A Probing and p-Probability Based Two Round Directional Neighbor Discovery Algorithm

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Abstract. Neighbor node discovery is one of the important steps in a wireless directed ad hoc network. Improving the efficiency of neighbor node discovery can not only reduce the collision during node communication, but also improve the performance of the wireless ad hoc network as a whole. In the Ad-hoc network of directional antennas, by analyzing and summarizing the deficiencies of the neighbor discovery algorithm, this paper proposes a probing and p-probability based two round directional neighbor discovery algorithm (PPTR). The second round adjusts the probability of neighboring neighbor nodes competing for slots based on the number of free slots, successful slots, and collision slots in the first round, thereby reducing the collision of neighboring nodes to reach the maximum number of neighbors discovered within a fixed time. We verified the protocol through network simulation. The simulation results show that the PPTR algorithm and the traditional neighbor discovery algorithm have the same neighbor discovery efficiency when the number of network nodes and the number of time slots are consistent. But The neighbor discovery efficiency increases on average 81.3% when the number of nodes increases to five times the number of timeslots.

Keywords: Ad-hoc · Neighbor discovery · Probabilistic optimization · Two rounds

1 Introduction

The wireless self-organizing network makes it minimally affected by geographical location through its self-configuration method, and its flexible structure makes the wireless self-organizing network in emergency communication, exploration and disaster relief, maritime communication and military communication, such as individual soldier communication systems on the battlefield, etc. All have irreplaceable positions and advantages. The directional antenna [1] is widely used in modern wireless communication because of its flexible structure, extremely high multiplexing rate, wide coverage, and reduced interference.

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The addition of directional antennas to the wireless self-organizing network improves network transmission performance and enhances anti-interference, making it have better communication performance in military communications and emergency communications. However, in the wireless communication system, the problem of low discovery efficiency caused by the difficulty of neighbor node discovery and the collision of neighbor nodes must first be solved.

Neighbor node discovery is a key part of a wireless ad hoc network [2]. An effective neighbor node discovery algorithm is indispensable for most MAC protocols based on wireless networks. When the time slot is fixed, the number of neighbor nodes will greatly affect the discovery efficiency of neighbor nodes. Therefore, improving the efficiency of neighbor discovery is an extremely important process. Reference [3] sets the beam selection probability for each node and continuously adjusts this value during the neighbor node search process, thereby reducing the neighbor node discovery time as a whole and improving the search efficiency. In addition, by setting a special packet format for the discovery and transmission of neighboring nodes, it simplifies information exchange and makes searching easier and more efficient. However, it is only suitable for moving neighbors, and only for a certain beam, it cannot effectively reduce the discovery time of neighbors. Reference [4] proposes to add feedback information in the neighbor node discovery algorithm. The node uses the feedback information of the other party to avoid the repeated transmission of information. Although the collision of neighbor nodes is reduced, it is difficult to apply to multi-hop networks and it cannot solve directional antennas's neighbors found the problem. Reference [5] proposes that all nodes send and receive information in accordance with the specified order of sending and receiving, so that neighbor node discovery is deterministic. Although the collision of neighbor node discovery is reduced, the algorithm is not universal for self-organizing networks. Reference [6] proposes an ALOHA algorithm based on binary tree timeslots. Neighboring nodes randomly compete for timeslots. If conflicts occur in some neighboring nodes, the conflicting tags will be resolved through binary tree splitting. The protocol uses dynamic, adaptive, and segmentation methods to adjust the time slot to the estimated number of neighbor nodes each time. Reference [7] proposes to determine whether to find the neighbor node in each scan by determining whether it is the sending or receiving mode in the next scan. That is, the selection probability of the scan initiating node and the responding node is adjusted by an algorithm to improve neighbor node discovery efficiency, the algorithm requires multiple rounds of interaction to achieve its purpose. It is an adjustment algorithm with memo function. Although the efficiency of neighbor node discovery is improved, it also wastes network resources and time.

