



An OSPF Based Backhaul Protocol for 5G Millimeter Wave Network

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Abstract. This paper proposes an Open Shortest Path First (OSPF) based Backhaul Protocol for 5th Generation (5G) mobile communication millimeter wave network (OBPG). This protocol includes the establishment stage and the transmission stage of the millimeter wave backhaul network. During the establishment stage, all millimeter wave micro base stations use fixed time division. The method is based on the OSPF protocol to establish the backhaul path between millimeter wave micro base stations. In the transmission stage, based on the network topology formed by millimeter wave micro base stations, the coloring method is used to allocate data transmission time slots. After that, the micro base station polls and schedules users for data transmission in the allocated data transmission time slot. The simulation results show that when the blocking probability of the millimeter-wave directional link is 30%, and along with the number of multiple associations between users and millimeter-wave micro base stations increases, the network throughput performance is about 20% higher than the performance of the number which is one less.

Keywords: 5G millimeter wave · Backhaul network · OSPF

1 Introduction

High capacity, large bandwidth, high speed and low energy consumption have become the main trends of wireless mobile communication networks in the future. A report predicts that by 2022, the global terminal monthly business transmission volume will reach 60PB, and this data is several times the current monthly data. Therefore, in order to meet the above-mentioned network requirements, studying future wireless mobile communication networks are imminent. The 5th Generation Mobile Communication (5G) communication system is definitely the mainstream of development. As one of the important components of 5G communication system, 5G millimeter wave (mmWave) network is also a research hot spot. To promote the further development of millimeter-wave mobile communications, the European Union launched the Millimetre Wave Evolution for Backhaul and Access (MiWEBA), EU-Japan joint project, Millimeter-Wave Small

Cell Access and Backhauling (MiWaves) project and mmWave-based Mobile Access network for fifth Generation Integrated Communications (MMAGIC) project. In addition, in the beyond 5G (B5G) research initiated by the EU within the framework of H2020, one of the key technical is also using the millimeter wave frequency band from 30 GHz to 300 GHz. In China, the National 863 Program has already launched the implementation of 5th Generation Mobile Communication System Evaluation and Test Verification Technology Research and 5th Generation Mobile Communication System Large-capacity Millimeter Wave Indoor Wireless Access Technology Research And verification and other project research.

Among them, in this paper, the application scenario of millimeter wave communication based on large-scale multiple-input and multiple-output (MIMO) mainly introduces the millimeter wave integrated access and backhaul network (mmWave IABN). In mmWave IABN, IAB micro base stations provide user equipment (UE) accesses and backhaul services, and micro base stations are divided into two categories, fiber-enabled small cell station (FSCS) and integrated small cell station (ISCS). FSCS provides wireless backhaul function, and the interface between the UE and the core network. ISCS is connected to FSCS through the backhaul link, and then connected to the core network. Therefore, it is important to establish a backhaul path between millimeter wave micro base stations.

Backhaul technology is mainly responsible for providing backhaul path planning and management, network management and other content, which are important functions of mmWave IABN. The original intention of mmWave IABN is to ensure the access to resources and make full use of idle or redundant communication resources to realize the backhaul of data. The industry and academia have carried out some related research work with the verification and use of 60 GHz millimeter wave backhaul network. Regarding the optimization of the backhaul path between millimeter wave micro base stations, for the backhaul path planning in the millimeter wave wireless backhaul network, Ref. [5–7] was optimized, and new algorithm was proposed to improve the overall network service quality in every literature. For the user association and path optimization, Ref. [8,9] proposed problem discovery and solution, and proposed different algorithms to increase the user rate and improve energy efficiency.

For the backhaul routing problem of mmWave IABN, some researches [12,15] had proposed and verified some backhaul path planning and routing design schemes. From the perspective of backhaul, mmWave IABN is essentially a static mesh network, which needs to directionally transmit different data streams between relay nodes. The main problem with the design and application of existing routing protocols is the current designed routing protocols do not fully utilize the advantages of directional transmission. Therefore, cross-layer designs related to resource scheduling needs to be considered when designing directional routing to improve the overall performance of the network. The existence of these problems provides guidance for designing new routing protocols in mmWave IABN. Therefore, considering the distribution and scheduling of data transmission in

access and backhaul network, the number of nodes and link allocation, it is very helpful to improve the overall network service quality and improve the user experience by designing active routing protocols. Therefore, the Open Shortest Path First (OSPF) routing protocol is a good choice, and it is of great reference significance to divide each micro cell to save resources and simplify the base station.

