packet sent by the source will be continually forwarded until it finally reaches the destination. The pseudo-code program is shown in Algorithm 1.

IV. SIMULATION AND EVALUATION

A. Simulation Setup

In a wireless multi-hop network, each node in the network can be used as the packet sender, the forwarder or the receiver. In addition, for existing link correlation characteristic in a wireless multi-hop network, multiple receivers own the same sending node and there exists correlation in their packet loss [1][8][9]. Therefore, our wireless multi-hop network model must have the following properties: Each node randomly distributes in a rectangular range; Each node has an unique identifier; Node position is fixed; The links in the network have lossy characters and link correlations.

We simulate the above network with spatial topological structures as: specify a horizontal region and assign specified number of nodes to this region and generate wireless multi-hop network topology by Waxman model [10]. References [11] and [12] have deduced the relationship between communication distance and PRR. Thus we can simulate the PRR between any two nodes via their distance. The realization of PRR is shown as in [11][12]. Assuming \( P(D) \) is the PRR between a sender and its one receiver where \( D \) is the sender-receiver distance, \( f \) is the frame size, \( Pt \) is the transmitting power, \( Pn \) is the noise floor, \( Pl(D) \) is the log-normal shadowing path loss, \( D0 \) is a reference distance, \( n \) is the path loss exponent, and standard deviation is sigma, Table 1 shows the specific simulation parameters, we can simulate the PRR of each link to describe the lossy characteristic in the wireless multi-hop network.

Link correlation is a key factor affecting the performance of an opportunistic routing. The higher the link correlation, the worse the performance of opportunistic routing is. In this paper we proposed correlation index \( p \) to describe the link correlation existing in wireless multiple-hop networks. \( p \in [0,1] \), the bigger value of \( p \) means the higher link correlation in the network. Each hop data transmission should follow as: A sender transmits a data packet to its candidate forwarders, if a link with lower PRR successfully completes the transfer, then the links with higher PRR also successfully complete the transfer; Similarly, if a link with higher PRR cannot complete the transfer, neither can the links with lower PRR.

The network simulation scenarios need to consider such the following factors: the node scale, the node density, the network region, the correlation index and the maximum number of retransmissions.

| Table 1. Network simulation parameters. |
|----------------|----------------|----------------|----------------|
| Symbol | Value | Symbol | Value |
| | | | |
| D0 | -15 dB | Pt | 0 dB |
| f | 50 bytes | Pl(D0) | 55 dB |
| n | 2 | sigma | 4 |

B. Results and Evaluation

Existing opportunistic routing protocols also contain some other mechanisms which are not unique to opportunistic routing, except for node forwarding mechanism. Such as the network coding mechanism [3][13], the sleep-wake-up mechanism [14], energy management mechanism [15][16], etc. These mechanisms all have promotion effects on the performance of opportunistic routing protocol, and can be added to the IFOR protocol. In this paper, we are committed to improve the node forwarding mechanism in opportunistic routing, thus we do not consider the performances of other mechanisms. We implement IFOR and ExOR which is a typical opportunistic routing protocol with classic node forwarding mechanism on a great deal of different wireless multi-hop networks.

Besides the main parameters in Table 1, the network distribution range is 90*90m² and the number of nodes equals 30. We transmit 500 data packets between different nodes using ExOR and IFOR respectively, and record their PRRs between the source and destination. Then, we execute the data transmissions under different link correlation and different maximum number of retransmissions.

The relationship between packet delivery ratio and maximum number of retransmissions can be found in Fig. 3. Here the link correlation \( p=0, 0.4, 0.8, 1.0 \) and maximum number of retransmissions \( k=1, 2, 3, 4, 5 \) respectively. From Fig. 3 we can see that, no matter what value \( k \) takes, IFOR can obtain higher packet delivery ratio than ExOR. And the greater the maximum number of retransmissions, the higher the packet delivery ratio is. The higher the link correlation, the smaller the difference between IFOR and ExOR is. In addition, when the maximum number of retransmissions is greater than 2, the packet delivery ratio is higher than 98%.

As shown in Fig. 4, we can observe the relationship between packet delivery ratio and link correlation. Under any link correlation conditions, IFOR all can obtain higher packet delivery ratio than ExOR. Higher link correlation can bring the lower of the packet delivery ratio between the source and the destination.

\[
\begin{align*}
\text{Fig. 3 Packet delivery ratio in relation to the maximum of retransmissions of ExOR and IFOR.}
\end{align*}
\]
IFOR protocol spends less runtimes compared to ExOR protocol. More network node will lead to longer runtimes in the opportunistic routing protocol. What’s more, under the same number of network nodes, IFOR protocol spends less runtimes compared to ExOR protocol.

V. CONCLUSION

IFOR don’t need to empirically predetermine the number of candidate forwarders to ensure the data transmission abilities. Simulations and analysis proved that IFOR can achieve the opportunistic routing selection in any wireless multi-hop network whose nodes are limited and evenly distributed. IFOR protocol can get higher packet delivery ratio and takes less runtimes than existing traditional opportunistic routing protocol. It can also bring higher transmission reliability.

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