Synthesizing the existing research of neighbor node discovery in directional self-organizing network, in order to reduce the competition and conflict of neighbor nodes in fixed time slots and improve the utilization of time slots, this paper proposes a probing and p-probability based two round directional neighbor discovery algorithm. In this protocol, the original neighbor node scanning discovery is changed from one round to two rounds, that is, the scanning time slot is divided into two parts for scanning. In the second round, according to the number of successful slots, idle slots and collision slots in the previous round, and then based on the slots of the second round, the neighbor nodes in the second round calculate the probability of competing for slots by the slave nodes in the current round, and then the slave nodes respond with this probability, so as to reduce the collision of adjacent nodes and improve the efficiency of adjacent nodes discovery [8]. This protocol can improve the utilization rate of time slot and reduce the collision between adjacent nodes when the time slot is fixed. The neighborhood discovery algorithm should have certain stability and universality [9].

The contribution of this paper is as follows:

(1) This paper proposes a new directional neighbor discovery algorithm of PPTR, which improves the efficiency of neighbor node discovery. The algorithm learns and verifies the method of estimating the actual number of neighbor nodes based on the occupied status of the scan time slot, and adjusts the probability of the next round of neighbor nodes competing for the time slot, which make it possible to find as many neighbor nodes as possible within a fixed time, reduce time slot conflicts, and improve time slot utilization.

(2) The algorithm has good portability and can be applied to most wireless networks. Especially in the case of a large number of nodes, this algorithm has obvious advantages.

The rest of this paper is arranged as follows. In the second chapter, the shortcomings of neighbor node scanning algorithm in Directional Transmission and Reception Algorithms (DTRA) are briefly introduced. The third chapter introduces the neighbor node discovery protocol based on probability adjustment. The fourth chapter introduces the simulation results and analysis. The fifth chapter summarizes this paper.

2 Motivation

2.1 Brief Introduction to Neighbor Scan of DTRA

DTRA protocol is a MAC protocol that uses specific scanning mode to carry out pure directional communication. DTRA protocol divides communication into three stages, as shown in Fig. 1, each stage is composed of several time slots of the same size, and each time slot is divided into several micro time slots of the same size. The first stage is the scan discovery stage, in which the nodes discover the neighbor nodes and establish the neighbor table around the nodes.

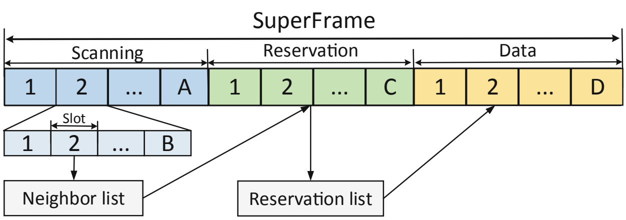

Fig. 1. Three step handshake in DTRA scanning phase.

This stage is the next two stages to solve the problem of adjacent node discovery and maintenance. The second stage is the reservation stage. According to the neighbor node table in the first stage, the resource reservation is made between nodes, and then the data communication between nodes is carried out in the third stage.

It can be seen that the adjacent node scanning phase of DTRA protocol is a key step for resource reservation and data transmission. However, due to its specific scanning mode, the efficiency of the protocol is low. When the number of adjacent nodes is far more than the communication time slots, the probability of collision is very high, which leads to the low efficiency of the nodes to discover the neighboring nodes [10].

2.2 Motivation

When scanning adjacent nodes, the time slot of node communication is fixed, but the number of adjacent nodes in current beam contention time slot is unknown [11]. As shown in Fig. 2, when the number of adjacent nodes is far greater than the number of current slots, the probability of collision increases, resulting in the number of adjacent nodes found by the current beam is very small [12]. Therefore, we need an algorithm that can adjust the probability of adjacent nodes competing for slots according to the number of adjacent nodes and slots, so as to improve the efficiency of neighbor node discovery [13].

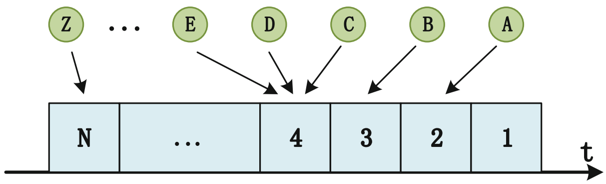

Fig. 2. Multiple neighboring nodes select the same time slot.

