Design and Implementation of D2D Communication-Based 5G Cloud Radio Access Networks Cell Outage Compensation Method

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Abstract. As 5G officially enters the commercial era, heterogeneous networks will face massive data traffic requirements and frequent communication overheads in the future. How to ensure user service quality and reduce energy consumption is a key challenge for major operators. The wireless cloud network is considered as one of the architectures to solve this problem, and its biggest advantage is that it can quickly and flexibly access the dynamically configured resources of the shared pool. Existing research on cell interruption compensation technology mainly focuses on the optimization and adjustment of parameters of neighboring cells, which easily affects the original network topology. This paper proposes a cell interruption compensation scheme based on D2D technology, focusing on routing and resource allocation. In two stages of research, a routing algorithm based on the attributes of social networks was proposed, and the encounter model in social networks was introduced in the resource allocation link. Simulation results show that the scheme further reduces system energy consumption and delays the growth rate of energy consumption compared with traditional methods.

Keywords: Power cyber-physical system · Routing re-construction · Genetic algorithm

1 Introduction

Cloud-Radio Access Networks (C-RAN) is a new type of broadband access network based on distributed remote base stations to centralize all or part of the baseband processing resources, form a baseband resource pool, and uniformly manage and dynamically allocate them. In the process of large-scale coverage of 5G networks, the quality of user services is reduced due to the massive data traffic requirements of heterogeneous dynamic users and frequent communication overhead. C-RAN is considered to be a solution to this problem. The architecture has so far received extensive attention from academia and industry [1].

Due to the complex 5G Cloud-Radio Access network environment, the probability of node failure is greatly increased. For any network operator, mitigating the impact

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of different potential failures on users is a very important task. If a problem occurs at a certain node, the efficiency and speed of dealing with the problem manually cannot meet the user's service quality requirements. That is, when the network fails, it must be guaranteed that the line can have a transmission rate of hundreds or tens of megabytes per second and can independently handle related issues. The specific embodiment of this kind of network autonomous management is called Self-Organizing Network (SON), which is defined as a network that can dynamically adapt to network changes and has the ability to optimize its performance and solve its failures. In SON, it mainly includes three function: self-configuration, self-optimization and autonomy. This article mainly focuses on the research of Cell Outage Compensation (COC) in autonomous healing, introduces Device-to-Device (D2D) technology in the terminal compensation link, and builds an energy-efficient collaborative compensation optimization model to solve the network optimization of edge users The compensation problem can solve the service interruption problem of users at the edge of the network while taking into account energy consumption.

In the Sect. 1, this article briefly introduces the research background and significance of the article, explains the importance of using SON in the 5G C-RAN network, and proposes the advanced nature of introducing D2D technology in the SON autonomous healing process; the Sect. 2 introduces the current Research progress on self-organizing networks and D2D technology, and analyzes some problems in the current research; Sect. 3 builds a system model with the goal of optimal system energy consumption in D2D paired connection, and divides the entire system model into routing The two stages of selection and resource allocation are to build an optimization model for research, and propose solutions for the optimization model; Sect. 4 verifies the correctness and advancement of the above optimization model through system simulation, and compares the results with the relay selection based on energy efficiency The schemes are compared; Sect. 5 is the conclusion of the full text, summarizes the work completed by the full text, and analyzes the shortcomings in the content of the article, pointing out the direction for the next step of research.

2 5G C-RAN Network, Autonomous Healing Technology and D2D Technology Research Status

Because C-RAN has the above advantages of Centralization, Cloud, Cooperation and Clean. A large number of related studies have also been carried out on C-RAN at home and abroad. Literature [2, 3] studied the application of SDN (Software Defined Network) and NFV (Network Function Virtualization) technology in C-RAN; literature [4, 5] studied the deployment of C-RAN architecture Research on strategy; and literature [6] research on resource allocation in C-RAN network and so on. But for the dense network like 5G C-RAN, there is little research on its autonomy.

