Research Article

5G Wireless Networking Connection and Playback Technology Assist the Low-Latency Propagation of New Media

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This article conducts an indepth study on the delay caused by time division multiple access (TDMA) technology and theoretically analyzes some methods that can reduce the TDMA delay. Traditional dynamic time slot allocation algorithms usually only consider the completion of conflict-free time slot allocation in distributed scenarios, but they do not clearly specify the order of time slot allocation. The order of time slots allocated to each node is ultimately consistent with the new data flow. The order of media dissemination is not the same. Aiming at the scheduling delay problem caused by the inconsistency of the new media low-latency propagation time slot allocation sequence and the data stream sequence, a protocol using the master time slot adaptive time slot exchange technology is proposed. The protocol designs the corresponding super frame structure and realizes the neighbor node discovery strategy and the time slot allocation based on the priority list. At the same time, the time slot switching technology is used to adjust the time slot sequence so that it tends to the data flow sequence. The exchange criterion based on the low-latency propagation data stream value of the new media is designed to solve the problem of optimizing the time slot of multiple data streams in the network. Through the simulation results and analysis, it can be seen that the architecture design proposed in this paper can fulfill the expected requirements of the wireless Mesh network and can achieve good low-latency performance for the highly dynamic network topology. It can also achieve good performance in terms of network throughput and data flow delivery rate, and it has adaptability to high dynamic topologies. By comparing with the traditional algorithm design, the design proposed in this paper has a large improvement in low latency and high submission rate. Therefore, it can be considered that the low-latency architecture design proposed in this article has better performance for new media's low-latency propagation and highly dynamic network topology.

1. Introduction

With the integration and development of mobile communications and Internet technologies, the scale of informatization has grown rapidly, and new businesses and corresponding applications have continued to emerge [1]. In 2019, the number of mobile network users in the world has exceeded 9 billion. By the end of 2020, the total number of devices connected to mobile communication networks in the world will be 1,000 times that of 2019. The explosive growth of mobile communication data traffic has also brought severe challenges to global network communications [2]. First of all, the fourth-generation (4G) mobile communication network technology can no longer withstand the increase in network energy consumption and bit cost, and

it is difficult to support a thousandfold increase in traffic capacity. Secondly, the increasing demand for network access will inevitably have a higher demand for spectrum. At present, the scarcity of spectrum, the fragmentation of available spectrum, and the large distribution span are difficult to use efficiently, which restricts the development of mobile communications in my country. Finally, the current ability to intelligently optimize the user's personality is still insufficient, and it is necessary to solve the problems of effective management of each network, increase network capacity, simplify interoperability, and enhance user experience. In order to cope with many difficulties and meet the increasing demand for mobile communication, the fifth-generation (5G) mobile communication network for the Internet of everything came into being [3].

5G technology is a new development after 4G network technology. At present, China is actively developing 5G technology research and development and is a representative of the fifth-generation communication technology. 5G technology will use 28GHz and 60GHz spectrum, which are extremely high frequency, much higher than the currently used spectrum [4]. 5G communication technology can provide customers with a faster transmission speed. Compared with the current 4G network, the transmission speed can reach 40 to 100 times that of the current 4G network. However, there are still some obstacles to the development of 5G technology, such as its extremely low signal reflection capability and extremely low latency. In the process of 5G development, new base stations and network optimization should be further used to further improve coverage and improve Internet quality [5]. In the process of 5G technology development, relevant Chinese manufacturers are actively exploring, accelerating independent research and development, applying the concept of polarizing code to the field of mobile phone data transmission, and accumulating a large number of patents during the research process. Huawei announced the use of polarization codes in the field of 5G channel coding and actively promoted it, took the lead in completing the first phase of the air interface key technology test and completed the test of IMT-2020 (5G) technology, and proposed a polarization code plan [6].

