



An Outage Probability Based Channel Bonding Algorithm for 6G Network

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Abstract. Multiple input multiple output (MIMO) can greatly improve the throughput and frequency utilization of wireless transmission systems. In the IEEE 802.11ax protocol, 4G, 5G, and even future 6G communications, MIMO has greatly increased the throughput of transmissions. Proper channel bonding strategies can improve channel utilization and transmission throughput. This paper proposes an outage probability based channel bonding algorithm (OP-CB). OP-CB calculates the outage probability according to the average signal-to-noise ratio (SNR) and the threshold signal-to-noise ratio. SNR is affected by transmission power and transmission distance. And then OP-CB performs channel bonding according to the outage of data transmission. The algorithm proposed in this paper can be used in massive MIMO (mMIMO) in 5G and future 6G communications. Combining the outage probability with the channel bonding technique can improve the success rate of data transmissions. In addition, we use software defined network (SDN) to improve the efficiency of the algorithm in 6G network. The simulation results show that OP-CB can improve the throughput of data transmission by about 40% when the transmission power is low or the transmission distance is large. OP-BC can also reduce the bit error rate (BER).

Keywords: mMIMO · Outage probability · Channel bonding · 6G communication

1 Introduction

With the popularity of 5G communication, 6G communication has gradually become a hot topic. Compared with 4G and 5G communication, the channel frequency used in 6G communication will be higher, and the number of channels will be much larger. Therefore, 6G communication will support more users to transmit at a higher rate. In addition, the combination of IPv6 and 6G networks brings many new features to 6G communications, which can be used not only in daily communication, but also in industrial fields, such as the Industrial Internet of Things (IIoT). Studying the reasonable utilization of channel resources in 6G networks is crucial to improving the overall performance of 6G networks.

MIMO builds multiple channels between the sender and the receiver by using multiple antennas, which greatly improves the channel capacity [1]. Multi-User Multiple-Input Multiple-Output (MU-MIMO) in IEEE 802.11ax protocol and 8-antenna MIMO in 4G communication are both typical MIMO systems. The 256–1024 antenna mMIMO used in 5G communication significantly increases system capacity and realizes reliable transmission through spatial multi-grading and multiplexing technology, which plays a key role in mobile communication [2]. In MIMO systems, a good channel binding strategy can maintain good channel utilization while ensuring good transmission quality. 6G communication is expected to use 10,000-antenna MIMO technology in the terahertz (THz) frequency band [3]. As shown in Fig. 1, the frequency band used by 6G communication is much higher than 4G and 5G. In such MIMO systems with more channels, a reasonable channel bonding strategy is very important.

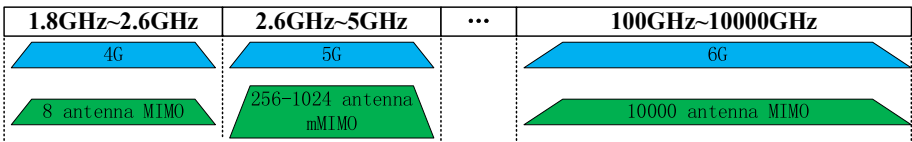


Fig. 1. Comparison of 4G, 5G, 6G bands.

D2D communication is also one of the hotspot technologies in 5G at present, and it is also an attractive research direction in 6G in the future. In the condition of many densely distributed devices in IIoT, D2D is an efficient communication method. D2D is a new technology that allows users to communicate directly through shared cellular resources with or without the control of a cellular system. In this way, the channel resource utilization can be greatly improved. The mMIMO-D2D system model is shown in Fig. 2.

Base stations (BS) and users have a large number of available channels. In this model u1 communicates with other users through the base station, u2 and u3 communicate directly (D2D) with each other under the control of the base station, and u4 and u5 directly perform D2D communication. In such a communication system with small transmission power, short transmission distance, and large number of nodes, a suitable dynamic channel bonding strategy is even more needed.

The IEEE 802.11ax is a typical protocol using MIMO technology. The channel bandwidth of this protocol supports 20 MHz, 40 MHz, and 80 MHz, and even can reach to 160 MHz through the channel bonding mechanism. Focusing on the IEEE 802.11ax protocol, this paper studies a dynamic channel bonding algorithm. By analyzing the outage probability and its influencing factors, we proposed an outage probability based channel bonding (OP-CB) algorithm for channel bonding in MIMO system. The outage probability is determined by the average SNR of the channel. Transmission power and transmission distance are important factors in received average SNR. OP-CB gets the average SNR based on the collected channel information, and then calculates the outage probability, and then dynamically bonds the channel according to the outage probability. The algorithm can be used in massive MIMO (mMIMO) in 5G and future 6G communication.

