Distributed Network Resource Allocation Protocol Based on Collision Scattering and Push-Pull Cascading Mechanism

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Abstract. Wireless directional ad hoc networks has attracted much attention from academic area in recent years due to its large antenna gain, small multipath interference, long propagation distance and space reusability. However, since the signal in other directions cannot be well sensed, the environment of the communication channel cannot be predicted, thus causing interference between multiple concurrent transmission links. Therefore, it is extremely important to study the wireless directional ad hoc networks and use its advantages to overcome its shortcomings. In this paper, the concurrent link interference problem in the wireless directional ad hoc networks is analyzed. Firstly, this paper analyzes the advantages and disadvantages of the classical Push mechanism and Pull mechanism. Then, a network resource allocation protocol, CSPC (Collision Scattering and Push-Pull Cascading), is proposed for the transmission and reception of network resources. CSPC protocol mainly uses the idea of collision scattering to increase the proportion of data transmission success by using frequency division of the time slot in the time slot where data transmission fails. The simulation results show that using CSPC protocol can efficiently increase the network throughput and solve the collision problem between concurrent transmission links.

Keywords: Wireless directional ad hoc networks · Push mechanism · Pull mechanism · CSPC

1 Introduction

The wireless directional ad hoc networks is a technology different from the traditional wireless communication network technology [1]. It doesn't need fixed equipment and base stations' support. A wireless directional ad hoc networks is a multi-hop mobility peer-to-peer network consisting of tens to hundreds of nodes and using wireless communication. Each node can be either a sending node or a receiving node. Nodes can also act as routers which make communication faster, more efficient, and more flexible [2].

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The wireless directional ad hoc networks utilizes directional antennas compared to the wireless omnidirectional ad hoc networks, so it has more advantages. For example, the effectiveness of the radiated power is improved, the confidentiality is enhanced, and the strength of the transmitting power and the anti-interference can be increased. Frequency reuse can be used to increase the spatial reuse rate of the wireless communication network. The transmission distance is long and the number of node forwarding can be reduced.

Since the development of wireless directional ad hoc networks technology, researchers at home and abroad have proposed a number of DMAC (directional media access control) protocols and made full use of the advantages of wireless directional ad hoc networks to improve spatial reuse rate and network throughput [3].

In an actual network, each node is independent. That is, each node can only send and receive data in a specific direction, but cannot detect and avoid interference of concurrent links in other directions. So, during the transmission of network resources [4]. It is easy to occur for collision conflicts, which causes conflicts between links and makes resource allocation efficiency of the entire network very low.

In view of the above problems, relevant research has been conducted. In [5], a multi-channel access method based on collision thinning is proposed for the link collision problem. The core idea is to use multiple channels to scatter single channel collisions and not only allocate one time slot but also allocate a random channel for each node. That is, each node is assigned a time-frequency resource block. Although this algorithm can reduce the link conflict to a certain extent, it still keeps the known traffic and service type of the sending node in the whole process. This algorithm actively sends the data transmission request, but the interference situation at the receiving node is not clear. In [6], a multi-channel MAC protocol based on pseudo-random sequence is proposed for link collision problem. The links for simultaneous data transmission are organized in different pseudo-random sequences, and the receiving node receives the service of the sending node. When the conflict between the concurrent links are perceived and estimated, the collision between the links is reduced. However, the algorithm does not know the traffic and service type that the sending node needs to send, and does not know how to allocate the resource block. The two algorithms in the above two papers correspond to the existing push mechanism and pull mechanism respectively.