The main contributes to this paper are as follows. An OSPF based Backhaul Protocol for 5G millimeter wave networks (OBPG) is proposed. A coloring method used to allocate transmission time slots was proposed. The simulation results show that when the blocking probability is 30%, when the number of multiple associations with users and millimeter-wave micro base stations increases, the network throughput performance is about 20% higher than the performance of the number which is one less.

The remainder of this paper is organized as follows. In Sect. 2, the system model of 5G millimeter wave backhaul network is proposed. It will be introduced from multiple levels, specifically introducing various parts of the 5G millimeter wave backhaul network, including micro base station links. Section 3 proposes OBPG. The two parts of how to use OSPF to establish a backhaul path between millimeter wave micro base stations and time slot allocation are introduced in this chapter. Section 4 is the simulation part. Based on the C/C++ programming language, the impact of network throughput in the 5G scenario with OSPF protocol is observed. Section 5 concludes this paper.

2 System Model

mmWave IABN has the following characteristics. One of the characteristics is access and backhaul resource sharing. Although the sum of available resources on the access and backhaul links of mmWave IABN is fixed, the allocation of available resources between access and backhaul can be freely changed, so as to meet the needs of the network's instant service transmission. Another characteristic is free and flexible network deployment configuration. It can use self-backhaul integrated with access to simplify the network establishment and transmission stage. It can use millimeter wave communication. Most of the existing work is focused on millimeter wave communication in the 28 GHz, 38 GHz, 60 GHz and E-band (71 GHz–76 GHz, 81 GHz–86 GHz) frequency bands. Therefore, mmWave IABN is considered to be a viable and effective solution for 5G mobile communication networks to fully meet the flexible and self-organizing characteristics of the integrated access and backhaul in the 3rd generation partnership project (3GPP) technical report. The 5G millimeter wave architecture can be seen in the Fig. 1.

At first, the entire 5G millimeter wave network is roughly divided into two parts. micro base stations and link. The so-called integrated access and backhaul base station (IAB) is that the base station integrates a wireless access link and a wireless backhaul link, where the access link is the communication link between the UE and the IAB base stations. The wireless backhaul link is a communication link between various optical fiber and non-optical IAB base stations. These links

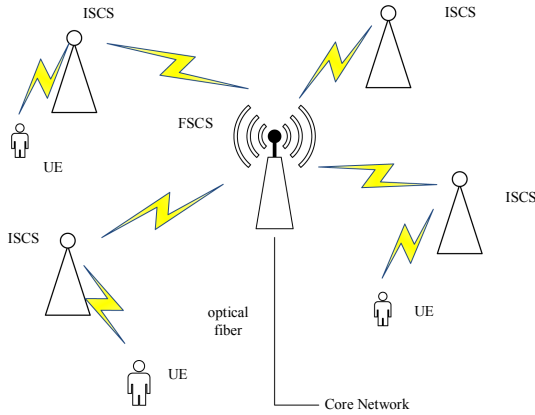


Fig. 1. 5G millimeter wave network structure

are used for data backhaul. Therefore, in addition to the wired connection with the core network, the IAB base station does not require a wired transmission network for data backhaul. Based on this, IAB base stations are easier to deploy in dense scenarios, which alleviates the burden of deploying wired transmission networks to some extent.

Among the specific nodes, there are the following three types of nodes. They are FSCS connected to the core network with a dedicated fiber, ISCS without fiber, and UE. Among them, FSCS provides the wireless backhaul function, and provides the interface between the UE and the core network. Other ISCSs transmit their UE services back to the FSCS in single-hop or multi-hop millimeter wave wireless communication. The UE will be distributed randomly and movably in the communication network, and each user equipment will be connected to more than one base station to prevent the link with the ISCS from being disconnected. The UE does not have the function of data forwarding.

