A New Coordinated Multi-points Transmission Scheme for 5G Millimeter-Wave Cellular Network

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Abstract. Millimeter-wave network based on beamforming is an interference-limited network. In order to mitigate the interference for the 5G millimeter-wave cellular network, the concept of cooperative multi-beam transmission (Beam-CoMP) is proposed in this paper to improve cell capacity. For users in the beam overlapping zone, there is strong interference between beams, so for such users, overlapping beams provide services to users through cooperation. This method can solve the problems of poor edge coverage and serious interference of overlapping coverage of beams at the same time. The specific process of beam cooperation is given and the Beam-CoMP method proposed is simulated to verify its effectiveness in improving the UE performance. The results show that cell capacity increases with the increase of the number of users in the service beam.

Keywords: Millimeter-wave · 5G · CoMP · Capacity · Interference

1 Introduction

With the development of high-speed wireless communication technology, millimeter-wave technology has more and more important applications in future wireless networks. 5G puts forward higher requirements for link rate, link delay and system energy efficiency. Therefore, in a series of new technologies [1–3], millimeter wave technology (30–300 GHz) has become one of the most important technologies recognized by the industry. For the applications of millimeter wave technology, opportunities and challenges coexist [4]. On the one hand, millimeter-wave band provides a large bandwidth, which can provide higher system capacity. On the other hand, millimeter-wave communication usually needs beam forming to increase the coverage distance because of the large propagation loss of millimeter-wave. Although millimeter-wave network and traditional network have different channel characteristics, antenna structure and hardware constraints, millimeter-wave network based on beamforming is still interference-limited network, that is, system capacity is mainly affected by the mutual interference in the network [5]. The important means to improve system capacity and spectrum efficiency is to reduce the network interference. Different from traditional

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interference, in millimeter-wave networks, due to the directional narrow-beam characteristics, millimeter-wave interference will increase significantly in the overlapping coverage area, which will directly affect the system performance and user service quality.

In traditional cellular networks, in order to reduce network interference and improve the quality of service for the users in overlapping areas of cells, a cooperative multi-point transmission (CoMP) technology [6–9] is proposed, which aims at reducing interference and enhancing transmission through coordination or cooperation among multiple base stations and sectors. CoMP is divided into interference coordination and joint transmission. The interference coordination mainly avoids the interference between beams by joint beamforming. Joint transmission achieves signal enhancement by transmitting the same information through multiple beams. At present, there are two main types of joint transmission CoMP, including inter-CoMP and intra-CoMP [10]. Inter-CoMP is a cooperative transmission between different sites; intra-CoMP is a cooperative transmission between multiple sectors of the same site. At present, there are many studies on inter-CoMP, including link capacity, link interrupt probability, asynchronous reception performance, and the impact of delay and return capability on link performance. But inter-CoMP needs a feedback network to exchange information between different sites, so the system complexity is high [11]. For intra-CoMP, the literature [12] compares its link performance with that of non-CoMP systems, and points out that intra-CoMP can bring link gain. The literature [13] compares the link performance gain of intra-CoMP with that of inter-CoMP, and points out that the performance of intra-CoMP is inferior to that of inter-CoMP. Meanwhile, a method to improve the link performance is given, that is, to increase the number of sectors in a cell. Intra-CoMP has advantages in information interaction complexity, time delay and system synchronization because all information exchanges are on the same site.

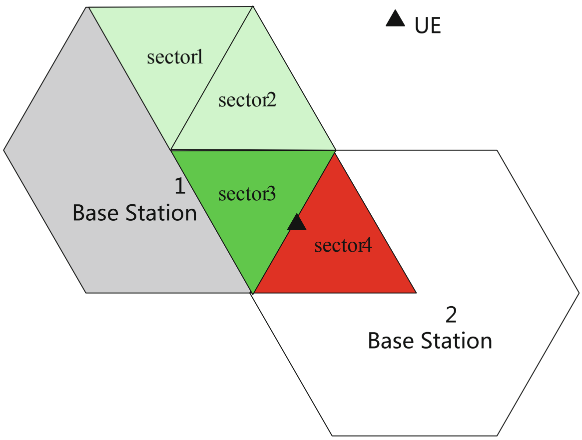

Fig. 1. CoMP system schematic diagram.

