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Research on Multiple Access Algorithms for Wireless Network

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Abstract: Nodes in the communication network mainly depend on the Media Access Control (MAC) layer protocol design. To ensure the MAC protocol achieves high throughput, low latency, and high service quality, this paper designed a "centralized-distribution" system MAC protocol combined with a slot allocation algorithm. This allows it to quickly adapt to the topology changes in the network and the overall network frame structure. For the centralized time slot allocation, since the system's frame structure changes across the entire network, the root node must gather information from other nodes. This ensures that the root node can collect the latest topology information when the network topology changes and subsequently adjust the frame structure of the whole network for the distributed time slot allocation. The simulation results show that the adaptive time-division multiple access mechanism can quickly adapt to changes in topology and the network's frame structure. It enables adaptive changes in node transmission times, ensures the rapid transmission and circulation of large-capacity data between nodes, and improves transmission efficiency.

Keywords: TDMA; Wireless network; MAC protocol; Time gap allocation

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1. Introduction

The Wireless Mesh Network (WMN) is a dynamic self-organization system composed of a group of wireless movable nodes independent of fixed network facilities [1]. Each node in the network completes the interaction and access of information through self-organization. In the hierarchical system of a wireless mesh network, the MAC layer works between the physical layer and the network layer. On the one hand, it shields the underlying technical details to realize the node access channel. On the other hand, it provides unified services to the network layer, including queuing, grouping, error control, confirmation, and other functions [2–10]. The performance of MAC layer protocol is closely related to the utilization rate of a wireless channel, thus affecting the performance of the whole network, which is an important research topic in wireless mesh network. Compared to the traditional mobile self-organized network, this network not only has the characteristics of terminal mobility, service randomness, limited wireless channel resources, and the absence of a central network, but also features high-speed terminal mobile, highly dynamic changes in network topology, high real-time security services, and a large network load. Research on self-organized network MAC protocols focuses on how terminals access the wireless channel and effectively use channel resources. These protocols play a decisive role in important indicators such as network delay, throughput, and channel in vehicular networks. An ideal MAC protocol can effectively address issues like hidden terminals, exposed terminals, access conflicts, and merge conflicts while ensuring real-time security, network performance stability, and access fairness [11].

When the network topology structure changes dynamically, the performance of the traditional MAC protocols based on fixed time slots will decrease, lacking good scalability. Additionally, the time delay of the node access channels will fluctuate greatly due to changes in the topology structure, which is not conducive to the accurate and efficient transmission of security services [12–15]. This paper proposes a time slot allocation mechanism that can quickly adapt to changes in topology and frame structure across the whole network. This mechanism can still guarantee a high utilization rate of the channel when the network topology structure changes significantly, and it has good scalability.

2. Centralized time-slot allocation mechanism

The allocation criterion with the minimum convergence time for the node "convergence-issue" is as follows: the root node is allocated successively based on the number of node hops (relative to the root node) during the centralized allocation of control time slots and is allocated in the opposite order in the next cycle. In the frame structure design of the system, the nodes can occupy the corresponding business slot and the reverse corresponding to the scheduling slot. Therefore, to achieve the criterion minimum "convergence-distribution" convergence time allocation, the root node allocates based on the number of node hops (relative to the root node). All nodes can obtain the reverse convergence time slot, and node information converges to the root node within one convergence frame. The root node then allocates the scheduling time slot in the next cycle according to the increasing number of node hops, and the convergence time slot of the next cycle of all nodes is opposite to the scheduling time slot. Therefore, the cyclic process effectively maintains the allocation criterion of "reverse allocation of convergence time slots and forward allocation of scheduling time slots", ensuring that the convergence time of each node for "convergence-issue" is always minimized.

Suppose that node k, which has jumped from the root nodes, receives an Access Request Frame (ARF) at its network node upon startup. As part of the node's network access process, the startup node sends an ARF to request access during the allocated scheduling time slot. Upon receiving the startup node's ARF, the network node records the jump number of the startup node in the "Node Jump Information" column of the adjacent node table. Subsequently, it transmits this jump information through the Convergence Distribution Function (CDF) during its designated convergence time slot, continuously updating and forwarding the information to the root node. Because it has been assigned to the scheduling slot in the opposite slot, and the network node's scheduling slot is an incremental jump number (relative to the root node), regardless of the boot node's jump value, the jump information can be within converged to the root node within a convergence frame. Moreover, in each cycle's convergence frame, all nodes in the network should gather their jump number information to send to the root node [16–18].