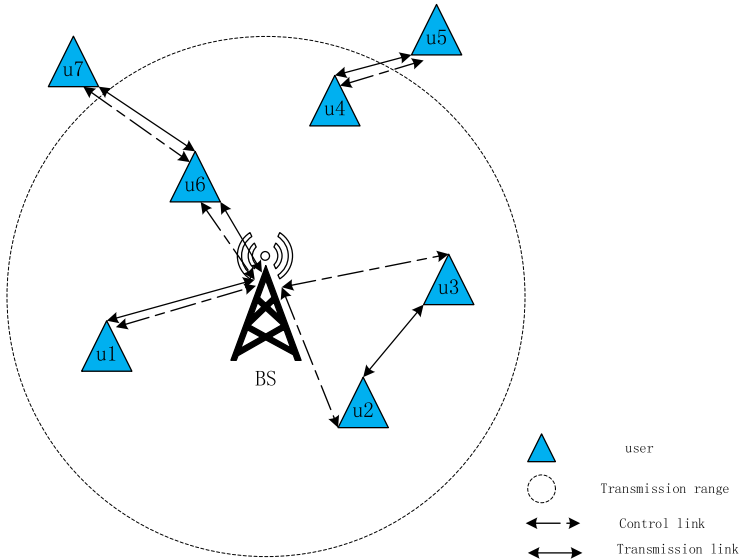


Fig. 2. mMIMO-D2D system model.

The rest parts of this paper are arranged as follows: the second part is related work. The third part introduces the concept of outage probability and its influencing factors. The fourth part introduces the OP-CB algorithm. The fifth part introduces the simulation of OP-CB in MATLAB and NS3 and the simulation results are analyzed. The last part concludes this paper.

2 Related Work

Channel bonding methods in a wireless network can be divided into static channel allocation, adaptive channel allocation, and variable bandwidth channel allocation. Static channel allocation allocates channels for each user when the network is deployed and each user will reduce the channel utilization due to load unbalance. Adaptive channel allocation considers the change of network states to make a quick respond and then adjust the channel allocation of each user. In paper [4], Yuan Zhao et al. proposed a channel bonding scheme based on packet loss mechanism and introduced a packet discarding mechanism to help the controller reduce the average delay of the system. In paper [5], YuKi Takei et al. studied the multi-interface parallel data transmission introduced into the 802.11n protocol to improve the performance of wireless communication in small pipes. The results showed that when the communication distance is less than 4 m, using multi-channel bonding could improve the communication quality. In paper [6], Aslam et al. studied the signal Rayleigh fading in massive MIMO and found that the distribution of the antenna array had a large impact on the throughput of the fading transmission. In paper [7], authors analyzed variable channels using game theory in IEEE 802.11ac networks and proposed a payment-based incentive method to make the system fairer in channel bandwidth allocation. In paper [8], authors used a power control algorithm. The

base station adjusted the transmit power of the signal according to the carrier sensing threshold to allocate a larger transmit power to the busy node. In paper [9], Sergio et al. discussed dynamic channel bonding (DCB) strategies in spatially dense WLANs. The result showed that choosing the maximum bandwidth for communication could improve the throughput for a single transmission. However, it was the unfair competition for other data transmissions. Therefore, transmission with random bandwidth could improve fairness, in the case of high-density WLANs.

The static channel allocation and the packet loss-based channel bonding mechanism will cause problems of poor fairness and low channel resource utilization. Although the random channel bonding strategy has good fairness, it is difficult to meet all data transmission requirements. This problem is solved in this paper by using a channel bonding algorithm based on outage probability. According to the calculated outage probability, combined with the bonding mechanism, different numbers of channels are bonded to data transmission to achieve efficient data transmission.

3 Description of Outage Probability

3.1 Outage Probability

Definition: Outage probability is an expression of link capacity. When the link capacity cannot meet the required user rate (the information quantity I is less than the transmission rate R), an interrupt event will occur. The probability of an outage event depends on the average SNR of the link and the channel fading distribution model. In a noise-limited system, the outage probability is defined as the probability that the instantaneous SNR is lower than a predetermined threshold SNR [10], which is shown in (1).

$$P_{out} = P[r \leq r_{th}] \tag{1}$$

In Eq. (1), r represents the instantaneous SNR at the receiver, and r_{th} refers to the minimum SNR required to meet the transmission requirements, that is, the threshold SNR. If the instantaneous SNR is higher than the threshold SNR, the quality of service will be guaranteed. The r_{th} depends on the requirements of the receiver, the type of modulation, and other factors. We can derive the outage probability based on the average SNR of the channel and the noise distribution of the channel. From the paper [10], in the absence of a relay node, the data is sent directly from the source node s to the destination node d , and the outage probability is shown in Eq. (2).