The push mechanism refers to the process of data transmission and reception signaling interaction initiated by the sending node. The physical meaning is to push the data generated at the sending node to the receiving node. The advantage of this mechanism is that the sending node knows the amount of traffic that needs to be sent and service type. Therefore, according to its traffic volume and service type, it can actively initiate data transmission request to the receiving node on multiple network resource blocks. The disadvantage of this mechanism is that the sending node does not know its receiving node or even multiple receiving the interference situation at the node, so the receiving node needs to feed back information such as whether the concurrent link conflicts on some resource blocks. After that, the sending node can get better network resources according to the conflict information fed back by the receiving node. The pull mechanism refers to the process of data transmission and reception signaling interaction initiated by the receiving node. The physical meaning is that the data generated at the sending node is pulled from the sending node. The advantage of this mechanism is that the data transmitted by the sending node on different network resource blocks is used to obtain various information, including, the allocation of the network resource block in which the sending node data is successfully transmitted, the situation of other sending nodes that are detected, and the situation in which the network resource block conflicts. Based on these information, the receiving node can estimate and perceive the concurrent link conflict situation around it, and the information can be used by the receiving node for protocol design or network resource allocation. The disadvantage of this mechanism is that the receiving node does not know the service that needs to be sent at the sending node. For example, quantity and type of business. So it only needs to obtain such information before it can allocate network resources.

Although both of the above mechanisms can reduce the link conflict problem to a certain extent, they are only for the protocol proposed by the receiving node or the sending node. The conflict problem is viewed from the perspective of the entire network of multiple nodes. It directly affects the throughput of the overall network. Therefore, we need to unite the transceiver nodes and propose a new protocol to further optimize the interference of the entire link. Therefore, this paper proposes the CSPC protocol. The core idea of this protocol is to overcome the shortcomings of the two mechanisms by combining the advantages of the push mechanism and the pull mechanism. When the sending node knows the traffic volume and type, but does not know the interference situation at the receiving node, it sends a data transmission request to the receiving node. Then the receiving node records the concurrent link interference and collision problem of the receiving end in the whole communication process, and returns the recorded interference condition to the sending node after the data transmission is completed, so that the sending node can know the sending service. The quantity and type can clearly understand the concurrent link interference of the receiving node, and solve the problem of concurrent link conflict.

The main contributions of this paper are as follows. (1) The CSPC protocol is proposed, which cascades the existing push mechanism and pull mechanism. (2) Effectively solve problems such as concurrent link interference. (3) Perform simulation to verify the improvement of network throughput by the CSPC protocol proposed in this paper.

The sections in this paper are organized as follows. The first section mainly introduces the wireless directional ad hoc networks, and the CSPC protocol is derived from the concurrent link interference problem. The second section establishes the system model of the algorithm. The third section describes the specific protocol, and introduces the central implementation of the CSPC protocol in detail. The fourth section carries out simulation verification, and the simulation results are obtained and analyzed. The fifth section is a summary of this article and some expectations for future work.

2 System Model

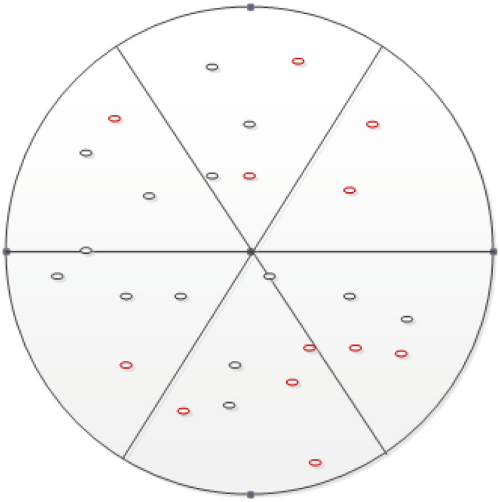

Fig. 1. Wireless directed ad hoc network node distribution.

In the directional ad hoc networks, N sending nodes and M receiving nodes are randomly distributed in the circular area shown in Fig. 1. The position coordinates of each node are represented by two-dimensional rectangular coordinates. Each node is equipped with directional antenna. The communication area divides into 6 sectors and each sector being covered by one beam. The sectors and beams are the same concept in this paper. It is assumed that the radiation intensity within the antenna radiation range is the same.