This article analyzes and expounds the related theoretical principles of the TDMA protocol delay and theoretically derives the delay reduction method from the three aspects of adjusting the time slot allocation sequence, uniformizing the time slot allocation and uniformizing the flow distribution. Then, we introduced the principle of the traditional dynamic time slot allocation algorithm and pointed out the existing problems and corresponding solutions. Aiming at the shortcomings of traditional dynamic TDMA, this paper proposes a new media propagation path sequence-based time slot allocation protocol algorithm SAOPPS-TDMA, which uses control information packet interaction to complete neighbor node discovery, and uses priority lists to complete distributed initial time slot allocation, alleviating the time slot scheduling delay overhead caused by the inconsistency of the time slot sequence and the data stream sequence, thereby increasing the data forwarding speed and reducing the data delay. In the case of multiple data streams, the algorithm uses the exchange criteria based on the value of the data stream to complete the time slot adjustment to ensure lower latency for high-priority data streams. The algorithm in this paper can provide support for the time slot allocation strategy of the Mac layer, thereby reducing the end-to-end delay of the network. The simulation shows that this design has a high Qos guarantee on the performance of low latency, high throughput, and high delivery rate.

2. Related Work

Option2 independent deployment solution is an independent 5G network structure, a complete 5G network constructed by NR and 5GC. It can be said that this is the final development form of 5G network, but it is relatively

difficult to implement; so, there is an evolutionary 5G network development plan. Wireless networking can be flexibly based on different deployment conditions. The option of the SA architecture is the ultimate goal of 5G network construction, which can reflect all the advantages of 5G. It should be noted that in the process of evolution, it is necessary to avoid excessively long evolution process to prevent excessive investment costs.

At present, related technical research on wireless Mesh networks mainly focuses on Mac layer channel allocation mechanism and network layer routing algorithm [7]. The efficiency of channel allocation determines the reasonable utilization of channel resources by the network, and the routing algorithm determines multihop data. In the forwarding path of the flow, these two technical points play a decisive role in the performance of the entire wireless Mesh network; so, since the emergence of the wireless Mesh network, it has been concerned and studied by many scholars at home and abroad [8, 9]. With the increasing emphasis and research on wireless Mesh networks, wireless Mesh network algorithms and protocols for different topological types and service requirements emerge in endlessly [10].

On the resource scheduling mechanism of single radio frequency and multiple channels, related scholars have proposed Slotted Seeded Channel Hopping (SSCH) channel allocation algorithm [11]. SSCH performs channel switching through a channel hopping list designed according to the initial channel and time slot seed. When two adjacent nodes switch to the same channel, they can communicate. This channel allocation does not require a special control channel, but the design requirements of the channel hopping list are extremely high, and it is not easy to obtain efficient channel utilization. Relevant scholars solve the multichannel hidden terminal problem through the control protocol interaction design of four-way handshake during the control channel contention period and improve the effectiveness of channel allocation by selecting the channel with the least load or the longest idle time during channel selection [12]. Relevant scholars solve the hidden terminal problem by switching to the public channel for channel status broadcasting at regular intervals and then switching to the public channel for channel negotiation at regular intervals [13–15]. This design can be realized without network time synchronization, but there is also an increase in the probability of control channel collisions, which leads to a bottleneck in network performance.

Researchers have proposed a multichannel allocation method in which the channels of certain nodes are fixed, thereby reducing the number of nodes for channel switching [16]. This scheduling mechanism reduces the switching overhead and channel allocation difficulty in network channel allocation, but it must have all network nodes. The information does not apply to distributed scheduling architecture. Based on the SSCH allocation algorithm, relevant scholars divide the wireless Mesh network into subnets twice the number of available channels and design a channel hopping list in combination with time slots, so that the subnets of each time slot are always on the same channel in pairs [17, 18]. In the time slot period, each subnet has a

time slot that can be in the same channel as other subnets. This channel allocation mechanism is suitable for wireless Mesh networks with a fixed topology [19, 20]. For highly dynamic network topologies, subnet division is a difficult problem to deal with.

3. Post-5G Low-Latency Propagation Edge Network

3.1. Post-5G Edge Network Architecture. In order to achieve demanding latency indicators, we design the edge network architecture shown in Figure 1. Different from the deployment of base stations in traditional cellular systems, we deploy a large number of Mesh components. Multiple components close to the new media position form a subedge network. Edge subnetworks can use SDN for centralized management. Different subedge networks at multiple new media locations can adopt packet-switched communication modes to provide extensive coverage of new media and support distributed routing.