$$P_{out} = 1 - \frac{2r_{th}}{\sqrt{\bar{r}}} \cdot K_1\left(\frac{2r_{th}}{\sqrt{\bar{r}}}\right) e^{-r_{th}(\frac{1}{\bar{r}})} \tag{2}$$

Where \bar{r} is the average SNR of the channel. K_1 is a first-order modified Bessel function. When node s communicates with node d through relay node m , the outage probability is shown in Eq. (3).

$$P_{out} = 1 - \frac{2r_{th}}{\sqrt{\bar{r}_1 \cdot \bar{r}_2}} \cdot K_1\left(\frac{2r_{th}}{\sqrt{\bar{r}_1 \cdot \bar{r}_2}}\right) e^{-r_{th}(\frac{1}{\bar{r}_1} + \frac{1}{\bar{r}_2})} \tag{3}$$

Where \bar{r}_1 and \bar{r}_2 respectively are average SNR from the source node s to the relay node m and from the relay node m to the destination node d .

To validate Eq. (3), a Monte Carlo simulation is done. Where SNR is exponentially distributed, and $\bar{r}_1 = \bar{r}_2$, $r_{th} = 15$, We repeat 1000 times and count the probability that the instantaneous SNR is less than the threshold SNR under different average SNR. The result is shown in Fig. 3. It can be seen that the outage probability obtained by the Monte Carlo algorithm after repeating 1000 times is similar to that calculated by Eq. (3). When there is no relay node, the conclusion is similar according to Eq. (2).

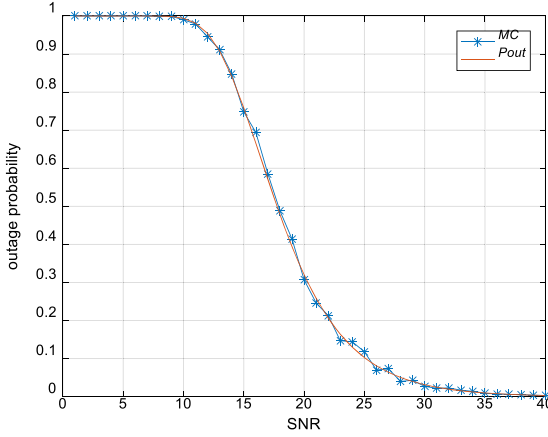


Fig. 3. Verification of the outage probability formula using the Monte Carlo simulation.

3.2 Factors Affecting Outage Probability

Assuming that the noise power at the receiver remains basically the same as N_0 , the SNR at the receiver is defined as Eq. (4).

$$SNR = \frac{P_r}{N_0} \tag{4}$$

In wireless transmissions, the relationship between the transmit power, the transmission gain and loss is given by Eq. (5) [11].

$$P_r(dBm) = P_t(dBm) + G_t(dBi) + G_r(dBi) - L_{pf}(dB) \tag{5}$$

Where P_r refers to the received power; P_t refers to the transmit power; G_t refers to the gain of the transmit antenna; G_r is the gain of the receiving antenna; Typical values for G_t and G_r are 3 and 0, respectively. L_{pf} is the free space loss. L_{pf} in 5 GHz band is given by Eq. (6) [12].

$$L_{pf}(dB) = 20 \lg f(MHz) + N * \lg d(m) + P_{f(n)} - 28 \tag{6}$$

where f is the channel center frequency, and here f is about 5000 MHz, d is the transmission distance, $P_{f(n)}$ refers to the influence of the n -story interval on the fading, the typical value here is 16, the typical value of the coefficient N is 30.

According to the above equations, bringing the typical value into the equations, the relationship between received power P_r , transmission distance d and the transmit power P_t is as shown in Eq. (7):

$$P_r(dBm) = P_t(dBm) - 30 \lg d(m) - 59 \tag{7}$$

According to Eqs. (4) and (7), the relationship between SNR, transmit power and distance can be known: the SNR is positively correlated with the transmit power and inversely related to the transmission distance.

It can be known from Eqs. (3), (4), and (7) that the outage probability is related to the SNR, which in turn is related to the transmission power and the transmission distance. The outage probability is inversely correlated with the transmit power and positively related to the transmission distance. We use MATLAB to simulate the relationship known from Eqs. (3), (4) and (7). The result is shown in Fig. 4, where $\bar{r}_1 = \bar{r}_2$, $r_{th} = 15$, and the average SNR is calculated from transmit power and transmission distance.