3 Proposed Probability Adjustment Algorithm

3.1 Key Idea

Based on the traditional Aloha algorithm, literature [14,15] proposed that when the number of slots and nodes is equal, the number of adjacent nodes found is the largest. Most research papers such as [16] focus on how to determine the relationship between the number of slots and the number of adjacent nodes, in order to adjust the time slots to achieve the maximum efficiency of neighbor node discovery. In each round, the number of adjacent nodes is estimated according to the results of the previous round of scanning, and then the current slot is dynamically adjusted for scanning again until the estimated number of adjacent nodes is consistent with the number of current slots. It can be considered that all the neighboring nodes are basically found and the current scanning is finished.

In the scanning phase of DTRA, the number of slots t is fixed. Therefore, the improved neighbor node discovery algorithm in this paper is to increase the number of adjacent nodes from one round to two rounds, as shown in Fig. 3. The first round of scanning is conducted according to the original set mode. According to the free slot En, successful slot Sn and collision slot Fn after the first round of scanning, the number of adjacent nodes around the current beam is estimated, According to the relationship between the number of adjacent nodes and the number of time slots, the probability Ps of neighboring nodes competing for slots in the second round is adjusted, so as to maximize the discovery efficiency of neighboring nodes [17]. Therefore, this paper focuses on how to find as many nodes as possible in a fixed time.

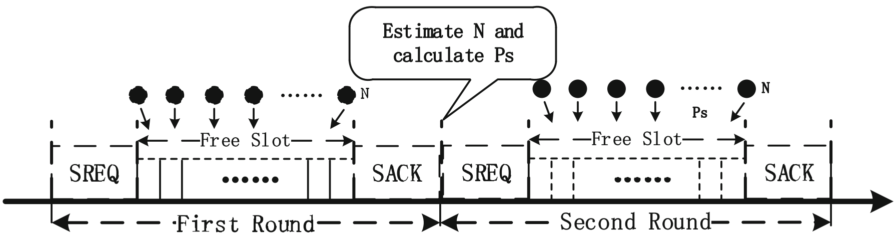

Fig. 3. Adjust competition probability.

In reference [18], a novel algorithm for estimating the adjacent nodes is proposed. Assuming that the discovery process of adjacent nodes is multinomial distribution, the probability P_e that a slot is idle when the total slot length is T is:

$$P_e = \left(1 - \left(\frac{1}{T}\right)\right)^N \tag{1}$$

The probability P_s that a slot is a successful slot is:

$$P_s = \left(\frac{N}{T}\right)\left(1 - \left(\frac{1}{T}\right)\right)^{N-1} \tag{2}$$

The probability P_f that a slot is a collision slot is:

$$P_f = 1 - P_e - P_s \tag{3}$$

Then the probability $P(E_n, S_n, F_n)$ of E_n free slots, S_n successful slots and F_n collision slots in one round is:

$$P(E_n, S_n, F_n) = \frac{T!}{E_n!S_n!F_n!} P_e^{E_n} P_s^{S_n} P_f^{F_n} \tag{4}$$

When the total time slots are t and there are N adjacent nodes to be discovered in the current beam, when there are E_n free slots and S_n successful slots, there are F_n collision slots:

$$P(N|E_n, S_n, F_n) = \frac{T!}{E_n!S_n!F_n!} \times \left[\left(1-\frac{1}{T}\right)^N\right]^{E_n} \times \left[\frac{N}{T}\left(1-\frac{1}{T}\right)^{N-1}\right]^{S_n} \times \left[1-\left(1-\frac{1}{T}\right)^N - \frac{N}{T}\left(1-\frac{1}{T}\right)^{N-1}\right]^{F_n} \tag{5}$$

According to the posterior distribution, when the value of $P(N|E_n, S_n, F_n)$ is reached to maximum, the estimated value of adjacent nodes is the best. Therefore, according to the number of free slots, successful slots and collision slots of the previous round, the optimal number of adjacent nodes E_e can be estimated.