The above analysis shows that inter-CoMP is not practical because of its high system complexity, which is mainly due to the limitations of user grouping and scheduling, channel estimation and feedback, synchronization and information feedback when different sites cooperate. Although intra-CoMP does not have the problem of high complexity of inter-CoMP, the performance gain of intra-CoMP is not as good as that of inter-CoMP. As shown in Fig. 1, inter-CoMP is the CoMP of different sites, such as sector3 and sector4. Both sectors have larger signal strengths at the user. Intra-CoMP is the CoMP of different sectors of the same site, such as sector3 and sector2. Because of the traditional antenna deployment and sector division, the signal strengths of sector2 at the user is small, so the gain of cooperation with sector3 is not as obvious as that of inter-CoMP.

In order to solve the above problems, the concept of cooperative multi-beam transmission (Beam-CoMP) is proposed in this paper, and it is introduced into beamforming-based millimeter-wave network to improve cell capacity. This method can solve the problems of poor edge coverage and serious interference of overlapping coverage of beams at the same time. Each sector of the site is a large-scale array antenna, which forms multiple beams to serve users in the sector by beamforming. In order to maximize resource utilization, full bandwidth frequency multiplexing of each beam is implemented. According to the location of users, users can be divided into two categories: users in non-overlapping zone and users in overlapping zone. For users in non-overlapping zone, users' services are provided by a single beam, in which multiple users share the whole time-frequency resources, and such users are relatively less disturbed by other beams. For users in overlapping zone, there is strong interference between beams, so for such users, overlapping beams provide services to users through cooperation. Beam-CoMP can eliminate interference and enhance signal diversity. Different from traditional CoMP, inter-CoMP is the cooperation of different sites, intra-CoMP is the cooperation of different sectors of the same site, and Beam-CoMP is the cooperation of different beams of the same site in the same sector.

Introducing Beam-CoMP into the beamforming-based millimeter-wave network is expected to solve the existing CoMP problems and bring the following obvious advantages:

(1) Increase the signal intensity of the users covered by the beam edge.

The signal quality of beamforming-based users in the edge coverage area is worse than that in the center area, which makes the service quality of edge users poor. By means of Beam-CoMP, users at the edge of beams can transmit jointly through multi-beams, which enhances the signal strength and improves the quality of service.

(2) Reduce interference in millimeter-wave networks and increase cell capacity.

The main interference in millimeter-wave network comes from inter-beam interference. Beam-CoMP can eliminate inter-beam interference, which can greatly reduce interference and improve cell capacity.

(3) Make up for the shortcomings of traditional CoMP and reduce the complexity of the system.

Because Beam-CoMP collaborates in the same sector of the same site, data interaction, synchronization and delay processing are easy to implement, and the system complexity is low. At the same time, there is no lack of signal intensity caused by the problem of sector coverage when adjacent sectors cooperate in intra-CoMP, which will lead to significant capacity improvement.

2 System Model

Firstly, the cell structure of 5G millimeter wave cellular network is defined as shown in Fig. 2. In the cell, network units mainly include sites and users. Large-scale antenna arrays are used in the base station. Cells are divided into several sectors by different antennas. Through beam forming technology, each sector can form multiple beams at the same time and serve multiple users separately. Assuming that a service-providing beam is random beamforming, it randomly points to a location in the sector. If the beam covers a user to be served, the beam will point to this location unchanged. If there is no user to be served in the coverage area randomly pointed by the beam, the beam will randomly point to another location until it finds users to be served. For users, we use Poisson Point Process (PPP), which is commonly used in stochastic geometry theory, to describe its distribution, that is, the user obeys PPP process with density. Users are randomly distributed in the sector.

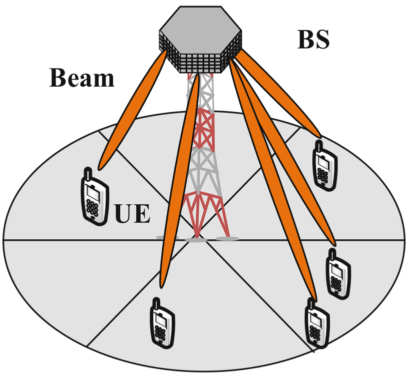

Fig. 2. Block structure diagram of 5G system.