“Mesh 1” and “Mesh 2”, respectively, represent the components near the location of the new media, and the physical infrastructure of these components is the same. Except for node 5 in the middle, all nodes of component 1 can be wirelessly connected to small cell base stations to realize the function of ultra-dense network. Without loss of generality, node 1, node 2, and node 3 of “Mesh 1” are input nodes, which are connected to the data plane of SDN. Node 9 is the output node, which uses the LTE frequency band to communicate with the new media. OBU has multiple wireless interfaces on each new media. Node 9 is configured with microcloud, which enables the edge network to have extremely high computing and storage capabilities, and node 9 has a feedback connection with the SDN control plane. These have enhanced the agility of the network. Unlike other wireless Mesh networks, each node in the component adopts a virtual communication mode and has a high cache. This can not only reduce the delay of the backhaul but also reduce the denial operation in the access control scheme. When the nodes of the Mesh component increase, the performance of path diversity increases. On the other hand, the increase in the total number of nodes leads to an increase in routing calculations and an increase in the cost of physical infrastructure. In this design, by considering the cost and performance trade-off, we only consider the configuration with a total of 9 nodes.

3.2. Network Flow Control for Low-Latency Propagation of New Media. Before the source transmits data, the circuit-switched network needs to establish a fixed bandwidth circuit (channel) between the source and destination nodes and then sends the data directly. Before communication, message switching usually does not need to establish a connection. Circuit switching is a connection-oriented service. Message switching is a connectionless service, and message switching has higher flexibility. Virtual circuit switching is actually based on traditional circuit switching, adding a packet mechanism. Compared with message switching, data packet switching adds a grouping mechanism.

The middle node will completely store the message from the previous hop and then forward it to the next node. In the message switching (or packet switching) mechanism, the source sends its message (or data packet) to the destination. Each node in the network has to make a decision to determine which node to send the message to in the next hop. The routing decision can be determined statically or dynamically. Finally, the message is passed to the destination. Due to the hop-by-hop nature of the transmission, the time interval will be very different because the route used by each message may be very different. If there is no optional path between source and destination, or the selected link has no remaining resources or capacity (the link quality is not good), the destination may not receive the transmission message. The network status information containing the fault information may not be fed back to the source and destination. There have been many solutions that propose improved designs. For example, data packets can wait in a queue until there are remaining resources on the link.

The packet-switched network makes the transmission of packets more reliable. With additional protocol options, the network sends the sequence number of the untransmitted data packet to the sender, and the large data block is divided into discrete data segments (data packets). Data packets are usually transmitted from new media on the network on a first-come, first-served basis. If the network is overloaded, data packets will be delayed or discarded after a finite time interval. The main advantage of packet switching allows “statistical multiplexing” on communication lines. Data packets from many different sources can share a line, so that a fixed capacity can be used very efficiently.

In our Mesh design, the first 4 subslot services can just be forwarded from the source node to the destination node. In the case of heavy business traffic, in order to ensure the business forwarding required by the ultra-low delay, we add 10 additional subslots to continue forwarding the data packets in the buffer. If there are still remaining data packets in the node after the end of the 10 additional subslots, these data packets will continue to be forwarded following the next time slot. In computer simulation, we always assume that the lower limit of the number of subslots for a complete transmission is 4 and only count the number of additional subslots required for service forwarding. A complete transmission is divided into a training phase and a data transmission phase. Consider here that the training phase contains only one time slot.

4. Algorithm Design of Time Slot Allocation Protocol

4.1. Uniform Distribution of New Media Traffic. Assuming that the queuing delay of the i -th node in the data stream is W_i , the service data arrival rate is λ_i , the number of occupied time slots is M_i , and the cumulative queuing delay W_{total} of the data stream is

$$W_{\text{total}} = \sum_{i=1}^K [M_i T_f / \lambda_i + T_f M_i / (1 - 2\lambda_i)]. \quad (1)$$

FIGURE 1: Edge network architecture for low-latency propagation of new media.