Table 1. Beam configuration

Beam number	Beam width(∘)
1	0–60
2	60–120
3	120–180
4	180–240
5	240–300
6	300–360

Before introducing the specific protocol, the paper also made the following assumptions. All nodes are randomly distributed in each sector, that is, the position coordinates of each node are random. Each transceiver node has 6 beams, and the beam range is as shown in Table 1. The protocol is based on the three-way handshake protocol of the DTRA (the Directional Transmission and Reception Algorithms) scanning stage. This paper utilizes the pre-existing settings for the scanning stage and the appointment stage. In the scanning stage, not only the time slot of the reservation stage but also a random channel is allocated for the node pair. Each node pair is assigned a time-frequency resource block. In the appointment stage, the transceiver node reserves a plurality of network resource blocks organized in time series. Therefore, when the protocol is specifically described, we mainly introduce the data transmission stage. It is assumed that in all the nodes set by the wireless directional ad hoc networks, the sending nodes scan the sending nodes, and the receiving nodes are all scanning receiving nodes. All nodes communicate on the same channel. The total number of time slots set by the entire protocol is adjustable. The CSPC protocol mainly solves the conflict problem of concurrent links. Through the above model, the interference conflict between links is more clear, which is convenient for recording and optimization, and the model improves the network performance of the entire network, mainly represented by throughput.

3 CSPC Protocol Description

In this paper, we mainly describe the data transmission stage, in which the transceiver node performs data transmission on the basis of the reserved resource block sequence. Here, the channel number sequence is chiefly reflected by the resource block sequence. The multi-channel access mean previously used in the scanning stage and appointment stage. Scattering link conflicts have improved the probability of correct reception of each link [6]. At the same time, the fairness of each node will also increase. However, in order to improve fairness, this paper uses frequency division in the data transmission stage. The rule is actually to classify the time slots according to the transmission state, performing two-index frequency division where the data transmission fails, and frequency-divide the resources occupys more resources until the data can be realized. The transfer was successful. The specific agreement is divided into the following three stages.

3.1 Scanning Stage

The process of the scanning stage is accord with this paper [7]. Moreover, the scanning course is conducted on a single channel. After several rounds of scanning, most nodes are found and recorded in the neighbor node table of the corresponding node, and the table mainly includes neighbor nodes address and the sector ID of the neighboring node. At the same time, the resources in the appointment stage make an appointment here, and each scan updates the reservation allocation table of the appointment stage, which mainly includes the reserved initiation node address, the reserved receiving node address, the used channel number, and the time slot. Finally, every node is going to get one neighbor node table and one reservation allocation table at the end of the scanning stage.

3.2 Appointment Stage

In the appointment stage, every node performs resource reservation in the data transmission stage according to neighbor nodes information table and the reservation allocation table acquired in the scanning stage. After the appointment is completed, node pairs which made the appointment are going to create a resource distribution table for a data transmission of the third stage.

Based on the literature [8], this paper comes up with a new idea. The prime procedures of the algorithm are presented in Fig. 2. In this picture, node S indicates the sending node, node D expresses the receiving node, REQ indicates that sending nodes send a request to receiving nodes, REP carries the information that the receiving node replies to the serial number which selected by sending nodes, that is, whether the next data transmission can be performed, and DATA indicates that the selected serial number is based on the data that needs to be communicated. After receiving the DATA, ACK indicates the data packet sent by the receiving node (the latter DATA and ACK are chiefly embodied in the data transmission stage in this paper). After the receiving node replies to the sending node with an ACK, the receiving node reports the link collision problem and the contradiction problem that it has heard through the TRG (trigger) frame to the sending node, and the sending node performs better resource allocation according to the received TRG frame. The following are the basic steps of the push-pull cascading mechanism, as shown in Fig. 2.