3.2 Competition Probability

Assuming that the total number of time slots in the scanning phase is constant and the number of adjacent nodes N of the current beam remains unchanged, then the number of scanning rounds is increased to two rounds, and the number of adjacent nodes of the current beam is estimated according to formula (5). The parameters and symbols of other assumptions are as follows (Table 1):

Table 1. Parameter table

Notation	Description
T	Total number of time slots in scanning phase
T_s	The total number of slots used to reply from the node
N_s	Number of successful nodes in competition

In the scanning phase, each round of SREQ-SRES-SACK neighbor node discovery process includes one SREQ packet sending time slot, Ts SRES time slot and one sack packet reply time slot:

$$T = 2 + T_s \tag{6}$$

The discovery efficiency of neighbor nodes means that any slot can become a successful time slot among the Ts slave node reply slots.

When N slave nodes compete for SRES slots T_s with probability P_s, i nodes decides to participate in the competition probability:

$$P_{contend}(N, P_s, i) = \binom{N}{i} {P_s}^i (1-P_s)^{N-i} \tag{7}$$

When i nodes decide to compete for T_s slots, the probability that any slot can become a successful slot is as follows:

$$P_{success}(T_s, i) = \binom{i}{1} \frac{1}{T_s} \left(1 - \frac{1}{T_s}\right)^{i-1} \tag{8}$$

According to formula (8), $P_{success}(T_s, i)$ can reach the maximum value when $i = T_s$.

Therefore, when N slave nodes compete for T_s slots with probability P_s, the probability that any slot can become a successful slot is as follows:

$$\begin{aligned} P_{slotsuccess}(N, P_n, T_n) &= \sum_{i=1}^{N} P_{contend}(N, P_s, i) \times P_{success}(T_s, i) \\ &= \sum_{i=1}^{N} \binom{N}{i} {P_s}^i (1 - P_s)^{N-i} \binom{i}{1} \frac{1}{T_s} \left(1 - \frac{1}{T_s}\right)^{i-1} \\ &= \frac{P_s}{T_s} \sum_{i=1}^{N} i \binom{N}{i} (1 - P_s)^{N-i} \left(P_s - \frac{P_s}{T_s}\right)^{i-1} \end{aligned} \tag{9}$$

Then, when N slave nodes compete for T_s slots with probability P_s, the expectation of the number of successful nodes N_s is as follows:

$$E[N_s] = \begin{cases} N \times \left(1 - \frac{1}{T_s}\right)^{i-1}, & P_s = 1 \\ \sum_{i=1}^{N} i \binom{N}{i} (1 - P_s)^{N-i} {P_s}^i \left(1 - \frac{1}{T_s}\right)^{i-1}, & 0 < P_s < 1 \end{cases} \tag{10}$$

Then the discovery efficiency of neighbor nodes in a single round is as follows:

$$\eta = \frac{E[N_s]}{T_s} \tag{11}$$

When the number of slots in a single round is fixed, if the discovery efficiency of adjacent nodes is maximized η, that is, the number of successful neighboring nodes in a single round is expected to be the maximum. From formula (10), when the probability of competing slots is $P_s = min\left(1, \frac{T_s}{E[N]}\right)$, the maximum expectation can be obtained.

Therefore, through the scanning results of the first round of the current beam, the optimal number of adjacent nodes Ne is estimated. In the second round, let $N = N_e$, and the probability P_s of the slave node competing for time slot in the round is obtained, so that the number of adjacent nodes found in the second round is the largest.

4 Simulation and Results

In order to evaluate the performance of PPTR, the enhancement algorithm proposed in this paper is simulated and verified on C++ simulation platform, and the simulation result is the average value of 10000 simulations. In the simulation environment, we set that the beam of the scanning response node and the initiating node is always aligned, that is, when the neighboring node competes for the communication time slot, the master node can be regarded as successful in discovering the neighbor node as long as the competition is successful.