During the aggregation process, each node receives CDF updates from nei_tab of other nodes in the network and generates its own CDF based on this information. This way, the jump information is constantly updated, and eventually, the nei_tab of the root node contains the jump information of all network nodes, including the startup node. The processing of nodes after receiving the CDF is shown in **Figure 1**:

(1) Check whether the node is in the network state. If yes, continue by comparing whether the root node (R_ID) of the sending node's CDF and its own root node (r_id) are identical and whether the merge status (Merge) is 0.

(2) Once the above conditions are met, the node updates all information from the CDF adjacent node table (Nei_tab) to its own neighbor node table (nei_tab). This update includes node jump information, an increased number of service time slots, and an updated number of subnet nodes. When updating node hop information, the node hop recorded in nei_tab column 0 is relative to the CDF sending node, and must be transformed to be relative to itself. The hop transformation algorithm is depicted in **Figure 2**.

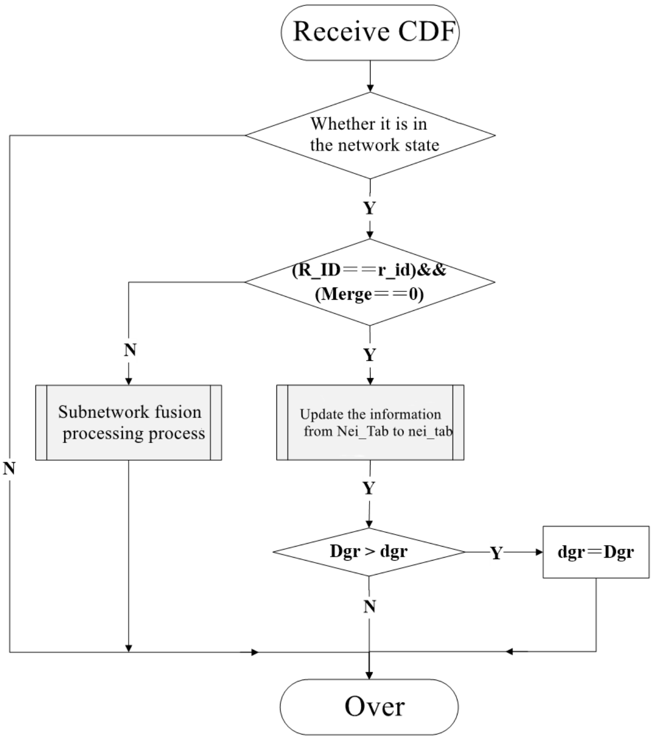

Figure 1. Processing flow when the node receives the CDF

```
for i from 0 to 32 do
if nei_tab [i] [0] = -1 then
   if (nei_tab[i ][0] ≠ -1) && (nei_tab[i ][0] > Nei_Tab[i ][0] + 1)  then
nei_tab [i] [0] = nei_tab [i] [0] + 1
   else if (nei_tab[i ][0] = -1)
nei_tab [i] [0] = nei_tab [i] [0] + 1
     end
  end
end for
```

Figure 2. Jump transformation algorithm

In the next cycle, the root node allocates scheduling slots based on the number of nodes recorded in the next neighbor table (_tab), sorted by increasing node jumps across the entire network. When node jumps are identical, IDs are allocated in ascending order. Each node is assigned a scheduling slot sequentially starting from slot 0. The root node records the scheduling slot allocation information in the scheduling slot information column (tab column 0) and transmits it with the ARF.

When a node jumps from the root node, it updates its scheduling slot allocation information upon receiving the root node's ARF and obtaining its own scheduling slot. Concurrently, each jumping node sends ARF during its allocated scheduling time slot. As a result of continuous updating and forwarding of scheduling time slot allocation information, all network nodes obtain their respective scheduling time slots within this cycle, including nodes that started up in the previous cycle. Distributing distribution information to the root node can also be completed within a scheduling frame, as the scheduling time slot allocation determines the direction of ARF transmission from nodes with fewer jumps to nodes with more jumps.

During the distribution process, the network node receives the ARF to update scheduling time slot distribution information. Both itself and the ARF sending node operate within the same network state. This process involves a "time slot allocation-multiplexing", as shown in **Figure 3**:

(1) The node updates the scheduling slot information (Tab column 0) and service slot increase information (Tab column 2) recorded by the ARF sending node to its own "allocation-reuse" table (tab column 0 and tab column 2), and performs the conflict detection and update process of slot reuse, and will be introduced in the later text.

(2) The node checks if there is a scheduling slot assigned to itself in the tab column 0 and if so, set the network stop identity (stop) to -1.