Assuming that BS serves N UEs in the cell, there are N transmission links in the cell. In the link i of $Beam_i$ Service UE_i, the receiving power Pr_i is

$$Pr_i[dBm] = P_t[dBm] + G_t[dBi] + G_r[dBi] - PL[dB] \tag{1}$$

Where P_t is the transmission power of the base station, G_t is the gain of the transmitting antenna, G_r is the gain of the receiving antenna,and PL is the path loss between the sender and the receiver. Assuming that each beam is aligned with the user it serves during transmission, the maximum antenna gain G_t is obtained at this time. If the user uses omnidirectional antenna, the value G_r should be 0 dBi. The path loss of signal propagation is calculated by using the channel model in millimeter wave LOS environment.

$$PL[dB] = \alpha + 10\beta \lg d + X_\sigma \tag{2}$$

The parameters in the model are measured at 28 GHz in Manhattan LOS environment. And $\alpha = 45.3$, $\beta = 2.9$, d is the distance between users and the base station, $\sigma = 0.04$.

Assuming the received total interference power of UE_i is P_{Ii}, the single to noise ratio of UE_i can be described as

$$SINR_i = \frac{P_{r_i}[mw]}{N[mw] + P_{I_i}[mw]} \tag{3}$$

According to Shannon's formula, the capacity of this link is

$$C_i = B \log_2(1 + SINR_i) \tag{4}$$

Where B is the bandwidth. Cell capacity is the sum of all link capacity, and

$$c = \sum_{i=1}^{N} c_i \tag{5}$$

The cell capacity of cooperation between beams is the sum of the capacity of two types of users. One is the capacity of users in the overlapping zone $C_{overlap}$, and the other is the capacity of users in the non-overlapping zone $C_{nonoverlap}$. For the capacity of users in the non-overlapping zone of the beam, the capacity can be calculated directly according to the above method. For the user in the overlap zone, K interference beams and service beams cooperate to provide services for the user, and the interference between beams PI is converted into useful signal P_r. And the $SINR$ is

$$SINR(i) = \frac{\Pr + \sum_{k=0}^{K} PI_k}{N_0} \tag{6}$$

Where N_0 is the Gaussian white noise. Assuming that there are N users in the beam overlapping region and M users in the non-overlapping region, the capacity can be described as,

$$
\begin{aligned}
C &= C_{overlap} + C_{nonoverlap} \\
&= \sum_{i=1}^{N} C_{overlap}(i) + \sum_{j=1}^{M} C_{nonoverlap}(j) \\
&= \sum_{i=1}^{N} B_i \log_2\Big(1 + \frac{P_r + \sum_{k=0}^{K} PI_k}{N_0}\Big) + \sum_{j=1}^{M} B_j \log_2\Big(1 + \frac{P_r}{N_0}\Big)
\end{aligned} \tag{7}
$$

3 The Proposed Coordinated Multi-points Transmission Scheme

In the mode of single-beam service for multi-users, multi-beam cooperation provides services for users in the overlapping zone. This can not only avoid the inefficiency of single-beam service, but also solve the problem of the degradation of UE performance at the edge of the beam when single-beam provides service for multi-users. In the Beam-CoMP transmission technology proposed in this section, the base station has the ability of multi-beam cooperative communication, and each beam can serve multiple UEs with full frequency band reuse.

As shown in Fig. 3, when allocating the frequency resources for the UEs in the beam overlapping area and non-overlapping area, the station firstly allocates the frequency bandwidth resources required by UEs in the non-overlapping area using OFDM technology according to the transmission requirements. The remaining system frequency bandwidth resources are allocated to the overlapping UEs at the beam edge. By utilizing the advantages of multiple beams easy to cooperate in the same single base station, the performance of beam edge UEs can be enhanced by cooperation. The transmitter of the base station modulates the data to the pre-allocated frequency band, and the receiver demodulates the data in the corresponding frequency band to complete the data transmission.