For the study of COC in autonomous healing, the existing method of achieving COC is to optimize the interruption area by adjusting the antenna gain or transmission power of the neighboring base station. In literature [7], a method for adjusting the transmission power and antenna is studied The comprehensive optimized cell interruption compensation mechanism of inclination is mainly to achieve the purpose of optimization compensation by changing the relevant parameters of adjacent base stations, but it is easy to cause changes in the network topology and the neighboring relationship of the base stations, and may introduce additional interference and energy consumption In the patent [8], the invention proposes a cell interruption compensation scheme that performs cooperative compensation through neighboring cells. The scheme is mainly to detect the channel service status of the neighboring base station and select the best idle channel through a game algorithm. The idle channel can provide network services for the interrupted cell users. However, in this scheme, the distribution of users is relatively regular, without considering the complicated characteristics of the distribution of users in the 5G network, and the re-allocation of the idle channels of neighboring cells will affect the network quality to a certain extent. The above two methods have certain limitations in the 5G C-RAN network composed of dense sites.

Due to its many advantages, D2D technology has also become a key research object at home and abroad in recent years. In terms of routing, literature [9] proposed a routing algorithm based on the user's actual location and a routing algorithm based on channel quality. On this basis, literature [10] re-optimized the system using bit error rate as the standard. Reference [11] uses channel utilization as a reference standard to optimize D2D routing strategies. In terms of resource allocation, the traditional research idea is to transform the resource allocation problem into a control variable optimization model, and then solve it through a heuristic algorithm or an optimization algorithm. Reference [12] introduces a resource optimization algorithm for the D2D communication system with the highest energy efficiency. This paper simplifies the resource allocation problem into two processes: power control and spectrum selection. The power control algorithm and channel selection algorithm based on KM are applied. Reference [13] uses network coding technology in D2D communication, which improves the quality and range of D2D communication while reducing the load of the base station, making the overall throughput of the network better. Reference [14] introduces access control, power control and spectrum selection into the resource allocation process, and uses the weighted bipartite graph maximum matching algorithm to solve, which also greatly improves the overall performance of the network.

The above research has contributed to the practical application of D2D technology, but there are still many shortcomings. In actual situations, the user's geographic location will often change, leading to inaccurate positioning, resulting in a great deal of traditional routing strategies limitation. Moreover, the above methods are mainly aimed at static networks. In a complex and rapidly changing 5G network environment, each change in the network environment will bring a huge amount of recalculation, and it is difficult to meet the highly dynamic network environment. This article will introduce the relevant attributes of social networks on the basis of the original research, and combine each terminal device with the person it uses. The social relationship of people is relatively fixed within a certain period of time. The introduction of social attributes makes the terminal device better. It adapts to the rapidly changing network environment, finds the best paired device, and reduces the additional energy consumption of the system.

3 System Model and Optimization Model

3.1 System Model

The schematic diagram of the D2D interrupt compensation scenario is shown in Fig. 1. The three RRHs cover areas A, B, and C, where the RRH of area A fails due to external factors, and some terminals on the edge of the network need to be terminals in areas B and C. For D2D compensation, there are three types of users: ordinary users, D2D directly connected users and D2D single relay connected users under the coverage of RRH.

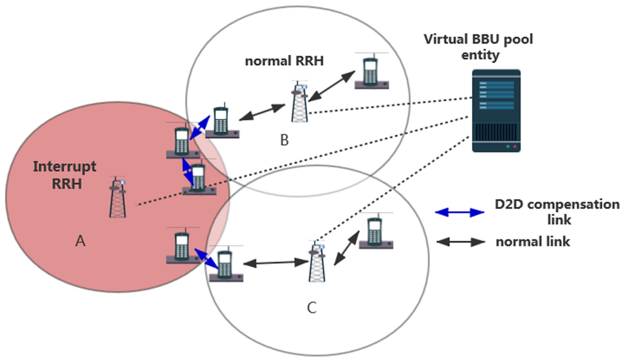

Fig. 1. Schematic diagram of D2D-based user compensation in 5G C-RAN (Color figure online)

In Fig. 1, one of the RRHs fails for some reason and requires the network to quickly repair itself to achieve the goal of maintaining network performance. For network edge users, D2D compensation can be performed by other terminal devices under the coverage of adjacent RRHs to restore the network. The black arrow in the figure represents the normal link between the terminal device and the RRH, and the blue arrow between the terminal devices indicates D2D Compensate the link. In order to facilitate research in the network topology, the relevant network environment is defined as follows:

Let the interrupted RRH in the area be detected, the set of RRH is B = {b_1, b_2,.., b_i,..., b_N}, The interrupted user set is U_0 = {u_1, u_2, ..., u_j,..., u_M}, The active user set is VA = {v_1, v_2, ..., v_k,..., v_L}. X = $\left\{x_{jk}\right\}$ represents the selection relationship matrix of relays between users, 1 means connected, 0 means not connected; $X^{'} = \left\{x_{ij}^{'}\right\}$ indicates the association between active users and RRH, 1 means connected, 0 means not connected. In order to facilitate processing, each interrupted user is connected to the network through appropriate D2D selection. The distance between RRH and active users is set to D_{ij}, The distance between active users and interrupted users is D_{jk}, The path loss index is γ, The transmit power of RRH is P_i^R, The transmit power of active users is P_j^V, Then when $x_{jk} = 1$ and $x_{ij}^{'} = 1$, D2D link is officially established. The channel between the D2D links is a Rayleigh fading channel. By default, mutual interference between D2D pairs and ordinary users is not considered. When allocating resources to D2D to users, adopt the method of orthogonal shared channels. The signal-to-noise ratio of the two-hop link from the source terminal to the relay terminal and the relay terminal to the destination terminal is as follows:

$$SNR_{ij} = \frac{|h|^2}{N_0}\mathrm{D}_{\mathrm{ij}}^{-\gamma} P_i^R \tag{1}$$

$$SNR_{jk} = \frac{|h|^2}{N_0}\mathrm{D}_{\mathrm{jk}}^{-\gamma} P_j^V \tag{2}$$

N_0 is the noise spectral density, γ is the path loss index, h represents the channel coefficient, and $|h|^2$ follows an exponential distribution with a mean of 1. For compensated user j, when connected to active user k, the corresponding channel capacity can be simply set as:

$$\mathrm{C_m} = \min\left\{\log\left(1 + SNR_{ij}\right),\ \log\left(1 + SNR_{jk}\right)\right\} \tag{3}$$

For the probability of successful connection between two hop links, which is expressed as:

$$p_1 = p(SNR_{ij} \geq \theta) = \exp(-\frac{N_0\theta\,\mathrm{D}^{\gamma}}{P_i^R}) \tag{4}$$

$$p_2 = p(SNR_{jk} \geq \theta) = \exp(-\frac{N_0\theta\,\mathrm{D}^{\gamma}}{P_j^V}) \tag{5}$$

θ is the signal to noise ratio threshold.

During the connection of the D2D link, the channel time slot occupied by the link is also an important consideration. We assume that the time slot occupied by the interrupted user i and the active user k is t_{jk}, $0 < t_{jk} < 1$.Based on the above, it can be concluded that the energy efficiency EE of the entire system can be expressed as:

$$EEm = \frac{\sum_{k=1}^{L}\sum_{j=1}^{M} C_{jk}}{\sum_{k=1}^{L}\sum_{j=1}^{M}\sum_{i=1}^{N} (1+\alpha)(t_{jk}P_i^R + (1-t_{jk})P_j^V) + (1+t_{jk})P_{cr} + P_{ct}} \tag{6}$$

α is a constant, which is generally determined by the power and the energy conversion efficiency when the power is changed. P_{cr} and P_{ct} is energy consumption of source terminal and destination terminal, which also set as constant. We can dynamically adjust the three values of t_{jk}, P_i^R and P_j^V to change the value of EE.We assume that the transmission power of each source terminal is constant, so the transmission power of the link is determined by the link connection x_{jk} and x'_{ij}, and our optimization goal for each link is to obtain the maximum energy efficiency of the system.