Each mmWave ISCS has multiple electronically steerable directional antennas (ESDA), which are used to send or receive access and backhaul data. Because data transmission on one link interferes with data transmission on another link, directional communication reduces interference between links, allowing us to use concurrent transmission to greatly increase network capacity. Moreover, the sectorized antenna also has better main lobe antenna gain and better anti-interference effect. As for the loss during path transmission, unlike microwave frequency band transmission, the highly directional transmission of millimeter waves using antenna arrays is an effective method to overcome severe path loss. Although millimeter wave transmission has extremely high sensitivity to blocking and shadows, mmWave ISCS is statically installed on tall outdoor buildings, making the directional line of sight (LOS) transmission environment between mmWave ISCS relatively good.

In the entire data transmission operation phase, several types of streams can be distinguished in space, mainly four types. These are the downlink backhaul

transport stream from FSCS to ISCS, the uplink backhaul transport stream from ISCS to FSCS, the downlink accesses transport stream from FSCS/ISCS to its associated UE, and the uplink access from UE to FSCS/ISCS Transport stream. The scheduling cycle on the network can be Uplink Scheduling (US) cycle and downlink scheduling (DS) cycle. According to Enhanced Cochannel Reverse Time Division Duplexing (ECR-TDD), each US and DS is divided into segments that do not overlap each other. For any US and DS, there are two stages of the scheduling and resource allocation stage and the data transmission stage. All transmission requirements and resource allocation will be calculated in a unified manner, so as to decide different transmission time slots and broadcast them in the entire network, thus completing the allocation of time slots.

3 OSPF-Based Backhaul Protocol for 5G Millimeter Wave Network

We detail the proposed OSPF-based Backhaul Protocol (OBPG) in this section. Particularly, the basic ideas of the proposed OBPG is overviewed in Sect. 3.1, which consists of two main stages. The first stage, i.e., the network backhaul paths establishment stage, is detailed in Sect. 3.2. And the second stage, i.e., the user access and backhaul data transmission stage, is presented in Sect. 3.3.

3.1 Basic Ideas of OBPG

For the backhaul protocol, there are two main functions, which are backhaul paths establishment and backhaul data transmission. Therefore, the proposed OBPG can be divided into two main stages, which are the backhaul routing path establishment stage, and the user access and backhaul data transmission stage.

In the backhaul routing path establishment stage, the time slots of the mmWave IABN can be statically allocated to each micro base station after deployment. Then within these allocated time slots, ISCSs can establish the backhaul routing path to the FSCS based on the OSPF routing protocol, such that each ISCS can hold the whole network topology and establishes at least one backhaul path to the FSCS.

In the user access and backhaul data transmission stage, based on the whole network topology obtained in the backhaul routing path establishment stage, each ISCS can run a coloring algorithm to allocate the user access time slots and the backhaul time slots in a distributed method. And ISCS can polling and scheduling the associated UEs to transmit data and backhaul them to the core network. From Fig. 2, we can know the composition of OSPG.

3.2 Network Backhaul Paths Establishment Stage

In the backhaul routing path establishment stage of OBPG, time division multiple access (TDMA) is used for access to the network. The time is divided into

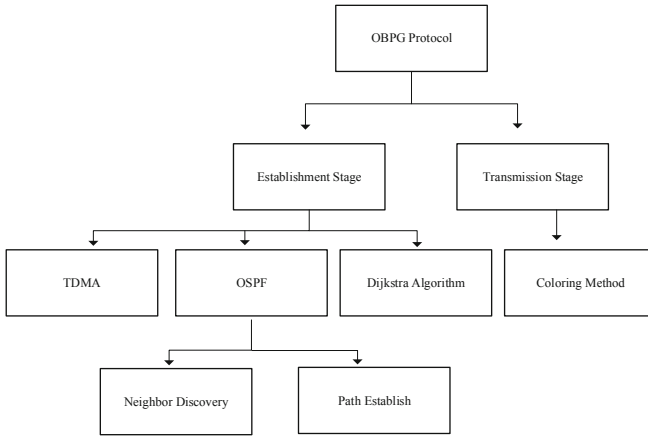


Fig. 2. OBPG protocol introduction

multiple time frames, and each frame is divided into multiple time slots according to different factors such as network size. Time slot allocation refers to the allocation of time slot resources to the traffic in the network according to different network environments. They do not interfere with each other and each takes up a certain amount of time. For example, in a scheduling period, as far as the FSCS is concerned, the FSCS does not send the access transport stream to the UE at the same time when sending the backhaul transport stream to the ISCS.