4.1 DTRA and PPTR Simulation Comparison

In DTRA protocol, when the number of adjacent nodes is more than the number of available slots, all nodes compete for fixed slots at the same time, which is prone to conflict, resulting in the discovery of very low number of neighboring nodes. In the first round, all nodes compete freely. In the second round, the probability of the current round of competitive slots is estimated according to the results of the first round of competition, and then the neighboring nodes are scanned. Note that the nodes that have been detected in the first round of scanning do not participate in the second round of competition. Compared with DTRA and this protocol, the simulation results of neighbor node discovery efficiency with the increase of the number of neighboring nodes are shown in Fig. 4. The parameters in the simulation are shown in the Table 2 below.

As shown in Fig. 4 shows the neighbor node discovery efficiency of different algorithms. The number of time slots is 15 and the number of neighboring nodes is 30. At the beginning, the two algorithms have little difference in neighbor discovery efficiency. With the increase of network node density, the probability of node collision in DTRA algorithm increases, so the adjacent node discovery efficiency becomes lower and lower. However, PPTR will be relatively gentle, from the initial growth of 10.4% to the final 882.1%, it can be seen that PPTR has more advantages in the case of dense network nodes. In the later stage, the curve of the number of neighbor nodes found is relatively gentle, because when the number of neighbor nodes increases, the probability of competition slot decreases, and the probability of collision also decreases, so that the discovery value of adjacent nodes will maintain a fixed value.

Table 2. Simulation parameter index

Parameter	Value
Number of scans	10000
Number of time slots	15
Slot ratio of the first round	1/5
Slot ratio of the second round	4/5

4.2 Comparison of Simulations with Different of Time Slots

In the same time slot, the different number of slots in each round will also affect the efficiency of neighbor node discovery. As shown in Fig. 5, with the different density of network nodes and the difference of two rounds distribution in different time slots, the number of final adjacent nodes found is different. The total number of time slots is 30, the blue line indicates that all time slots are divided in half, that is, the first round used to estimate the number of network nodes accounts for 1/2 of all time slots, and the second round based on probability competition time slot also accounts for 1/2 of all time slots. In this case, with the increase of the number of network nodes, the number of adjacent nodes found drops sharply. In the other two cases, the discovery efficiency of adjacent nodes will not be greatly reduced due to the change of the density of neighboring nodes.

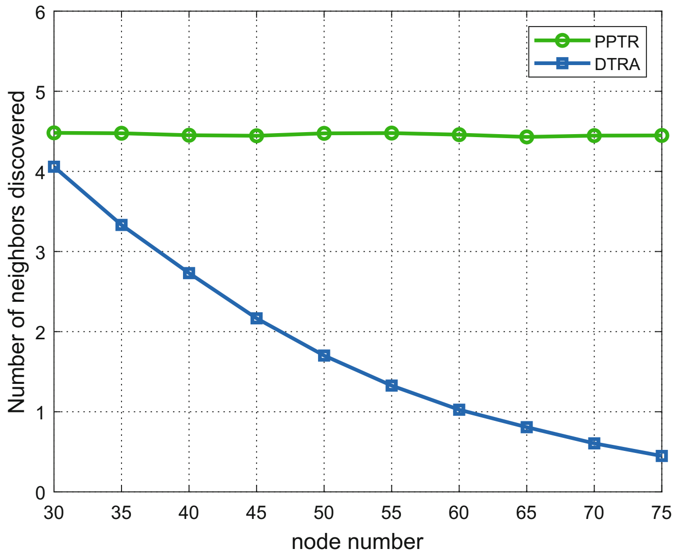

Fig. 4. DTRA vs PPTR.

For the green line, the first round accounts for 1/5 of all time slots and the second round takes up 4/5 time slots. In the first round, the number of neighboring nodes and the competition probability of the next round can be estimated by scanning competition. In the second round, compared with the other two situations, the number of slots available for competition is more, so the discovery probability of adjacent nodes will be relatively stable.