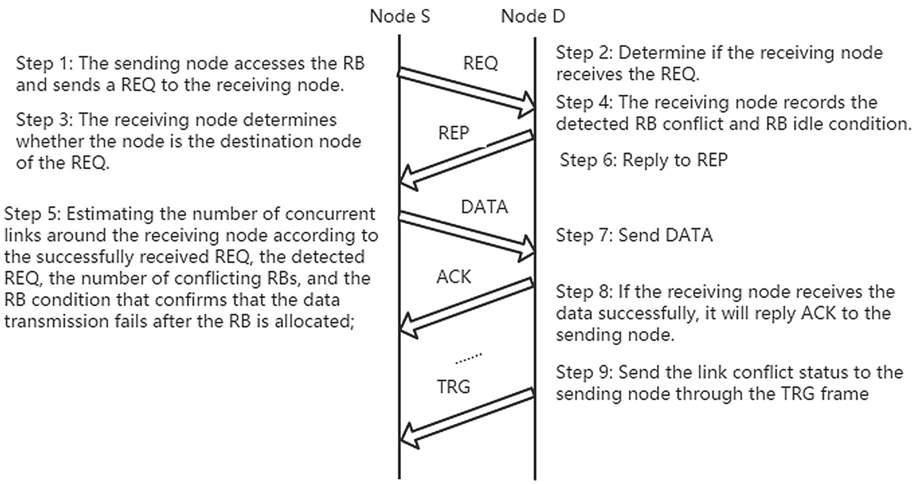

Fig. 2. Step diagram based on the push-pull cascade mechanism.

Step 1: The sending node contends to access multiple resource blocks according to the traffic volume and service type to be sent to different receiving nodes, and sends a REQ data transmission request frame to the receiving node on each resource block, and requests to allocate these resource block resources as subsequent data transmission resource block.

Step 2: If the receiving node successfully receives the REQ on a certain resource block, go to step 3. Otherwise, go to step 4.

Step 3: The receiving node determines whether the node is the destination node of the REQ. If yes, go to step 6. Otherwise, record the REQ transceiver node and mark the REQ link as the concurrent interference chain road (the sending node of the node and the node), then go to step 5.

Step 4: The receiving node records the detected resource block conflict and resource block idle condition, and then proceeds to step 5.

Step 5: Estimate the number of concurrent links around the receiving node according to the successfully received REQ, the detected REQ, the number of conflicting resource blocks, and the resource block condition that confirms the data transmission failure after the resource block allocation. Afterwards, go to step 6.

Step 6: Perform resource allocation based on the dynamic resource block number configurable according to the optimal resource block utilization rate, the estimated number of concurrent links at the local node, and whether the number of resource blocks in the network system can be dynamically changed. The algorithm, or the resource allocation algorithm based on the fixed resource block number, respectively obtains the resource block allocation situation in the new configuration, or the access probability P of the conflicted resource block in the fixed configuration, and then replies on the corresponding resource block according to the REQ information of the sending node. The REP data transmission request acknowledgement frame includes the resource block allocation condition under the new configuration or the access probability P of the conflicted resource block. Go to step 7.

Step 7: Receive the data information DATA sent by the sending node. If the data on all the allocated resource blocks is successfully received, feed back the ACK on the corresponding resource block, and then go to step 8. Otherwise, record the resource block that confirms the data transmission failure after the resource block allocation, situation, and link information for transmission failure.

Step 8: Wait for the next round of channel access. If the sending node has channel access right, go to step 1. If the receiving node has channel access right, then according to which node is waiting to send, send TRG to trigger the corresponding transmission of the frame scheduling. The node accesses the channel, and then proceeds to step 9.

Step 9: If the sending node successfully receives the TRG frame, go to step 1, otherwise go to step 8. In this paper, the resource block sequence is mainly the channel number. If two links choose resource block sequences are fully orthogonal, there are not collision occur even within the mutual communication range. If two links choose partially overlapping resource blocks sequence, the link conflict is going to exist.