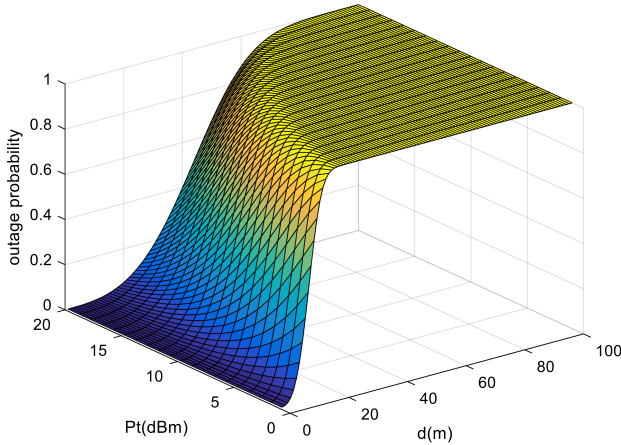


Fig. 4. Relationship between outage probability, transmit power and transmission distance when OP-CB algorithm is not applied.

As can be seen from Fig. 4, when the transmission power gradually decreases from 20 dBm or the transmission distance gradually increases from 1 m to 100 m, the outage probability rapidly becomes large and approaches 1. When there is no relay node, the conclusion is similar according to Eq. (2).

According to Eqs. (2) or (3), We can increase the channel SNR or reduce the threshold SNR to reduce the outage probability.

According to Shannon formula shown in Eq. (8), If the channel capacity C is kept constant and the channel bandwidth B increases, the required SNR (i.e., threshold SNR) can be reduced.

$$C = B \log(1 + SNR) \quad (8)$$

Therefore, when the transmission distance is large or the transmission power is low, the SNR at the receiver is relatively low. We can increase the transmission bandwidth by bonding more channels to reduce the outage probability. In addition, we have simulated different numbers of transmit and receive antennas in our previous work [13]. The relationship between SNR and channel capacity proves that under the same SNR condition, the increase of the number of bonded channels will increase the channel capacity and increase the data transmission rate.

4 OP-CB: Outage Probability Based Channel Bonding

OP-CB can be used in single-hop networks and multi-hop networks (This article only considers the case where there are 0 or 1 relay nodes for explanation) in MIMO systems. It is a dynamic channel bonding algorithm. The receiver calculates the outage probability based on the collected transmission power, transmission distance, number of hops and other information. If the outage probability is larger than the set threshold (10% in this paper) outage probability, bond more channels until it is less than the threshold outage probability. In this way, we can reduce the outage probability of data transmission and improve the transmission quality.

4.1 Working Process of OP-CB

The pseudocode of OP-CB is roughly shown in Table 1. Line 1 to 2 show that the nodes first scan the channels, to get the CSI and store it in matrix C_1 . Line 3 to 5 show that the source node or relay node adds SNR of the current hop to the REQ and sends it to the next hop to establish a connection. Line 6 to 19 show that the destination node selects the channel with the highest SNR based on the information in the finally received REQ and then calculates the outage probability. If the calculated outage probability is greater than the threshold outage probability (20%), add bonding channels. Line 20 to 22 describes the process of updating the system after data transmission is completed.

In order to implement the above algorithm, the base stations in 6G network need to exchange CSI and coordinate work. Because of the high frequency band used for 6G communication, the single-hop transmission distance is relatively short according to Eq. (6). Therefore, compared to 4G and 5G communication, more base stations need to be set. What's more, in the 6G era, people's range of activities has expanded from the ground to the air. In order to ensure the complete coverage of the network, 6G network will integrate the ground network and the air network, and the network topology will expand from two dimensions to three dimensions. To make a large number of base stations work in coordination, we use SDN to coordinate and control the base stations