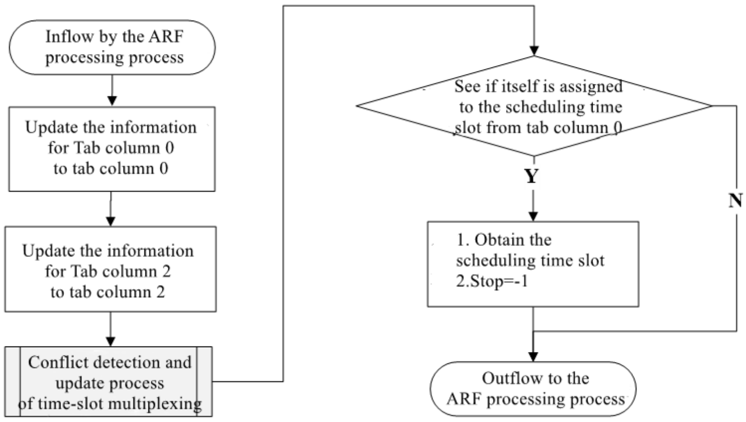

Figure 3. The "time slot allocation-reuse" processing process when the node receives the ARF

3. Distributing distribution mechanism

When the node is allocated to the scheduling time slot, it can fix and occupy the corresponding service time slot in each service frame, realizing the minimum service time slot guarantee [4]. To further improve the channel utilization of the system MAC protocol, distributed time slots can be multiplexed by interacting ARF and Feedback Frame (FF). Because each node receives information from at least two other nodes at the end of each cycle, even if there is a "convergence link interrupt" issue, a supplementary distribution mechanism can be used for scheduling slots between these nodes. Therefore, when their own scheduling slot arrives, network nodes can ensure awareness of neighboring nodes within their scope. Additionally, since each scheduling time slot corresponds to a service time slot, nodes can select unconflicting scheduling time slots for reusing service time slots after excluding the adjacent two hops. However, each node reuses time slots within the scheduling frame, the "conflict avoidance-conflict detection" method is adopted to resolve conflicts arising from time slot reuse.

For conflict avoidance, nodes collect information on service time slots reused by nodes within a two-hop range by receiving ARFs sent by other nodes before their own scheduling time slot. This allows nodes to select a service time slot outside the two-hop range to avoid conflicts when their scheduling time slot arrives. Nevertheless, since each node can only send one ARF per scheduling frame, there might be delays in transmitting time slot multiplexing information to all nodes within the two-hop range, leading to potential multiplexing conflicts. Therefore, conflict detection between nodes is still needed.

As shown in **Figure 4**, nodes undergo the ARF or FF "slot allocation-reuse" processing, which involves time slot reuse conflict detection and update processes in two main stages. Using i for variables to find Tab or tab, and two nodes A and B for example to introduce the process. Assume node A received the ARF of node B:

(1) Node A determines whether node B multiplexes the time slot i by judging whether Tab [i] [1] is equal to 0, and proceeds to the next stage without reuse.

(2) If node B multiplexes slot i, node A checks whether slot i is multiplexed by whether the tab [i] [1] is equal to -1. If tab [i] [1] is equal to -1, node A sets tab [i] [1] to 1, indicating that slot i has been multiplexed by a hop node, and adding the ID field to ta_tab [i] indicates that the node with complex slot i is node B. And then move on to the next stage.

(3) If tab [i] [1] is not equal to -1, node A determines whether there is a hop node multiplexing time slot i but not node B by judging whether tab [i] [1] is equal to 1 and whether ta_tab [i] is equal to the ID field. If so, update the tab [i] [3] to the ID field value, indicating that node B has a reuse conflict. If otherwise, proceed to the next stage.

After entering the next stage:

(1) Node A determines whether the skip node of node B multiplexes the time slot i by judging whether Tab [i] [1] is equal to 1, if it ends otherwise.

(2) If node B multiplexes the time slot i, then determine whether it has multiplexing conflicts by judging whether the tab [i] [3] is equal to the ID. If so, tab [i] [1] is set to -1, with the multiplexing slot i abandoned, and ta_tab [i] set to 32 indicating that the slot i has been reused. If otherwise set the ta_tab [i] to 32. The process ends.