3.3 Data Transmission Stage

When the appointment stage is finished, all nodes are going to create a data resource distribution table. The data transmission stage receives and sends information based on the resource distribution table and the neighbor node table. Considering the simulation behind, our data transmission stage is mainly composed of the following three parts.

(a) The first part is to generate a directional link [9]. It has been clarified in the front system model that the sending node and the receiving node contain 6 beams. Now each sending node establishes a link with all receiving nodes, and each sending node A and receiving node B need to be recorded (Fig. 3). In the case of beam activation when forming a link, the activation here refers to the beam that the two nodes cover each other when forming a link, that is, the calculation angle determines the beam.

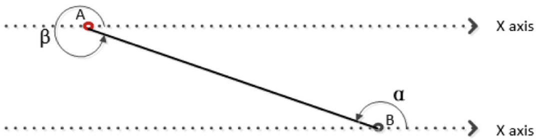

Fig. 3. Transceiver node activation beam confirmation map.

Record the information in beam activation confirmation table (two-dimensional table with rows and columns, for example, table (a, b)). That is, it is determined that each sending node needs to activate a beam when establishing a link with all receiving nodes, wherein the row of beam activation confirmation table represents all sending nodes, the column represents all receiving nodes, and a is a beam that the sending node needs to activate when establishing a link, b is the beam that the receiving node needs to activate. Here, the resource block is regarded as a time slot, and a directional link needs to be generated. For each of the sending nodes n, m of the receiving nodes of the sending node n are randomly selected from the M receiving nodes, and each of the selected receiving nodes is allocated [T/m] time slots (T is the total number of time slots). The m receiving nodes are allocated time slots in a random manner to form a data transmission time slot allocation table. Each row of the table indicates the destination node of the sending node in the relevant time slot, and each column indicates the corresponding time. The receiving node of the slot, in the case that one receiving node corresponds to multiple sending nodes, there will be conflicts between the links, so the data transmission time slot allocation table should be sorted. Check each column of the table, whether the receiving node m is in multiple rows. When it appears, only one of the repetitions is randomly reserved, and all the remaining repetitions are set to any other identical value. The time slot allocation table after the sorting does not theoretically have any interference between the links.

(b) The data transmission of the push mechanism is performed in the second part. For each sending node n, in each of the digital transmission time slots t, check the receiving node of the time slot, that is, forming a two-dimensional table (n, t). For each receiving node m, look for the t-th time column of this table to know who is the sending node. If table (n, t) not equal to 0 and n not equal to 0, it is determined that the nodes n, m point to each other. At this time, look up beam activation confirmation table to determine the beam activation of node n, m and go to set. The command is activated. In short, it is to clarify the situation of the sending and receiving nodes of each time slot and activate the beam where the sending and receiving nodes are located. Checking whether there is the same b in the column of the receiving node m in beam activation confirmation table, and if so, checking the receiving node m. There is a plurality of sending nodes pointing to m in the beam pointing to the sending node n. The result indicates that DATA fails. Otherwise, it means that DATA is successful. If table(n, t) not equal to 0 and n not equal to 0 is not satisfied, it is in somewhere. If no m and n are pointed to each other in the time slot (for example, if a time slot column is 0), then any beam of a receiving node p needs to be randomly activated to listen, and the receiving node p is randomly activated in the beam. Whether there are multiple sending nodes pointing to the receiving node p, you can check whether the column of the receiving node p in the beam activation confirmation table contains the randomly activated beam. If it is not judged to be idle, it is judged to be busy. After the interception, the result is recorded in the status situation record table to display the four cases of data transmission: DATA failed, DATA succeeded, free, busy. At this point the completion of the data transmission stage of the push mechanism.