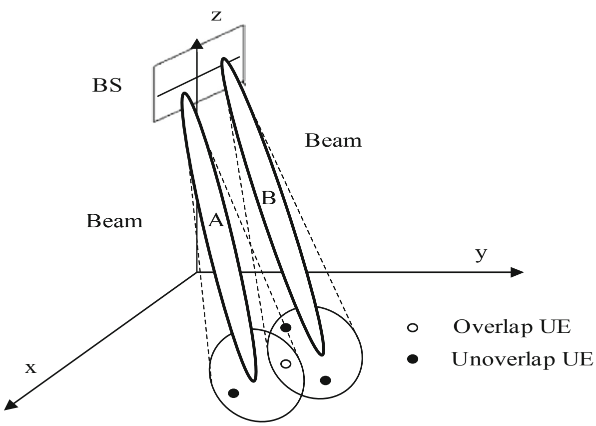

Fig. 3. The proposed Beam-CoMP scheme.

The specific process of beam cooperation is as follows:

(1) As shown in Fig. 3, assume that the total frequency resource bandwidth of the system is $BW_{\circ}$ The beam $i(i = 1, 2, \ldots, n,\ n > 1)$ provides service for the users $UE_{ij}(j = 1, 2, \ldots, m_i,\ m_i > 1)$ in the non-overlapping region. Where n is the beam number, and m_i is the user number in the non-overlapping region of beam i. The users in the overlapping region are $UE_k(k = 1, 2, \ldots, l)$, and l is the user number.
When the system transmits data in the down link, the site sends information to UE with full frequency reuse. When the station and UE determine the connection, the station associates the beam i with the UE to establish the transmission link. Then go to step (2).
When UE transmits data up to the site, UE initiates a transmission request. After the site permits, the site connects the beam i to the UE to establish a transmission link. Then go to step (5).

(2) The cooperative beam i determines the minimum frequency resources required for all non-overlapping areas BW_i. As shown in Fig. 4, then go to step (3).

(3) Compare the minimum frequency resource bandwidth required BW_i for each beam serving UE_{ij} in the non-overlapping region. As shown in Fig. 5, the maximum bandwidth required is selected among all the individual beams participating in the collaboration max (BW_i). All UEs in the non-overlapping area of each beam are allocate with the same bandwidth max (BW_i). And the UEs in the overlapping region share the left bandwidth $BWR = BW - \max(BW_i)$, as shown in Fig. 6.
Through OFDM, the station modulates the data of UEs in the non-overlapping region to the corresponding frequency bandwidth BW_{ij} for transmission, and modulates the data of the users in the overlapping area to the corresponding bandwidth BWR_k for data transmission. Then go to step (4).

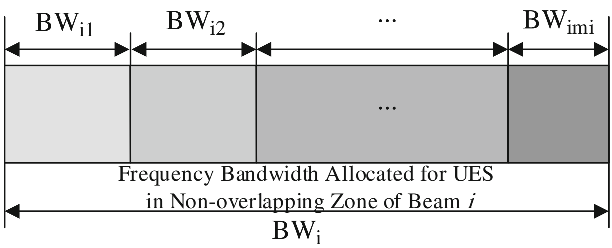

Fig. 4. Frequency bandwidth allocated for UES in non-overlapping zone of beam *i*.

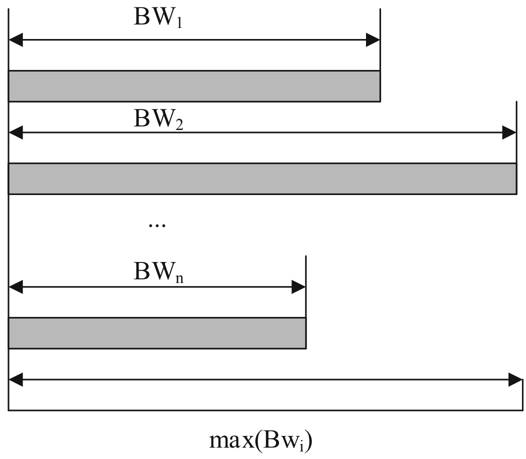

Fig. 5. A schematic diagram of the minimum bandwidth required for UE in the non-overlapping region.