$$\max_{\{t_{jk}\},\{x_{jk}\},\{x'_{ij}\}} EE \tag{7}$$

Constraints included:

$$\forall j, k, c_{jk} \geq c_M \tag{8}$$

$$\forall j, k, \sum_{j=1}^{M}\sum_{k=1}^{L} x_{jk}t_{jk} \leq 1 \tag{9}$$

$$\forall i, j, p_{ij} \geq p^* \tag{10}$$

$$\forall i, k, p_{jk}^{'} \geq p^* \tag{11}$$

$$\forall i, j, SNR_{ij} \geq \theta \tag{12}$$

$$\forall j, k, SNR_{jk} \geq \theta \tag{13}$$

$$P_{\min}^{R} < \forall i, P_i^R \leq P_{\max}^{R} \tag{14}$$

$$P_{\min}^{V} < \forall j, P_j^V \leq P_{\max}^{V} \tag{15}$$

C_m is the channel capacity threshold for user information transmission, and p^* is the threshold for link connection success rate. $P_{\max}^{R}$ and $P_{\min}^{R}$ are the minimum and maximum limit values of RRU transmit power respectively, $P_{\max}^{V}$ and $P_{\min}^{V}$ are the minimum and maximum limit values of active user transmit power, respectively.

3.2 Optimization Model of Routing Process

Generally speaking, increasing the transmission power of the source terminal can improve the success rate of link connection, but with the increase of the transmission power, it will also bring greater interference, reduce the signal-to-noise ratio, and make it difficult to guarantee the communication quality. It brings more waste of resources and cannot be achieved in actual scenarios. To determine the appropriate transmit power to make the signal-to-noise ratio and link connection success rate meet the conditions, the optimization goal of this process is to find the minimum connection energy consumption, and then determine the appropriate Transmit power

$$\underset{\min}{Q1} = \min(P_i^R + P_j^V + P_{cr} + P_{ct}) \tag{16}$$

Constraints satisfy Eqs. 8–15.

In recent years, people have paid more and more attention to the analysis and research of social networks. Many behavior patterns at the user level often affect the mutual perception between devices, and related research on social networks has slowly penetrated into other fields. D2D terminals are generally light and easy to carry. Today's smart terminals already have the ability to perceive the effective information in the user, the surrounding environment and the network they are in [15]. This article introduces social network attributes into the routing process. The schematic diagram is shown in Fig. 2:

In social network theory, the three key parameters that measure the intimacy between two users are centrality, similarity, and trust. Therefore, based on these three quantities,

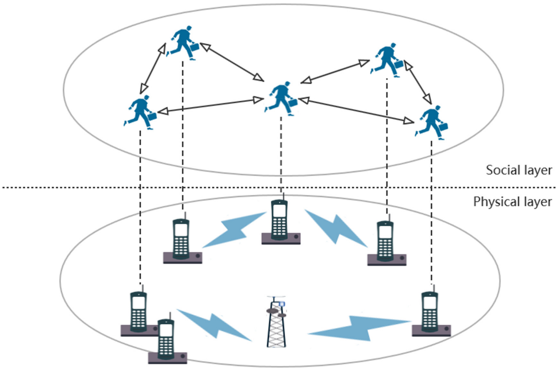

Fig. 2. D2D model with social attributes

an abstract modeling is performed to synthesize a utility function and set a threshold. When the intimacy between users is greater than this threshold, it indicates that the success rate of D2D communication between devices is also high. The social layer uses this scheme to filter the set of relay devices that meet the conditions, and then uses the existing scheme to select relay terminals at the physical layer, which can effectively avoid unnecessary energy loss and reduce the probability of communication failure [16].

Centrality. Degree centrality indicates the importance of a node, which shows the popularity of a person in the concept of a social network. The higher the popularity, the more frequently he communicates with others, and the easier it is to establish connections with others. In the physical layer, the centrality of the device is determined by the number of times the probe message is received. Here we set the number of times the active user v_j receives the probe message as $Freq(v_j)$, then the formula for the centrality is:

$$Cen(v_j) = Freq(v_j) \Big/ \sum_n^N Freq(v_n') \tag{17}$$

N represents the total number of nodes in the network, v' represents other active users in the network.

Similarity. The current research on the route discovery process mainly focuses on parameters such as channel quality and transmission rate, and ignores the user's communication needs. As a result, devices that meet the conditions during the route selection process refuse to communicate because of insufficient intimacy, resulting in a waste of resources. In fact, in social networks, due to the relatively fixed social circle, people are always willing to exchange information and share resources with users who have similar social behaviors or hobbies. The possibility of people with similar odors becoming friends Big. In the routing process, if D2D has the same interest in candidate users and source users, the success rate of communication will increase. In the concept of social networks, the similarity between two users is expressed by the cosine of their social distance, and the formula is:

$$Sim(u_i, v_j) = \left|I(u_i) \cap I(v_j)\right| \Big/ \sqrt{\left|I(u_i)\right| * \left|I(v_j)\right|} \tag{18}$$

I represents the user's interest set.