After the allocation of time slots, the next step is the specific transmission of OSPF data packets. The search and relationship confirmation of the three different base stations in this paper are based on the content of the OSPF routing protocol, and also include issues such as the way, the data packet and the format of the data packet. The basic principles of the OSPF routing protocol are introduced below.

OSPF is a relatively mature and very stable dynamic routing protocol. The entire protocol flow is based on 5 data packets (Hello, data base description (DBD), link state request (LSR), link state update (LSU), link state acknowledge (LSAck)) and 3 relationship tables (neighbor table, topology table, and routing table). The main operating mechanisms of the OSPF protocol are as follows.

One of the main mechanisms is neighbor discovery. The purpose of neighbor discovery is synchronization of the link state database. Among them, the steps related to neighbor discovery are as follows. Discovery and two-way communication, which is the most basic operation. The other mechanism is maintaining neighbors, maintain the determination of neighbors by periodically sending HELLO packets. If the neighbors have not received for a period of time, it means the connection is disconnected and the neighbor is invalid. Designated router (DR) and backup designated router (BDR) election, OSPF protocol defines DR, acts as the core-all routers in the entire network topology only send information to the DR, and the DR is responsible for forwarding the content. OSPF also

proposed the concept of BDR to prevent DR failure. The routers other than DR and BDR are called DR Others, which only establish adjacency with DR and BDR, and do not exchange any link information between DR Others. The route calculation can only be performed after the link state database of each node is synchronized. The state of the neighbor needs to be confirmed in seven steps (as shown in Fig. 3) to achieve true adjacency.

- (1) The first state is down. It's the initial state where the communication has not started.
- (2) The second state is init. The node received Hello message sent by the neighbor, indicating that the neighbor already knows its existence.
- (3) The third state is two-way. In this state, two-way communication has been established, and DR and BDR elections are started in the network.
- (4) The fourth state is exstart. In this state, the master-slave router is elected by sending a DBD that does not carry the link state advertisement (LSA) header. During subsequent database synchronization, the master-slave router is used to decide who initiates the exchange first.
- (5) The fifth state is exchange. The router sends the DBD carrying the LSA header to the neighbor to tell the neighbor node its own link state information.
- (6) The sixth state is loading. In this state, LSR is sent to the neighbor to request the updated link information to be filtered in Exchange.
- (7) The seventh state is full. In this state, the two neighboring nodes have reached the complete adjacency state and can perform route calculation.

The above states only guarantee the consistency of the link state data base (LSDB) between neighbors at the initial moment. When the network topology changes, the corresponding link state will need to be updated throughout the network. The realization process is the transmission of the link state update packet and the reception of the link state update packet.

With the help of the OSPF protocol, a millimeter-wave micro base station can establish a shortest path from any micro base station that is not connected to the optical fiber to the micro base station that is connected to the optical fiber. Among them, the algorithm we use is Dijkstra algorithm, which has been improved to a certain extent in the traditional algorithm.

The implementation of Dijkstra algorithm in the OSPF protocol involves the following steps.

- (1) The router draws a network topology diagram according to the neighbor table of each node in the network. This diagram contains the positions of the points and the connected edges.
- (2) The router takes itself as the root of the tree and performs Dijkstra algorithm on the entire topology graph to construct a shortest path tree from the root of the tree to each node in the graph, and the weight from the root to any other node is always the smallest. The weight is calculated by time, energy consumption, distance, etc.