Table 1. pseudocode of OP-CB.

```

1: Nodes scan all channels to get channel state information (CSI);
2: Nodes store the information in matrix  $C_i$ ;
3: //For relay node or source node:
4: Add current_SNR to REQ;
5: Send REQ to next-hop node;
6: //For destination node:
7: While non-solved REQs exist:
8:     If free channels exist:
9:         Choose channel with the highest SNR;
10:        Do compute outage probability;
11:        While  $P_{out} > 0.2$ :
12:            Add bonding channels to decrease outage probability;
13:        End While
14:        Update  $C_i$ ;
15:    End If
16:    Else:
17:        Return No free channel;
18:    End Else
19: End While
20: Transmit data;
21: If data transmission finished: Release channels;
22: Update  $C_i$ ;

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in a certain area, which makes the data forwarding between base stations more efficient. The three-dimensional 6G network using SDN controllers is shown in Fig. 5. Under the control of the SDN controller, CSI is transmitted from the user to the base station.

After determining the number of bound channels, the base station sends channel binding information to the user.

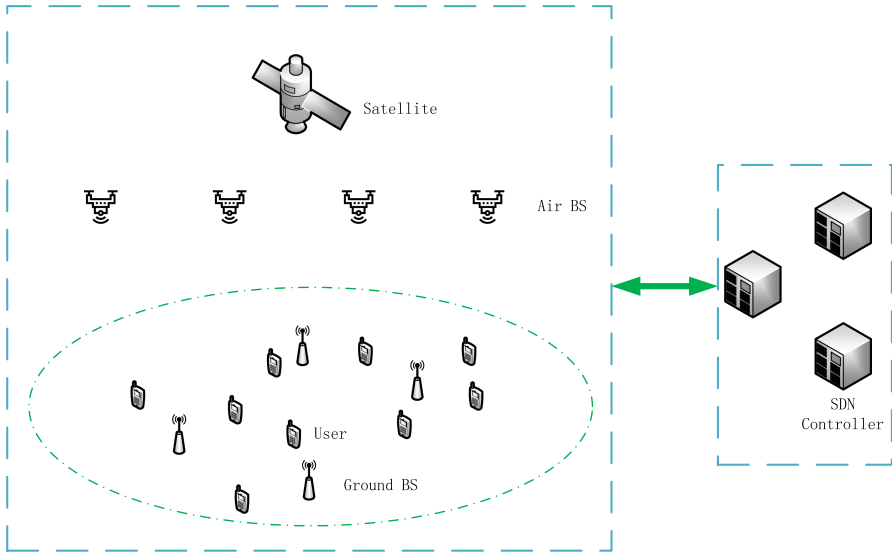


Fig. 5. 6G network with SDN controllers.

4.2 Analyze of OP-CB

Combining the outage probability with the channel bonding algorithm, we can control the bandwidth to adjust the threshold SNR of the data transmission. If the success rate of data transmission is to be guaranteed, it is necessary to ensure that the average SNR of data transmission is greater than the threshold SNR. We can bond multiple channels for transmission and increase the transmission bandwidth to reduce threshold SNR.

We use MATLAB to show the working process of OP-CB and evaluate it. Figure 6 is a comparison of the results of the outage probability at different SNRs using and not using the OP-CB algorithm. The number of channels bonded in OP-CB is shown in Fig. 7. The average SNR ranges from 1 to 40, and the SNR is exponentially distributed. The threshold SNR is set to 15 dB. The threshold of the outage probability set here is 0.2.

It can be seen that in the process of changing the SNR from 40 dB to 1 dB, when the OP-CB algorithm is not used, the outage probability is rapidly increased. When the SNR is about 23 dB, it exceeds 0.2. With the SNR gradually decreasing, the outage probability increases rapidly.

When using OP-CB, as the SNR is gradually reduced from 40 dB to 1 dB, the outage probability gradually become larger. But when the outage probability reaches 0.2 (SNR is about 16 dB), multiple channels are bonded for data transmission, and outage probability is reduced. As SNR decreases further, the outage probability continues to

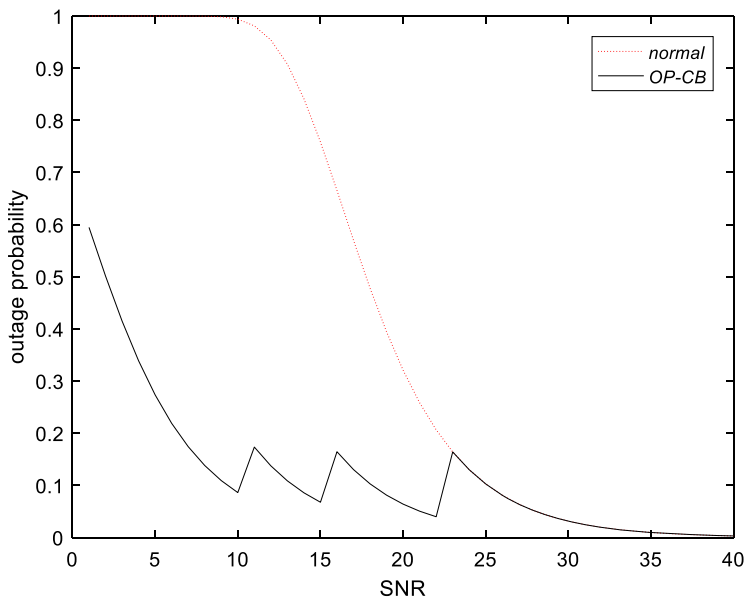