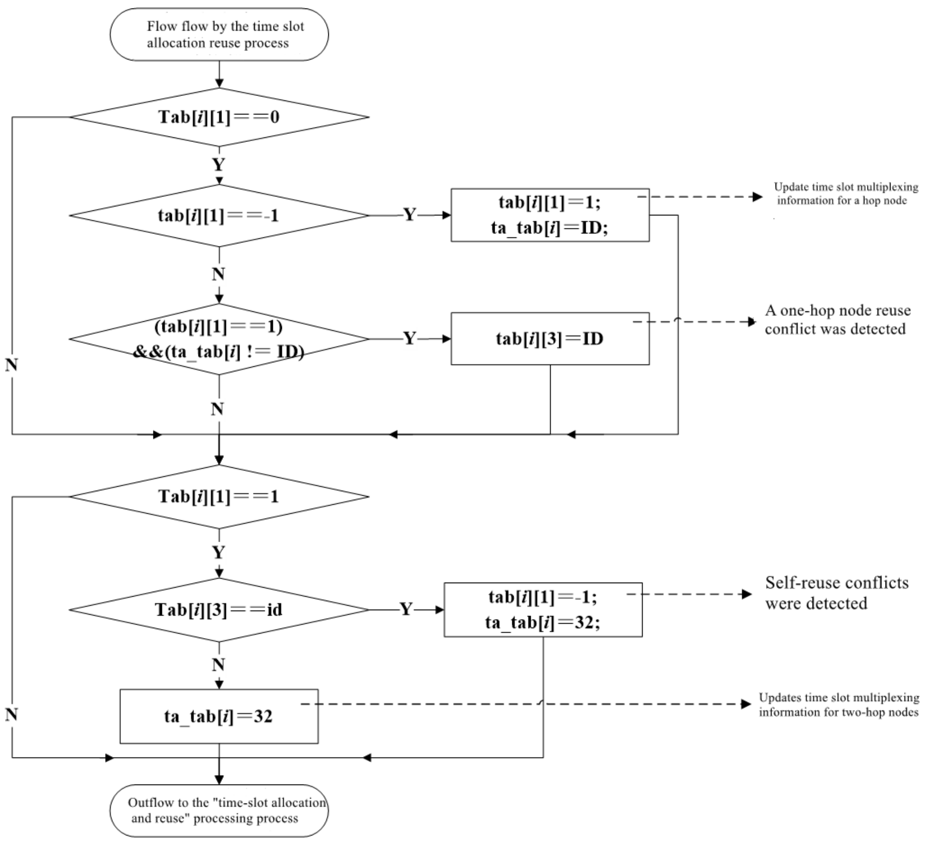

Figure 4. Multiplex conflict detection and update process

After each node sends the ARF or FF, the reuse conflict column (tab column 3) of the allocation-reuse table is initialized because the logged reuse conflict information has been sent to the hop node. However, the third column of the tab is at the end of the scheduling frame. If a conflict is reported in the next cycle, the conflict continues for one cycle. Thus, when the scheduling frame ends, the node views the tab column 3 and switches to the broadcast state if there is still reuse conflict information. In the first service frame, the node performs its own service time slot in the sequence of 10 broadcast time slots, wherein the broadcast time slot 0 sends the reuse conflict information by sending the ARF, so there is no reuse conflict in the following service frame.

4. The algorithm simulation and the results

4.1. Network model

The proposed improved algorithm was run on version 8.0 of the OPNET emulator. The network is composed of 32 mobile nodes, the wireless transmission range of each node is 150 m, and the network coverage area is 500 m. Nodes can move randomly within the scope of the network topology [5]. We performed simulations for different mobility levels using the "Random Waypoint Model". Different movement levels are achieved by adjusting the movement speed of the node and the movement pause time, which in our simulations was 0. For each scenario, the sending node and the destination node pairs are randomly selected. The sender produces a packet in an exponential distribution of one packet per second, and the effective planting load of each packet is 512 bytes. Each simulation lasted for 10 minutes. The protocol for the simulation is a comparison of the two Time Division Multiple Access (TDMA) before and after refinement with positional information. We call this basic TDMA and improved TDMA, represented by TDMA and I_TDMA, respectively. The MAC layer protocol used is IEEE802.11 with a 1 Mbit/s capacity.

4.2. Delivery success rate of the package

Figure 5 shows the packet-sending success rate for the basic TDMA and for the improved I_TDMA in three cases. It can be seen that after routing and maintaining TDMA with location information, the success rate of packet transmission is basically no different at rest, which can reach 100%. In the case of movement, we see a great improvement in the transmission success rate of TDMA after routing and maintenance using location information, with an average improvement of 40%–50%. Simulation results show that the improved algorithm not only enhances the packet-sending success rate of TDMA by 40%–50% but also reduces the end-to-end delay by an order of magnitude. Moreover, this improvement remains consistent regardless of the node's movement speed. This improvement not only greatly upgrades the performance of TDMA, but also the ability of TDMA to adapt to the dynamic topology, enhancing the applicability of TDMA in networks with highly mobile nodes.