(c) The third part is the push-pull cascading mechanism. In the place where the DATA fails in the push mechanism, the corresponding time slot is frequency-divided. The frequency division rule (collision scatter process): the 2 exponential frequency division, assign e + 1 to e, that is, the a's direction is set to the correspondence data transmission time slot allocation table, table (n, t) is matched with three parameters: m, e, c. Parameter e is an index of 2 (set e equal to 0 at the beginning), parameter c is between 0 and half of 2 to the power of e. The proportion of the sub-slots obtained when the frequency is successfully succeeded is filled in the corresponding failed place of the status situation record table generated by the push mechanism, and the other busy, free, and correct places are the same as before. The second status situation record table, at this time, completes the data transmission part of the push-pull cascading mechanism.

4 Simulation Performance

The performance of the proposed CSCP is compared with the push mechanism. The simulation results are as follows.

The number of time slots set in Figs. 4 and 5 is 20. As can be seen in Fig. 4, when the number of transceiver nodes is 1:1, the one-hop throughput of both mechanism nodes decreases with the number of nodes, but with the number of nodes increases, the node-hop throughput decreases. The lower

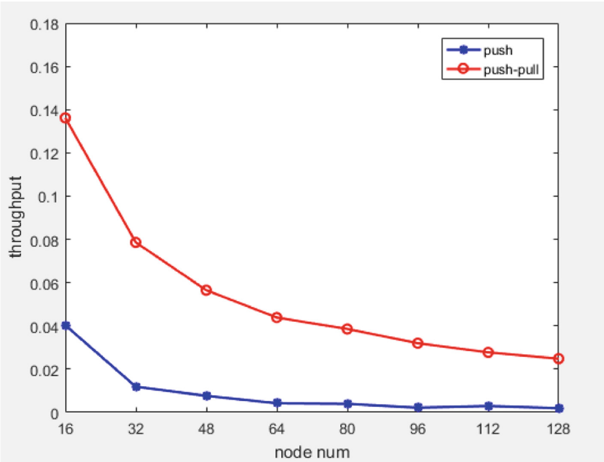

Fig. 4. The throughput of the two mechanisms in the case of 1:1 transceiver node ratio.

the throughput is. However, the push-pull mechanism has a higher throughput than the push mechanism, because the link collision increases as the number of nodes increases. The frequency division method can effectively scatter conflicts. It can be obtained through simulation. When the number of nodes is small, the throughput can be increased by at least 3 times, and when the number of nodes is large, at least 14 times can be improved.

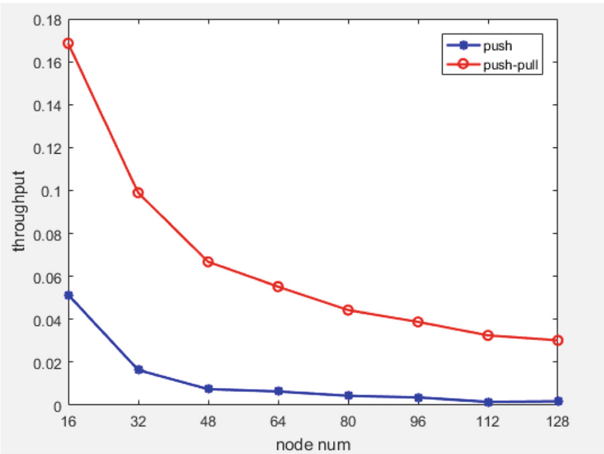

Fig. 5. The throughput of the two mechanisms in the case of 2:1 transceiver node ratio.

In Fig. 5, it can be seen that when the ratio of the number of transceiver nodes is 2:1, the overall trend of the two mechanisms is similar to that of the ratio of 1:1, but the throughput of the two mechanisms is 2:1. Compared with the ratio of 1:1, the throughput is improved. When there are fewer nodes, the throughput can be increased by at least 3 times. However, when there are many nodes, the throughput can be increased by at least 21 times. Therefore, the appropriate configuration of the number of transceiver nodes can improve the throughput of the network further.