Fig. 6. Comparison of outage probability results with different SNRs with OP-CB algorithm and normal channel bonding.

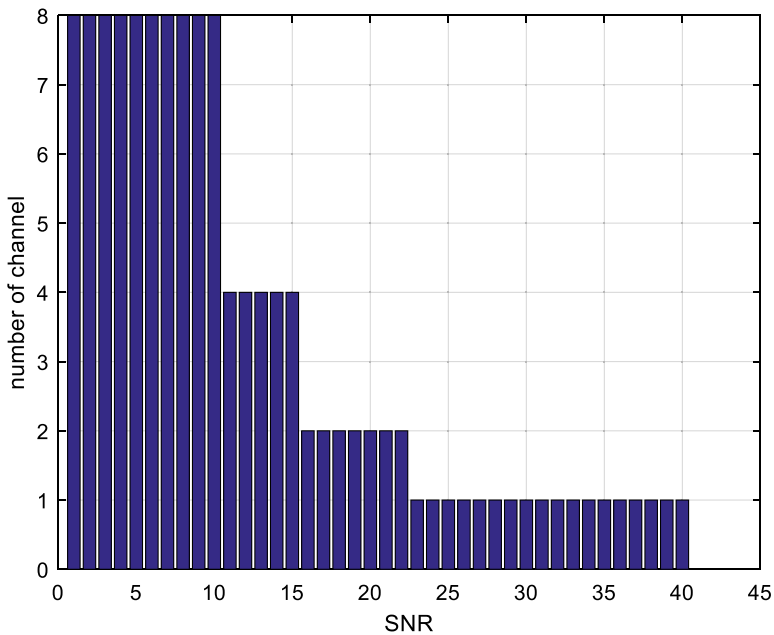


Fig. 7. Number of channels bonded at different SNRs using the OP-CB algorithm.

increase. When outage probability reaches 0.2 again (SNR is about 16 dB), more channels are bonded. Until the SNR is less than about 5, there are not enough channels to use for data transmission, so the outage probability is greater than 0.2. It can be seen that after using the OP-CB algorithm, the overall outage probability is significantly smaller than that of the unused OP-CB algorithm.

As can be seen from Fig. 6 and Fig. 7, when the OP-CB algorithm is used, as the SNR gradually decreases, the number of bonded channels increases in order to keep the outage probability as small as possible. According to the IEEE 802.11ax protocol, 1, 2, 4, and 8 channels can be bonded with bandwidths of 20 MHz, 40 MHz, 80 MHz, and 160 MHz, respectively.

It can be seen that OP-CB controls the outage probability of data transmission to a small value while saving channel resources as much as possible.

5 Simulations and Results Analysis

The simulation of this paper is divided into two parts. Firstly, we use MATLAB to compare the transmission rate and bit error rate (BER) using OP-CB, bonding mechanism and normal channel bonding. Then we use NS3 to simulate and compare the throughput with and without the OP-BC algorithm.

The MATLAB simulation uses the simulation tool MATLAB2016a and the operating system is the window 10 home version. The simulation tool used in the NS3 simulation is NS3.26, and the operating system is Ubuntu16.04 LTS.

5.1 Simulations on MATLAB

A. Simulation Scene and Parameter Settings. In the simulation scenario, there are 8 antennas available for the base station. The topology is shown in Fig. 2. User 7 communicates with the base station through user 6. When using bonding mechanism, 2 channels are bonded between user 6 and the BS, and 1 channel is bonded between user 6 and user 7. When using normal channel bonding, 1 channel is bonded between user 7 and user 6, and 1 channel is bonded between user 6 and BS. When using OP-CB, the number of bonded channels is dynamically determined by the outage probability. Other simulation parameters are shown in Table 2.

Table 2. Parameter settings of simulation on MATLAB.

Parameter name	Parameter value	Parameter name	Parameter value
Transfer protocol	IEEE802.11ax	Number of users	<4
Data block length	9byte	Frequency band	5 GHz
Modulation model	256QAM	RTS/CTS	open
Number of antennas	8		