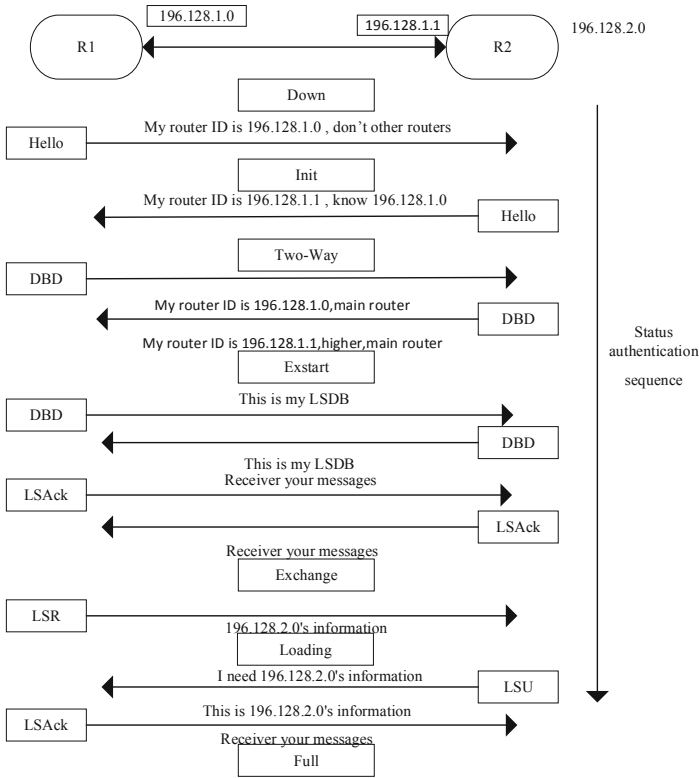


Fig. 3. OSPF protocol status determination

- (3) Then add network information to each node in the tree, called “leaf node”, add the cost and next hop from the root to these networks to the routing table, and finally get the root to the network routing cost is sum of distance from root to network node and cost from network node to leaf node.

Suppose that a network node and link distribution can be drawn as a directed connected topology diagram as shown as follows.

R5 executes the Dijkstra algorithm, draws the trunk of the shortest path tree with itself as the root, as shown in Fig. 5 and Fig. 6. Finally, the network information is added to the nodes of the tree as leaves, and the entire shortest path tree is constructed.

In addition, the traditional Dijkstra only calculates a path from the local node to the destination node, but this protocol needs to obtain multiple paths. From any micro base station that is not connected to the optical fiber, a shortest path to each micro base station that connects to the optical fiber is established. Then it will choose one of multiple paths as the best path.

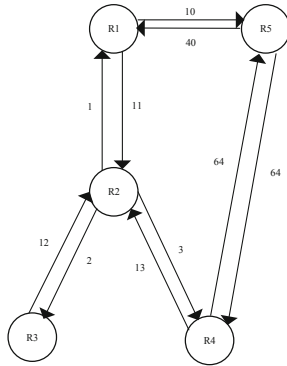


Fig. 4. Cost of nodes in a example

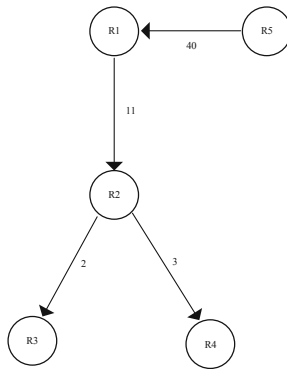


Fig. 5. Shortest path tree generation

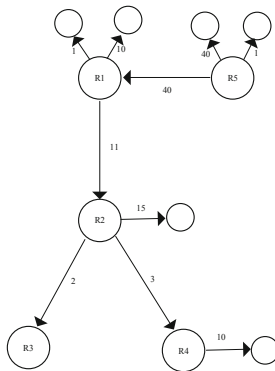


Fig. 6. Leaf nodes in the path tree

3.3 User Access and Backhaul Data Transmission Stage

In the user access and backhaul data transmission stage, each base station has established a global network topology, and then running a coloring method on such a network topology to allocate data transmission time slots. The so-called coloring method is to allocate time slots for each base station, and assign them to different link nodes, users and base stations in different transmission time slots, but two nodes that are not neighbors can schedule the same time slot (with the same color).

The specific coloring process is shown below. Different time slots are set to different node colors. From Fig. 7, at first, all the nodes have no color. At the beginning, the first color is used to color the root node. The coloring must be effective. Then go to the next node, first the next node will be colored with the first color, and then judge whether this node is the same as the adjacent node. If they are the same, it is judged as invalid, and then the second color is used until the coloring is effective. If it is different, it is determined as effective coloring, and the coloring of the next node is continued.