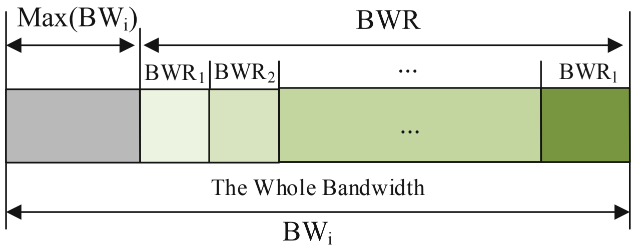

Fig. 6. Schematic diagram of total frequency resource bandwidth allocation.

(4) Each UE receives data individually and demodulates data on the corresponding frequency bandwidth.

Uplink resource allocation and data transmission are similar to downlink. The beam cooperation method proposed in this section can effectively enhance the transmission performance. In the case of single-beam serving multi-UEs, for users in the overlapping zone, multi-beam cooperation at the same site provides services for edge users. Multiple beam cooperation can improve the efficiency of resource utilization and service efficiency. At the same time, cooperative transmission among multi-beams can not only guarantee the normal communication of users in non-overlapping area, but also improve the performance of users in overlapping area. Moreover, because multi-beams in a single site cooperate, it is easy to collaborate among beams.

4 Simulation Results and Analysis

In this section, the Beam-CoMP method proposed in the previous section is simulated to verify its effectiveness in improving the UE performance. The simulation scenario assumes that there are overlapping beams in a sector of the cell. The specific simulation parameters are shown in Table 1. In the simulation, users are randomly distributed in the beam. Each beam in the sector is fully frequency reused, and the UE in each beam is served by the beam. For simplicity, the total frequency resources of the beam are divided equally. When there is no user in the beam, the beam will not work and will not interfere with the overlapping beams. The simulation takes 5000 times as the average.

Table 1. Simulation parameters of Beam-CoMP scenarios.

BS height	10 m	BS transmitter power	27 dBm
Cell radius	50 m	BS antenna gain	16 dBi
Antenna array	8 × 8	UE antenna gain	0 dBi
Carrier frequency	28 GHz	HPBW	30°
Bandwidth	500 MHz	Temperature	298 K

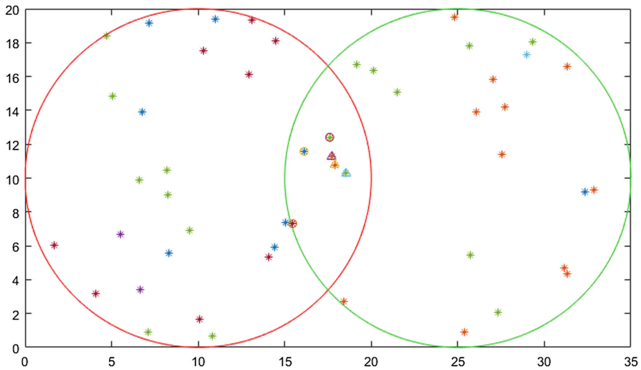

Fig. 7. Users with random positions in the beam.

In the beam overlapping model shown in Fig. 3, two beam overlapping (beam A and B) are taken as examples to illustrate the method of beam cooperation. Suppose there are four users in two beam ranges. The total frequency bandwidth of the system is BW. There are two users in beam A, three users in beam B and one user in the overlapping area of two beams. Users in non-overlapping area of beam A get BW/2 bandwidth, while users in non-overlapping area of beam B get BW/3 bandwidth. According to the beam cooperation method in the previous section, both beams allocate BW/3 frequency bandwidth to users in the overlap zone. Although the bandwidth resource of BW/6 is wasted in Beam A, the overlapping users can avoid the inter-beam interference and improve the performance because they get the same frequency resource of two beams.

For cells that do not use beam cooperation, the beam overlap model shown in Fig. 3 is also used for analysis. Assuming that the frequency resource of the system is BW, there are two users in beam A, three users in beam B and one user in the overlapping area between the two beams. In beam A, the frequency bandwidth allocated by each user is BW/2; in beam B, the frequency resource bandwidth allocated by each user is BW/3. Because there is no inter-beam cooperation, when the user in the overlapping zone receives the signal of beam A, he will be disturbed by beam B, and when the user in the overlapping zone receives the signal of beam B, beam A will interfere with it. Therefore, in this scenario, no matter which beam the user tries to receive in the overlapping region, the signal will be interfered by other beams, which will degrade the user's performance.