Suppose the ratio of the arrival rate of the i -th node to the number of occupied time slots is θ_i :

$$\theta_i = T_f \lambda_i / M_i. \quad (2)$$

Let the function $f(x)$ be

$$f(x) = x T_f - \frac{x^2 T_f}{1 - 2x M_i}. \quad (3)$$

The cumulative queuing delay $W_{\text{total-sin}}$ of a single-hop data stream and the cumulative queuing delay $W_{\text{total-mul}}$ of m data streams are, respectively,

$$W_{\text{total-sin}} = \sum_{i=0}^{K-1} [M_i \bullet f(\theta_i)], \quad (4)$$

$$W_{\text{total-mul}} = \sum_{j=0}^{m-1} \sum_{i=0}^{K_i} [m \lambda_i f(\theta_{ji})]. \quad (5)$$

Assume that the upper-layer business load is normal, the entire network is in a stable state. The total data flow of the wireless adhoc network is fixed, which is equal to the flow of the upper-layer data service load. Suppose the upper-layer service load flow is σ , then σ satisfies

$$\sigma = \sum_{i=1}^K \sum_{j=1}^m (M_i \lambda_{ji}). \quad (6)$$

Assuming that the time slot occupied by each node is the same as M , we get

$$M \sigma = \sum_{i=1}^K \sum_{j=1}^m (M_i \lambda_i \theta_{ji}). \quad (7)$$

4.2. Neighbor Node Discovery Strategy. In the declare 1 phase, each node corresponds to a control time slot, and the node's competition statement is broadcast in its own control time slot. As shown in Figure 2, all nodes send DCR1 in the corresponding control time slot in turn. When

FIGURE 2: Schematic diagram of node sending competition in declare stage.

the declare 1 phase is completed, all nodes will receive the DCR1 packet of the one-hop neighbor to obtain the one-hop neighbor information. At the same time, the DCR1 packet includes the time slot contention information, and the node will also know the situation of the one-hop neighbor node competing for the time slot. The DCR1 packet mainly contains the node ID number, node competition time slot statement, node competition degree, and check code to ensure that the information is correct.

The declare 2 phase is the same as the declare 1 phase. Each node also corresponds to a control time slot. In its own control time slot, it broadcasts the competition declaration of neighboring nodes around a hop summarized in the declare 1 phase. As shown in Figure 2, all nodes send DCR2 in sequence in the corresponding control time slot. When the declare 2 phase is over, all nodes will receive the DCR2 packets from the one-hop neighbors, so as to obtain the one-hop neighbor information of the surrounding one-hop neighbor nodes, that is, obtain the surrounding two-hop neighbor information and time slot contention information. The DCR2 packet mainly contains the node ID number, the one-hop range neighbor node competition information, and the check code to ensure that the information is correct.

4.3. Distributed Time Slot Allocation Based on Priority List. Each node will obtain neighbor information and contention within the two-hop range according to the two-hop neighbor information table and allocate time slots based on this information. Because the time slot allocation algorithm adopted by the wireless ad hoc network is usually distributed, it is necessary to use a unified time slot allocation table to complete the distributed time slot allocation. The time slot allocation table determines the occupancy priority of each node in different time slots; so, this section refers to this as a priority list.

Each node has the highest priority in a time slot. The priority list is represented by positive infinity. This time slot is called the main time slot of the node, and the other time

slots are called the normal time slot of the node. When several nodes within the two-hop range compete for the same time slot, the final owner of the time slot will be determined according to their priority.

In order to ensure the QoS of some services, the priority of some special services can be increased. Nodes can add a degree of competition when sending DCR1 packets. The degree of competition is 0 by default, which means no priority. When more time slots need to be competed, the node can increase the degree of competition. When allocating time slots based on the priority list, the node will consider the degree of competition of the competing nodes and add the fixed priority of the priority list to the degree of competition of the node. In the network of Figure 2, suppose that node 9 has emergency services and needs more time slots, the contention level in the DCR1 packet sent by it is set to 2, and the declare 2 phase ends. Based on the priority list, the dynamic priority of node 9 in time slot 4 and node 5 becomes 10 and 9, which is higher than the priority of node 8; so, node 8 will give up occupying time slot 4 and time slot 5. Node 9 will get time slot 4 and time slot 5.

4.4. Main Time Slot Adaptive Time Slot Exchange. Each node has the highest priority in a time slot, and this time slot is called the primary time slot of the node. Because of the principle of space division multiplexing, some nodes may occupy multiple time slots. After the dynamic division of time slot resources is completed, the inconsistency between the time slot sequence and the data stream sequence may cause a large scheduling delay; so, the main time slot is required exchange. The main time slot is adaptively exchanged in the exchange frame. Because the exchange frame initiated exchange request packet content is less, the number of interactions is more, the concurrency is not high, and the channel access technology used in the exchange frame is CSMA.