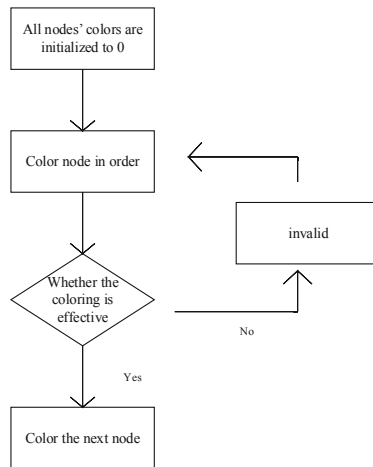


Fig. 7. Coloring process

At this point, the entire OBPG has been established. This section is an overview of the theoretical section. The following is the introduction of the simulation section.

4 Simulation

This section is the content of simulation. The simulation of multi-hop backhaul technology in cellular networks is based on the C/C++ programming language.

It adopts a sub-module approach and first writes OSPF protocol related data packet modules and data transmission modules. With the basic infrastructure, the next step is to build a 5G scenario. The 5G scenario includes the division of nodes, the connection of links, and the allocation of time slots. Connecting the two modules in series is the entire 5G millimeter wave based on the OSPF routing protocol. Back to the network simulation, and get the corresponding simulation results.

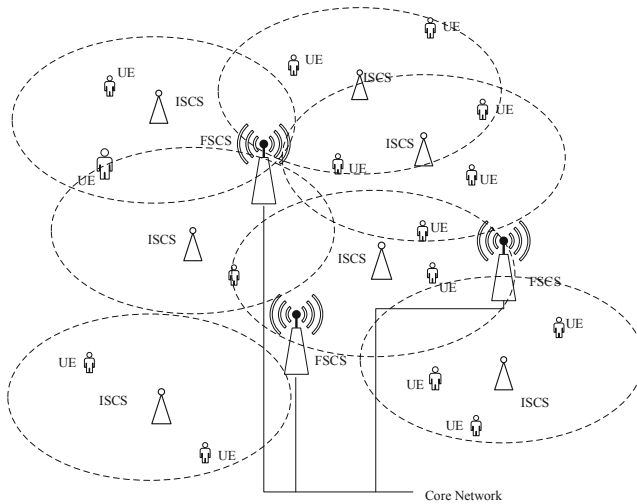


Fig. 8. 5G scene construction

In the Fig. 8, it can be seen that 10 mm-wave micro base stations are deployed within a range of 20×20 . These millimeter-wave micro base stations have 7 mm-wave micro base stations that are not connected to optical fibers, and 3 mm-wave micro base stations that are connected to optical fibers. What's more, the probability p of the directional link being blocked is simulated by random numbers in the program.

Now suppose several situations, simulation output of 5G millimeter wave network scenarios with the impact of various factors will be given in the next simulations.

Assuming that the deployment of the base station has been determined, k refers to the number of base stations to which the user is connected, when the $k = 2$ and $k = 3$, and the number of UE is continuously added to the network, the following curve can be obtained.

Obviously from Fig. 9, the increase of users will inevitably lead to an increase in the amount of data, and user access is more frequent and huge, which requires higher throughput of the network. It further confirmed the higher requirements for mobile bandwidth in 5G scenarios and solutions for ultra-dense deployment to meet higher user density.

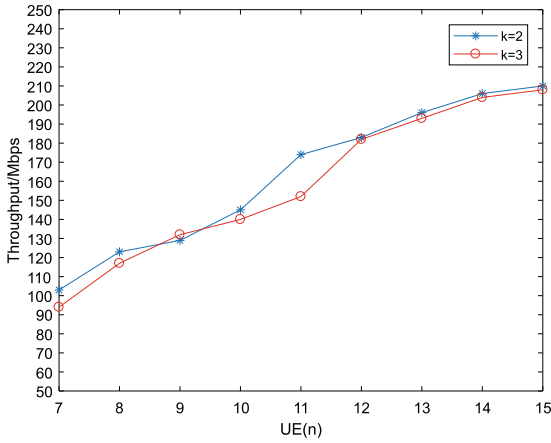


Fig. 9. UE number n-throughput curve

Next, with the distribution of UE unchanged, the impact of different k on network throughput will be compared.