In the discovery of neighbor nodes with fixed time slots, all time slots are divided into several rounds. The first round is used to estimate the number of neighbor nodes, and the subsequent rounds are used by undiscovered nodes to continuously adjust the probability Ps to compete for time slots. As shown in Fig. 6, the time slots are divided into 2 rounds, 3 rounds and 4 rounds, respectively. When the round number is divided into 4 rounds, the number of neighboring nodes is estimated in the first round, and the undiscovered nodes

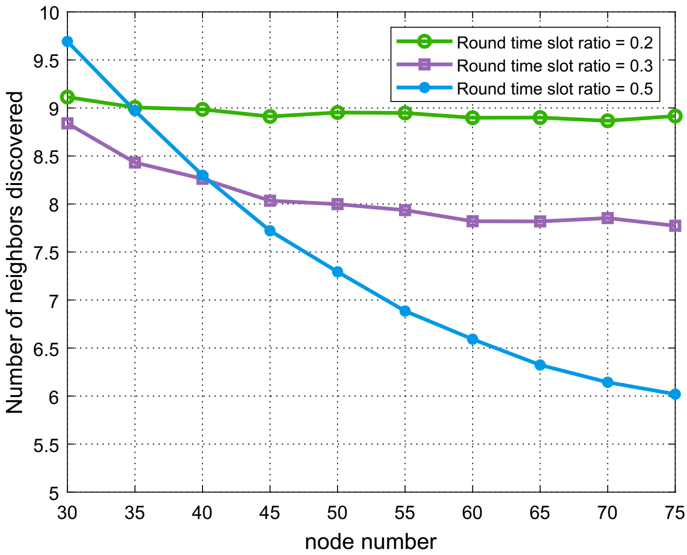

Fig. 5. Neighbor discovery efficiency of different proportion. (Color figure online)

in the second round compete for the second round of time slots based on the probability Ps, and so on, the nodes in the following rounds continuously adjust Ps to compete Time slot. As shown in Fig. 6, Changes in the number of rounds

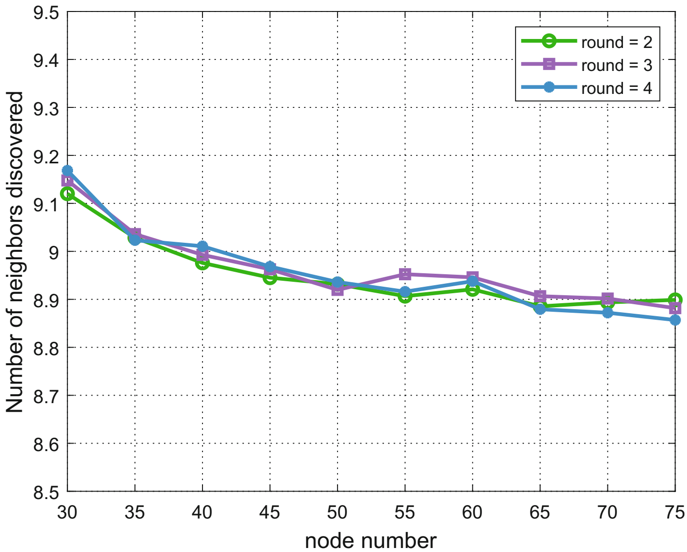

Fig. 6. Neighbor discovery efficiency of different proportion.

have no effect on the simulation results. This is because under a fixed time slot, although the number of rounds increases, the number of time slots per round decreases, and then Ps also decreases, and there are fewer nodes competing for time slots, so the total number of neighbors found no change.

5 Conclusion and Future Works

This paper proposes A Probing and P-probability based two round directional neighbor discovery algorithm. Its purpose is to improve the efficiency of neighbor node discovery. Readers can estimate the information of surrounding nodes and calculate the probability of competing slots in other projects according to the design of the protocol. Simulation results show that PPTR improves the number of adjacent nodes found in a certain period of time, reduces the probability of slot collision, and greatly improves the utilization of time slots. Moreover, the algorithm is not only suitable for DTRA, but also can be extended to other wireless ad-hoc network protocols with good compatibility.

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