The sending node monitors the channel before sending data, finds that the channel is free within a DIFS, and then sends a data packet to the receiving node. After receiving

the information packet from the sending node, the receiving node will wait for a SIFS time and then reply with an ACK message to confirm receipt. If the channel is busy or the continuous idle time does not reach DIFS, the sending node will enter the conflict avoidance state and will wait for a random period of time. If the sending node does not receive the ACK from the receiving node, then the sending node will retransmit that packet. Random time adopts binary exponential backoff algorithm; that is, the more collisions, the longer the waiting time.

In the wireless adhoc network, the source node of the data flow will send a time slot exchange packet to the next node in the data flow direction, requesting the exchange of the main time slot. If the main time slot sequence is inconsistent with the data flow direction, the exchange will occur. The next node in the direction of the data flow is called the forward successor node, the previous node is called the forward predecessor node, and the next node in the reverse direction of the data flow is called the reverse successor node. The node is called the reverse predecessor node, node 3 is the forward successor of node 2, node 1 is the forward predecessor of node 2, and node 4 is the forward 2-hop successor of node 2. The forward successor node of a node is also the reverse predecessor node.

After the source node and the forward successor node complete the time slot exchange, the forward successor node will continue the time slot exchange to its forward successor next hop node and so on. This way of sequential time slot exchange in the direction of data flow has become a positive new media propagation of time slot exchange. At the same time, because the forward successor node has exchanged time slots with the next hop node of the forward successor node, the main time slot of the forward successor node has changed, which may cause the time slots of the source node and the forward successor node to be reversed again. The node and the forward successor node need to exchange time slots again. This time slot exchange initiator is the successor node, and the receiver is the source node. This time slot exchange in the reverse direction of the data flow becomes a reverse new media propagation. The entire data stream is adjusted in the sequence of time slots in this repeated forward and reverse new media propagation, so as to achieve a result consistent with the direction of the data stream.

Data flow A is slave node 1 $\rightarrow$ 4, and data flow B is slave node 4 $\rightarrow$ 1. The two data streams must converge at a certain node when they are propagating forward to new media. This node is called the intersection of two opposite data streams. After the intersection point receives the initiation time slot exchange packet of the two data streams, it finds that the successor nodes of the two data streams are the predecessor nodes of each other. At this time, the data stream with the higher value of the data stream will be selected to continue the positive new media propagation. The request to reject the exchange is made to the data flow node with lower value. When the node receives a request to reject the exchange, it will give up and continue to spread to the new media. Assuming that the value of data stream A is high, and the intersection is node 2, node 2 will initiate a rejection request to node 3, and node 3 will abandon the for-

ward new media propagation when receiving the rejection request. At the same time, node 2 will send to node 3 an initiating time slot exchange packet, so that the time slot allocation sequence will be consistent with data stream A.

The main time slot adaptive time slot exchange technology mainly uses forward and reverse new media propagation to exchange the node's main time slot, so as to achieve the same time slot allocation sequence and data flow direction. The algorithm flow of forward new media propagation is shown in Figure 3.

5. New Media Low-Latency Simulation Experiment

5.1. Communication Performance under Different Dynamic Topologies. The simulation of the highly dynamic wireless Mesh network topology is mainly reflected in the node's moving speed. The faster the node's moving speed, the faster the topology of the wireless Mesh network will change. In the case of different network topologies, the performance of the communication architecture design is verified through the packet delivery rate, average end-to-end delay, and throughput of the data stream. Among them, the position and speed of all nodes are randomly generated during the simulation and are uniformly distributed within the range. The movement model of the node is that the movement speed of the node does not change in size during the simulation time. When the node moves to the boundary of the communication range, the direction of movement is changed according to the reflection principle, but the speed remains the same. Obviously, when the moving speed of a node is randomly generated, the larger the speed range, the more drastic the dynamic change of the topology of the wireless Mesh network. The parameter settings of the simulation scene are shown in Table 1.