B. Simulations Results and Analysis. Figure 8 is a comparison of the data transmission rate as a function of SNR when different channel bonding methods are used. When using the OP-CB algorithm, the channel bonded is determined according to the outage probability, and the outage probability is calculated by comparing the current SNR with the threshold SNR (10% in the simulation). When the outage probability is too large, the base station allocates multiple channels for the current data transmission, reducing the outage probability. The simulation results show that using OP-CB algorithm can obtain higher data transmission rate, and with the increase of SNR, the rate of increase is faster than using other methods.

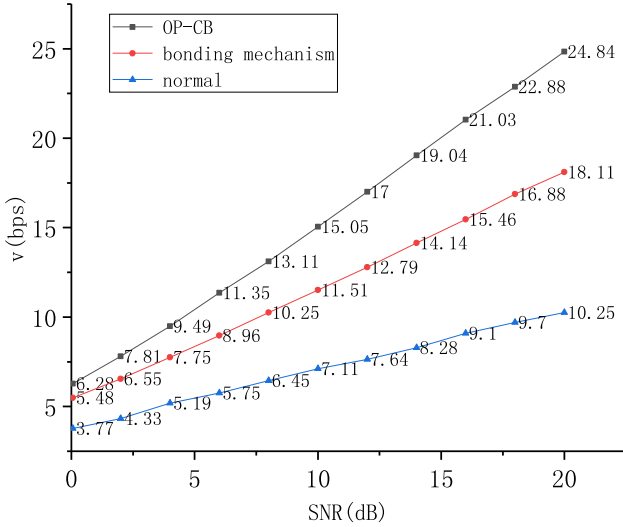


Fig. 8. Comparison of transmission rates in three cases.

Figure 9 shows the error bit rate comparison of data at the receiver when different channel allocation mechanisms are used. When the OP-CB algorithm is adopted, the final result obtained is optimal among the three channel allocation methods. When the SNR exceeds 13, the BER is first reduced to near 0.

5.2 Simulations on NS3

A. Simulation Scene and Parameter Settings. Use NS3 to simulate both single-hop and two-hop transmissions. The network topologies are respectively shown in Fig. 10a and Fig. 10b.

In the single-hop scenario in Fig. 10a, the source node s1 and the source node s2 communicate with the node BS using channels 36 and 52, respectively. In the two-hop scenario in Fig. 10b. The source node s1 communicates with the destination node d1 through the relay node n using channel 36, and the source node s2 also communicates with the destination node d2 through the relay node n using channel 52.

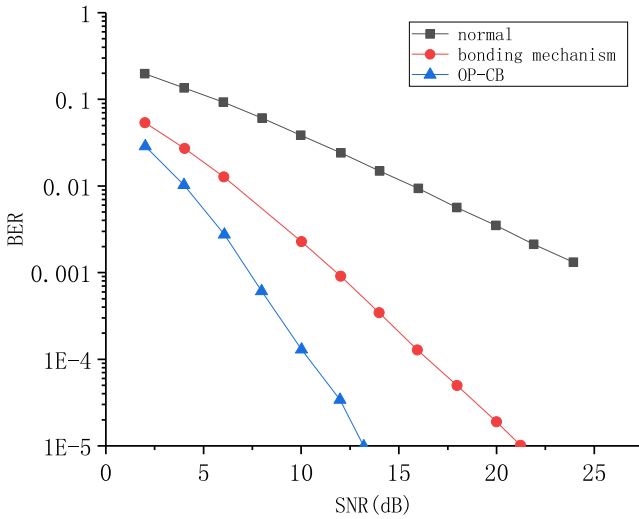


Fig. 9. Comparison of transmission bit error rate (BER) in three cases.

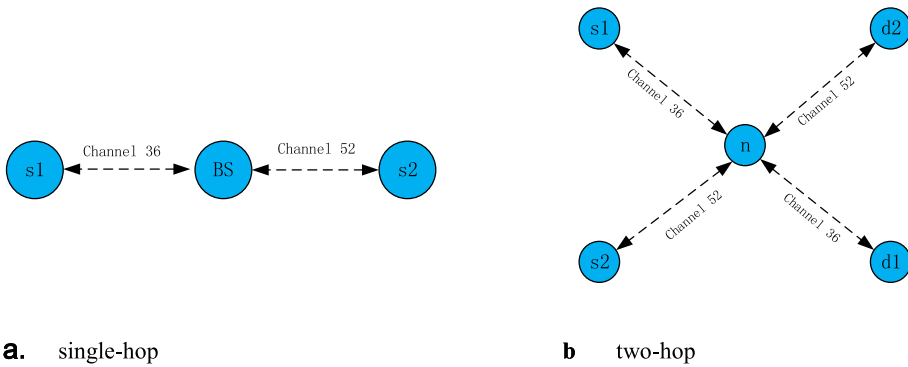


Fig. 10. NS3 simulation network topologies.

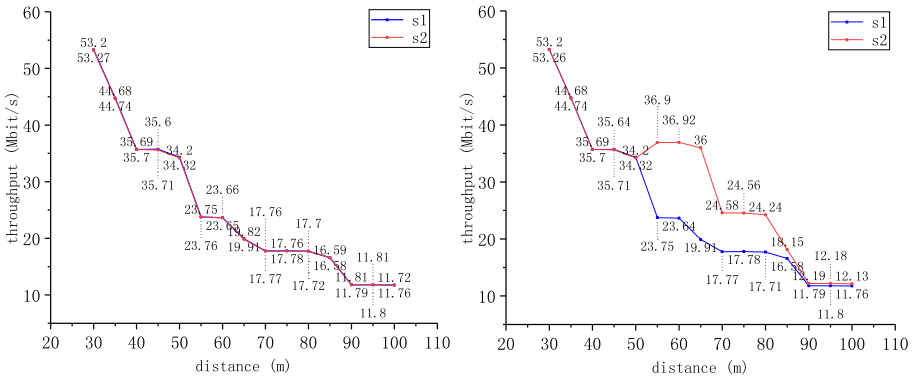
The distance between the source nodes s_1 , s_2 and the BS node in the single-hop network remain equal and changes synchronously. In the two-hop network, the distance between the relay node and the source node s_1 , s_2 and the destination node d_1 , d_2 also remains equal and changes synchronously. In both network topologies, the transmit power remains the same. Other simulation parameters are shown in Table 3.

B. simulation Results and Analysis. Figure 11 shows the comparison of the throughput of the used and unused OP-CB algorithms with the data transmission distance in a single-hop network topology. Figure 11a shows that the source nodes s_1 and s_2 do not use the OP-CB algorithm. Since the transmit power and transmission distance are the same, the throughput of the two transmissions is almost the same, and both decrease rapidly with increasing distance. Figure 11b shows that s_2 uses the OP-CB algorithm and s_1 is not used. It can be seen that before 50 m, the distance is not large enough, s_2 does

Table 3. Parameter settings of simulation on NS3.