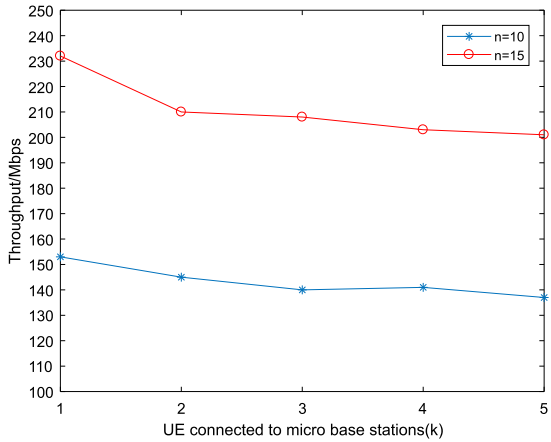


Fig. 10. Number of UE connected base stations k-throughput curve

In order to avoid accidents, the tests were conducted under the conditions of the number of UE $n = 10$ and $n = 15$. From Fig. 10, through the simulation curve, we can see that the more the number of base stations finally selected, the lower the network throughput. This is because it improves the tendency of the better link when selecting the link, and reduces the probability of data retransmission to a certain extent. Thereby it reduces the requirements for network throughput.

The directional link also has a blocking probability. According to theory, the greater the blocking probability, the more data should be retransmitted. This will definitely increase the throughput of the node. Assuming that there are fifteen users in the network, the distribution of users and the deployment of base stations have been determined, and the impact of the probability of the link being blocked on the throughput of the network is shown in the following figure.

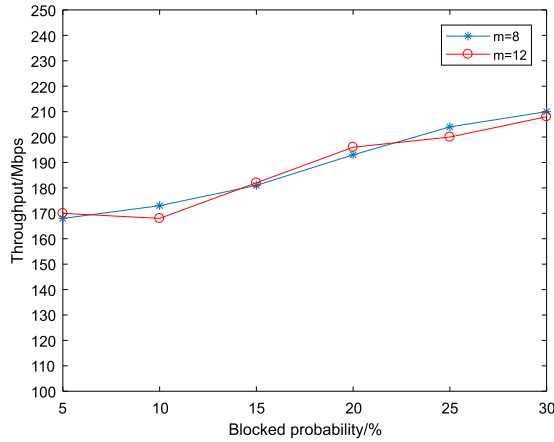


Fig. 11. Link blocking probability p-throughput curve

As shown in the Fig. 11, this is indeed the case. When the number of base stations $m = 8$ and $m = 12$ and the number of user equipment $n = 15$ are tested, you can see that the higher the probability of the link being blocked, the more data needs to be retransmitted, which greatly increasing the amount of data generated in the network is in line with our expectations, reducing the transmission efficiency, making the network require higher throughput to carry the normal operation of access and backhaul.

5 Conclusion

This paper is a simulation study of OBPG. First, in the introduction section, the current status of 5G millimeter wave networks and the current research status at home and abroad are investigated, which leads to some shortcomings in the routing protocol of 5G millimeter wave backhaul networks. The OSPF protocol is linked to try to solve this problem. Next, the specific combination of the OSPF mechanism and the operation of the 5G millimeter wave backhaul network are introduced, including in the establishment stage and the transmission stage, not only this but also the combination of slot allocation, coloring method, improved Dijkstra algorithm. With theoretical foreshadowing, it was

implemented in simulation according to the process sub-module, and simulated more realistic 5G scenarios, such as three types of base stations, directional communication, blocked probability and other factors involved. It also observes the influence of factors such as the number of users or the number of connected base stations or the total number of base stations or blocking probability under other circumstances on network throughput. It was found that OSPF can well adapt to the construction of 5G millimeter wave access and backhaul integrated networks, and the purpose and significance of the research are obtained. In summary, this paper contributes the OBPG routing algorithm, which mainly refers to OSPF, and integrates a coloring method and other mechanisms. It has a good performance in simulation and has reference value. Of course, it can be more perfect in the subsequent research. Because this paper only mainly studies the network throughput requirements under the protocol, and there are many indicators that can describe network performance, such as delay, round-trip time, utilization, etc. A single indicator cannot completely define the pros and cons of a network's performance. The conclusions drawn after simulation are considered to be more reliable. These all require further research.

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