5.1.1. Impact on the Submission Rate of the Data Stream. Figure 4 shows the simulation results of the data flow delivery rate under the dynamic changes of different network topologies. It can be seen from the figure that the faster the node moves, and the delivery rate of the data stream is not less than 80%. This is because the faster the dynamic change of the network topology, the easier the communication link is to fail. For a multihop data flow, any communication failure in the forwarding path will cause the communication failure of the data flow. When it is fast, the communication failure probability of multihop data streams will become larger and larger. For topology update, the faster the node moves, the faster the topology information becomes invalid, which leads to errors in the forwarding path selected for the data flow in the routing algorithm.

It can also be seen through simulation that for communication scenarios with a simulation scale within the range of five hops, the design presented in this article can still guarantee more than 80% of the data when the speed random value parameter reaches 100 m/s (360Km/h). This shows that for highly dynamic wireless Mesh networks, the improved architecture design used in this article has a very high data stream delivery rate guarantee.

FIGURE 3: Flow chart of forward new media communication.

TABLE 1: Simulation scene parameter settings.

Parameter	Parameter value
Node moving range	3000 m × 3000 m
Simulation time	20s
Number of nodes	30
Data frame time slot length	15 ms
Control subframe 1 time slot length	2 ms
Control subframe 2 time slot length	4 ms
Node communication rate	1.6Mbps
Data stream size	2048 bytes
Node communication distance	2000 m

5.1.2. Impact on End-to-End Delay. The end-to-end delay simulation results are the average end-to-end delay simulation results of the data flow at different node moving speeds under three loads. Among them, light load means sending two data streams with a length of 5242 Bytes per time frame,

medium load means sending 6 data streams with a length of 5242 Bytes per time frame, and heavy load means sending 15 data streams with a length of each time frame.

From the end-to-end delay simulation results in Figure 5, it can be seen that although the end-to-end delay of the data stream has greater volatility, and it does not increase significantly with the increase in the speed of the node; that is, it does not increase with the network. The trend of high dynamics of topology changes is obviously increasing. The greater volatility is due to the large randomness of the node positions in the network as the random speed value pairs increase, which will cause large undulations in the latter part of each curve. The average delay does not increase significantly relative to the high dynamics of the topology. The reason is that when calculating the data flow delay, only the delay of the successfully delivered data flow is counted. For the delivery failure caused by the intensification of the network topology change, the data stream of is not included in the delay statistics. Therefore, the end-to-end delay in the figure is mainly related to the average data flow forwarding path hop count caused by the network scale

FIGURE 4: Simulation results of delivery rate under time slot allocation protocol algorithm.

FIGURE 5: Simulation results of end-to-end delay under time slot allocation protocol algorithm.

and has little correlation with the highly dynamic topology changes. However, if the failed data stream is retransmitted, it will obviously cause the delay of the data stream to increase exponentially, thereby causing an increase in the average delay. However, the retransmission mechanism is generally controlled by the transport layer or application layer in the network communication model; so, this article will not discuss the mechanism.

It can also be seen from the end-to-end delay simulation results in Figure 5 that the greater the network load, the

greater the average delay of the data stream. This is because when the load increases, the delay of the data stream will be caused by the caching mechanism. In the case of low load, it can be seen from the figure that the average delay fluctuates around 1.6 s. For the architecture design with a data stream size of 5242 Bytes, an average data stream forwarding path hop count of 3 hops, and a scheduling frame period of 0.8 s. The transmission can be completed within 2 time frames, which meets the goal of theoretical design. And if the size of the data stream is reduced, obviously, the time

FIGURE 6: Simulation results of network throughput.

FIGURE 7: Delay performance simulation results under light load conditions.

frame period will be proportionally reduced, and the delay will also be proportionally reduced.

5.1.3. Impact on Network Throughput. Figure 6 shows the throughput of the wireless Mesh network under different moving speeds. It can be seen from Figure 6 that the throughput of the wireless Mesh network is above 1.8Mbps, and the physical layer communication rate of each node is 2 Mbps. If you remove the overhead of the Mac layer control protocol, the actual communication rate is 1.54Mbps, and the multiplexing rate is above 1.5. For a wireless Mesh network with a tie neighbor hop distance of 3 and an average number of time slots per time frame of 1, it is in line with the theoretical expectations of the time slot allocation algorithm. As the moving speed of wireless Mesh network nodes accelerates, the network throughput changes tortuously

within a certain range. Counting the time slots occupied by the data of communication failures, the wireless Mesh network can cause the time slot reuse rate to increase when the topology is highly dynamic. The location distribution of available time slots is more uniform, making these idle time slots more likely to be reused, thereby increasing the multiplexing rate of time slots, which will increase the throughput to a certain extent.