In the simulation, a random number of users are generated in the cell beam (beam A and beam B), and the frequency resources are allocated to each user in the beam. In the overlap zone, if two users share the same frequency, the user will be affected by the same frequency interference if they do not cooperate with each other. If the method of beam cooperation is adopted, user will not be affected by the same frequency interference. On the contrary, because of the same service frequency, both beams can cooperate to provide services for the user in the overlap zone and effectively improve the performance of users in the overlap zone. For users with different frequencies in the overlap area, they will not be subject to the same frequency interference.

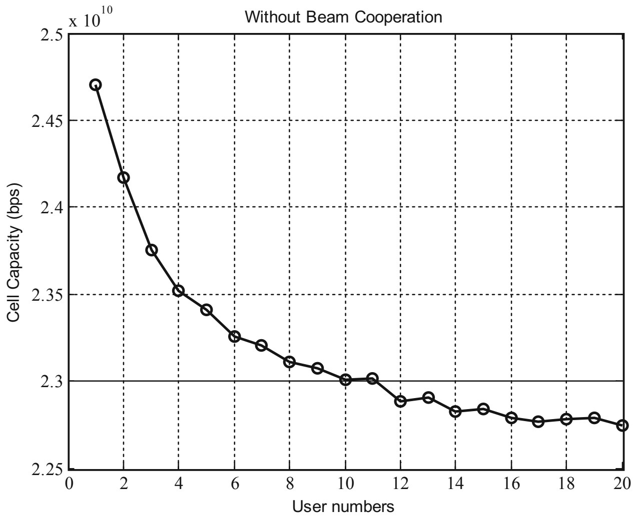

Fig. 8. User number versus capacity without beam cooperation.

Figure 8 shows the relationship between capacity and number of users in a non-beam cooperative cell. As can be seen from the simulation diagram, with the increase of the number of users, the cell capacity is gradually decreasing. This is because with the increase of the number of users, the probability of users existing in the overlapping zone is also increasing. So users in the overlapping zone are also increased by the interference between beams, and cell capacity tends to decrease.

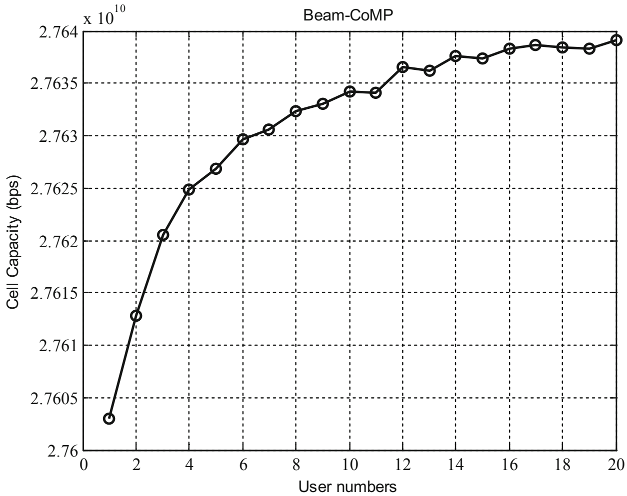

Fig. 9. User number versus capacity with beam cooperation.

Figure 9 shows the change of cell capacity with the increase of the number of users when there is beam cooperation. It can be seen from the graph that cell capacity increases with the increase of the number of users. This is because with the increase of the number of users, the number of users distributed in the overlapping area of the beam increases correspondingly. When there is co-frequency interference between users, because of the use of beam cooperation, users in the overlapping zone are provided by beam cooperation. And users are not disturbed, so they have better performance.

5 Conclusions

This paper proposed a simple and effective method to solve the beam interference problem in the 5G millimeter-wave cellular network. The specific process of beam cooperation is given and the proposed Beam-CoMP method is simulated to verify its effectiveness in improving the cell capacity. The results show that cell capacity increases with the increase of the number of users in the service beam. While without beam cooperation, with the increase of the number of users, the cell capacity is gradually decreasing because of the mutual interference. This method can solve the problems of poor edge coverage and serious interference of overlapping coverage of beams at the same time.

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