4.3. End-to-end delay

In **Figure 6** we see that in all three cases, the improved TDMA whose end-to-end delay is much smaller than the basic TDMA, basically does not change with the node movement speed. This direct transmission of data packets through location-based routing protocol not only reduces the number of flooding but also has no process of establishing complete source routing packets, which reduces the end-to-end delay greatly.

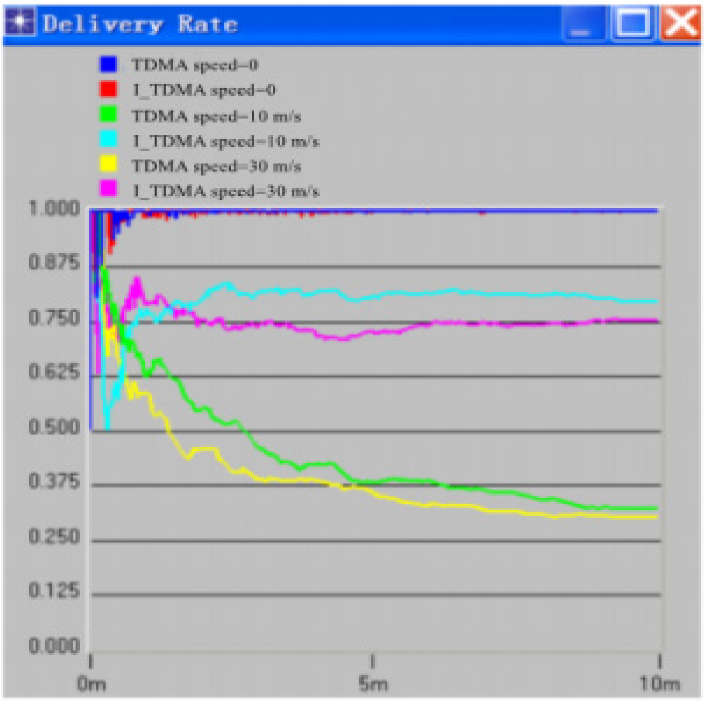

Figure 5. Comparison of delivery rates

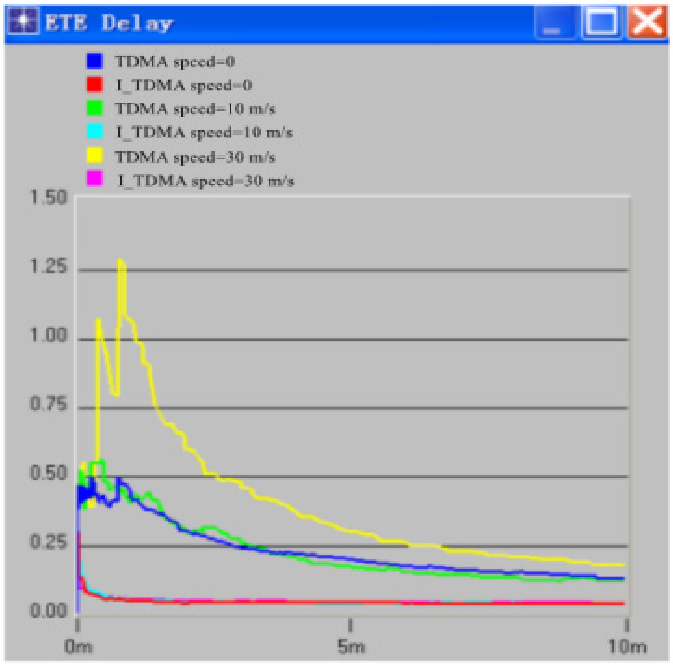

Figure 6. Comparison of ETE delays

5. Conclusion

This paper designs the "centralized-distributed" time slot allocation mechanism for the system MAC protocol. Firstly, for the centralized time slot allocation mechanism, it mainly designs the allocation process of scheduling time slot when the frame structure changes. The whole "convergence-distributed" process only needs a scheduling frame and a convergence frame of time, to realize the rapid interaction of control information between the root nodes and other nodes. With the rapid change of frame structure in the whole network, the node also obtains the applied increased scheduling time slot or service time slot. In the next stage, for the distributed time slot allocation mechanism, it is stipulated that the nodes can multiplex the service time slot by scheduling the time slot, and the number of time slot reuses is calculated according to the maximum connectivity of the network [19,20]. In the process of reuse, the nodes schedule the slot multiplexing information, check whether the nodes are within the reuse information, and use the first service frame to broadcast the conflict information, so that the detected conflicts can be quickly eliminated.

Disclosure statement

The author declares no conflict of interest.

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