5.2. Performance Comparison with Traditional Dynamic Slot Allocation Algorithm. This section combines this algorithm with topology update mechanism and routing mechanism for simulation. Figure 7 is the simulation result of the average end-to-end delay performance of the two time slot allocation algorithms under low load conditions. The light load sends two data streams with a length of 5242 bytes for each

FIGURE 8: Delay performance simulation results under moderate load.

FIGURE 9: Delay performance simulation results under heavy load.

time frame. Excluding the fluctuations caused by random factors, the algorithm SAOPPS-TDMA proposed in this paper can achieve smaller end-to-end delay performance in most cases under low load conditions.

Figure 8 is the simulation result of the average end-to-end delay performance of the two algorithms under moderate load when six data streams with a length of 5242 bytes are sent in each time frame. It can be seen from Figure 8 that the algorithm SAOPPS-TDMA in this paper has a smaller average end-to-end delay in most simulation situations.

Figure 9 shows the simulation results of the average end-to-end delay performance of the two algorithms when 25 data streams with a length of 5242 bytes are sent in each time frame under heavy load. It can be seen from the figure

that the performance of the algorithm SAOPPS-TDMA in this paper has been improved significantly, which can greatly reduce the end-to-end delay of the data stream.

6. Conclusion

This paper studies the principle of traditional dynamic TDMA, obtains its characteristics and shortcomings, improves and perfects the time slot allocation algorithm based on the priority list, and proposes the SAOPPS-TDMA protocol. The protocol designs an efficient superframe structure, through the grouping of control information, and it completes the discovery of neighboring nodes in the one-hop range and two-hop range and obtains the local topology of the node. The