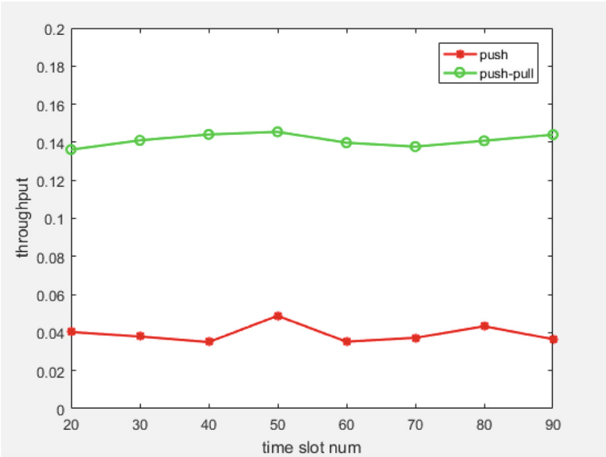

Fig. 6. Throughput of two mechanisms with different time slot values (N = M = 16).

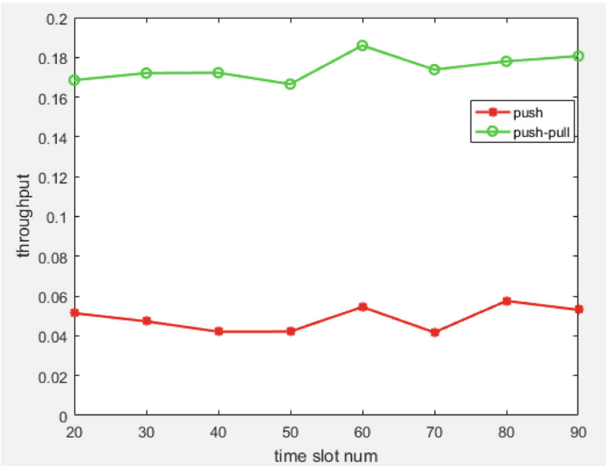

Fig. 7. Throughput of two mechanisms with different time slot values (N = 16, M = 32).

Figures 6 and 7 show the throughput comparison of the two mechanisms under different time slot values. The simulation results only show the case of a small number of transceiver nodes. Because through simulation, the number of transceiver nodes is larger than when the number of nodes is small.

In Fig. 6, the number of sending nodes and receiving nodes is the same. It can be obtained that the throughput of one-hop of the push-pull mechanism node changes relatively smoothly with the increase of the number of time slots, and the push mechanism is slightly ups and downs, but the amplitude is not large. It can be seen that, if the same number of transceiver nodes, the change of the internship has little effect on the node throughput.

In Fig. 7, the ratio of the transceiver nodes is set to 2:1. As the number of slots increases, two mechanisms' one-hop throughput of the nodes fluctuates. When the number of slots is 60, the throughput of two mechanisms reach a small peak, and then stabilizes, but the overall push-pull mechanism improves the throughput relative to the push mechanism. It is about 3 to 4 times.

In summary, it can be seen that the use of the protocol could improve the throughput of the network node one-hop. And throughput can be increased by about 3 times when the number of nodes is low. Of course it can be increased by more than 15 times when the number of nodes is relatively large. Moreover, it can be found through simulation that the number of time slots does not have much influence on the network throughput of two mechanisms.

5 Conclusion and Future Work

In order to address the link conflict problem as well as the link starvation problem in wireless directional ad hoc networks, this paper proposes one push-pull cascade-based coordinating network resource allocation protocol for transceiver nodes. The protocol considers the idea of frequency division, that is, collision scattering to deal with the proposed problems. It includes three stages: the scanning stage, the appointment stage and the data transmission stage. According to simulation results, the protocol could obviously increase network throughput. In the future, further research on neighbor discovery problems or link conflicts during the scanning stage is needed.

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