Parameter name	Parameter value	Parameter name	Parameter value
Transfer protocol	IEEE802.11ac	Number of antennas	8
Application layer protocol	UDP	Number of users	2 or 4
Packet size	1472byte	Frequency band	5 GHz
Modulation model	256QAM	RTS/CTS	Open

not start to bond more channels, and the throughputs of the two transmissions remain almost identical. When the distance is greater than 50 m, since the outage probability is greater than the threshold designed in this paper, s2 begins to bond more channels. As the distance increases, the throughput of both transmissions decreases, and the throughput of s2 falls slower than that of s1. More, the overall throughput of s2 is 40%–50% higher than that of s1. However, when the distance is large, the gap of throughput between s2 and s1 is not very large.



a. s1 not uses, s2 not uses

b. s1 not uses, s2 uses

Fig. 11. Comparison of throughput between unused and unused OP-CB algorithms in a single-hop network topology.

Similarly, in the result of the two-hop network topology shown in Fig. 12, while s2 using the OP-CB algorithm and s1 not, and the distance is 60 m, the outage probability exceeds the set threshold, and s2 begins to bond more channels. The throughput of s2 is about 40% higher than that of s1. Because of the relay node, the transmission distance is about twice that of the single-hop network in Fig. 11, when the throughput is basically the same.

The simulation results show that the OP-CB algorithm considers the outage probability of data transmission, which will increase the information volume of the transmission

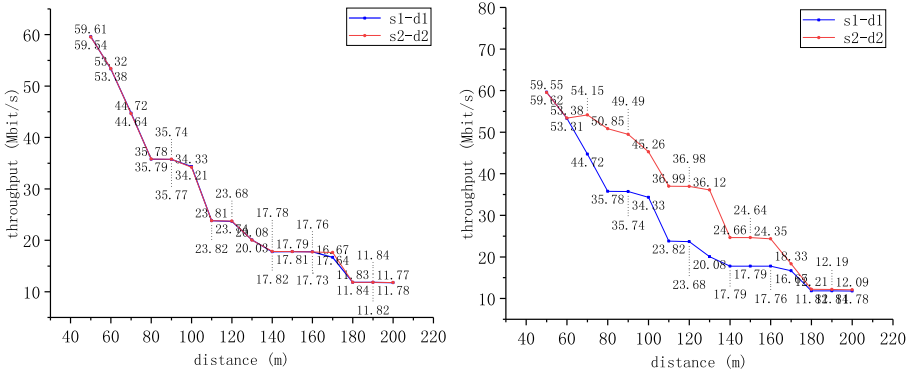


Fig. 12. Comparison of throughput between unused and unused OP-CB algorithms in a two-hop network topology.

channel, achieve a larger data transmission rate under the same SNR condition, and improve the transmission throughput.

6 Summary and Future Work

The reasonable allocation of channels plays a key role in the efficient and reliable transmission of data in MIMO systems, especially in mMIMO and D2D scenarios in 5G and future 6G communication. This paper introduces the concept of outage probability, analyzes the relationship between outage probability and influencing factors such as transmit power, transmission distance, and bandwidth. We also give related expressions. Then we propose a channel bonding algorithm based on outage probability. Simulation results show that in single-hop and multi-hop network topologies, using OP-CB algorithm can improve system throughput, data transmission rate, and reduce data error bit rate.

For the future work, we will further study the use of deep learning in 6G networks (broader spectrum and greater number of channels) to optimize channel allocation methods based on the various characteristics of channels.

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