local topology and priority list are used to complete the conflict-free time slot allocation in a distributed scenario, and the design of the priority list ensures the fairness of the time slot allocation. The main time slot adaptive switching technology is used to adjust the time slot, so that the time slot allocation sequence and the data flow sequence tend to be consistent, reducing the scheduling delay of node forwarding and enhancing the delay and throughput characteristics of the entire network. For network scenarios where multiple data streams exist, exchange criteria based on the value of data streams are designed to ensure that high-value data streams can be adjusted to the priority of the time slot sequence, reduce the delay, and complete the delay reduction of the critical path of the network. The simulation results show that in the case of a single radio frequency and a single channel, for the highly dynamic wireless Mesh network topology, the low-latency design proposed in this paper is sufficient to achieve the expected results. Due to time and space limitations, there is no specific control protocol composition and frame in the Mac layer channel allocation. The implementation details of the format and verification algorithm are studied in depth. There is no indepth analysis on the time synchronization of the communication time frame and the specific design of the time slot guard interval based on the TDMA architecture, these are often key factors affecting network performance in practical applications, and they are also important parts that require careful study of wireless Mesh networks. For the channel allocation method of a single radio frequency and multichannel wireless Mesh network, in the channel allocation for data stream forwarding nodes, due to the implementation of the simulation code, the exact location and number of the forwarding time slots have not been taken into consideration in the channel allocation. Therefore, there is room for improvement in the efficiency of channel allocation for data streams, and further research should be done to improve network performance.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- [1] Y. Ji, J. Zhang, Y. Xiao, and Z. Liu, "5G flexible optical transport networks with large-capacity, low-latency and high-efficiency," *China Communications*, vol. 16, no. 5, pp. 19–32, 2019.
- [2] I. Parvez, A. Rahmati, I. Guvenc, A. I. Sarwat, and H. Dai, "A survey on low latency towards 5G: RAN, core network and caching solutions," *IEEE Communications Surveys & Tutorials*, vol. 20, no. 4, pp. 3098–3130, 2018.
- [3] J. du, C. Jiang, J. Wang, Y. Ren, and M. Debbah, "Machine learning for 6G wireless networks: carrying forward enhanced bandwidth, massive access, and ultrareliable/low-latency service," *IEEE Vehicular Technology Magazine*, vol. 15, no. 4, pp. 122–134, 2020.
- [4] M. S. Elbamby, C. Perfecto, M. Bennis, and K. Doppler, "Toward low-latency and ultra-reliable virtual reality," *IEEE Network*, vol. 32, no. 2, pp. 78–84, 2018.
- [5] A. Nasrallah, A. S. Thyagaturu, Z. Alharbi et al., "Ultra-low latency (ULL) networks: the IEEE TSN and IETF DetNet standards and related 5G ULL research," *IEEE Communications Surveys & Tutorials*, vol. 21, no. 1, pp. 88–145, 2019.
- [6] J. Sachs, L. A. A. Andersson, J. Araujo et al., "Adaptive 5G low-latency communication for tactile internet services," *Proceedings of the IEEE*, vol. 107, no. 2, pp. 325–349, 2019.
- [7] T. Kawanishi, A. Kanno, and H. S. C. Freire, "Wired and wireless links to bridge networks: seamlessly connecting radio and optical technologies for 5G networks," *IEEE Microwave Magazine*, vol. 19, no. 3, pp. 102–111, 2018.
- [8] M. A. Lema, A. Laya, T. Mahmoodi et al., "Business case and technology analysis for 5G low latency applications," *IEEE Access*, vol. 5, pp. 5917–5935, 2017.
- [9] G. Praveen, V. Chamola, V. Hassija, and N. Kumar, "Blockchain for 5G: a prelude to future telecommunication," *IEEE Network*, vol. 34, no. 6, pp. 106–113, 2020.
- [10] A. Mahmood, M. I. Ashraf, M. Gidlund, J. Torsner, and J. Sachs, "Time synchronization in 5G wireless edge: requirements and solutions for critical-MTC," *IEEE Communications Magazine*, vol. 57, no. 12, pp. 45–51, 2019.
- [11] M. Elsayed, M. Erol-Kantarci, B. Kantarci, L. Wu, and J. Li, "Low-latency communications for community resilience microgrids: a reinforcement learning approach," *IEEE Transactions on Smart Grid*, vol. 11, no. 2, pp. 1091–1099, 2020.
- [12] J. Xu, K. Ota, and M. Dong, "A real plug-and-play fog: implementation of service placement in wireless multimedia networks," *China Communications*, vol. 16, no. 10, pp. 191–201, 2019.
- [13] W. Saad, M. Bennis, and M. Chen, "A vision of 6G wireless systems: applications, trends, technologies, and open research problems," *IEEE Network*, vol. 34, no. 3, pp. 134–142, 2020.
- [14] J. Qiao, Y. He, and X. S. Shen, "Improving video streaming quality in 5G enabled vehicular networks," *IEEE Wireless Communications*, vol. 25, no. 2, pp. 133–139, 2018.
- [15] M. Bennis, M. Debbah, and H. V. Poor, "Ultrareliable and low-latency wireless communication: tail, risk, and scale," *Proceedings of the IEEE*, vol. 106, no. 10, pp. 1834–1853, 2018.
- [16] N. A. Mohammed, A. M. Mansoor, and R. B. Ahmad, "Mission-critical machine-type communication: an overview and perspectives towards 5G," *IEEE Access*, vol. 7, pp. 127198–127216, 2019.
- [17] D. Lavery, M. Ruffini, L. Valcarengi et al., "Networks for future services in a smart city: lessons learned from the connected OFCity challenge 2017," *IEEE Communications Magazine*, vol. 56, no. 8, pp. 138–144, 2018.
- [18] A. Morgado, K. M. S. Huq, S. Mumtaz, and J. Rodriguez, "A survey of 5G technologies: regulatory, standardization and industrial perspectives," *Digital Communications and Networks*, vol. 4, no. 2, pp. 87–97, 2018.
- [19] A. Aijaz, "Packet duplication in dual connectivity enabled 5G wireless networks: overview and challenges," *IEEE Communications Standards Magazine*, vol. 3, no. 3, pp. 20–28, 2019.
- [20] A. Ebrahimzadeh and M. Maier, "Distributed cooperative computation offloading in multi-access edge computing fiber-wireless networks," *Optics Communications*, vol. 452, pp. 130–139, 2019.