Trust. At the social level, the closer the two people are, the more trust they have in each other. Corresponding to the physical layer, the more interactions between the two devices, the greater the trust between each other. Social relations are related to the frequency and duration of contact between two people. The communication frequency and communication duration between the two devices can be obtained from the cloud BBU pool. Here, we abstract the trust between the two users u_i and u_j as a formula:

$$Tru(u_i, v_j) = \frac{CF(u_i, v_j)}{\sum_{t \in N} CF(u_i, v_t)} * \frac{CT(u_i, v_j)}{\sum_{t \in N} CT(u_i, v_t)} \tag{19}$$

$CF(ui, vj)$ represents the communication frequency between two users. $CT(ui, vj)$ represents the communication time between two users.

Utility Model. Based on the basic concepts in the above three social networks, this paper summarizes the utility function as:

$$U(u_i, v_j) = \alpha \cdot Tru(u_i, v_j) + \beta \cdot Sim(u_i, v_j) + \gamma \cdot Cen(u_i) \tag{20}$$

Among them, the three values of α, β, γ are parameters, satisfying $\alpha + \beta + \gamma = 1$, which can be changed according to the actual situation. In this formula, set the threshold value U_{thr}, and make the utility function value of the surrounding nodes and the destination node greater than. The threshold nodes are put into the candidate relay set to complete the preliminary screening.

3.3 Optimization Model of Resource Allocation Process

Within the coverage of an RRU, we can first analyze the geographic distribution of each device. If the distance between the two users meets the distance for D2D communication, the two terminal devices have the conditions to establish D2D communication. The introduction of the encounter model in resource allocation can allocate channel resources according to the communication success rate to avoid waste. One of the important quantities in the encounter model is the duration of the encounter. In [17], a general gamma distribution used to describe the encounter time of two terminals is proposed $\Gamma(k, u)$, where k and u are two variables It is related to the mean and variance. In literature [18], the probability of successful communication between the two devices can be calculated according to the meeting time of the two devices. The formula is:

$$\omega_{jk} = 1 - \int_0^{T\min} f(x, k, u)dx \tag{21}$$

Where $T_{\min}$ represents the shortest encounter time that two terminals can establish D2D communication, $f(x, k, u)$ is the probability density function of the duration of their encounter, both of these values are provided by the base station.

After obtaining the success rate of D2D communication between two devices, we can set the priority according to this success rate to allocate resources. The greater the communication success rate P, the higher the allocation priority β, the definition of β is as follows:

$$\beta = k(\omega_{jk} - a) + 1 \tag{22}$$

α represents the average value of the D2D communication success rate in the current range, which is determined according to the specific conditions of each area, and can be given by the BBU pool, k represents a parameter, and the method of taking the parameter k is described below. Since the priority β is derived from the communication success rate P, the two values should have a proportional relationship. At this time, we can get the following formula:

$$\frac{\beta 1}{\omega 1} = \frac{\beta 2}{\omega 2} = \frac{\beta 3}{\omega 3} = \ldots = \frac{\beta n}{\omega n} \tag{23}$$

Combining formula (22) and formula (23), we can find the value of k: $k = {}^{1}\!/_{a}$, so for the allocation priority β, the formula is:

$$\beta = ({}^{1}\!/_{a})(\omega_{jk} - a) + 1 \tag{24}$$

After obtaining the priority β, we can sort the connected D2D terminal pairs and allocate resources. Channels with high channel quality are preferentially assigned to users with high priority.

4 Case Analysis

In order to be able to verify the effectiveness of the algorithm proposed in this paper, we analyze it through simulation examples. Simulate and verify the whole in two stages.

4.1 Routing Stage

The D2D model used in the simulation is a single-relay two-hop model. It is assumed that there are two RRU-covered cell areas. One of the RRUs is faulty and is set to area A. The coverage of the RRUs without faults is set to area B. The coverage radius of a single RRU is 200 m, assuming that the number of terminals to be compensated in area A is 10, the number of active interruptions in area B is 20, and the terminal positions in each area follow an even distribution. The channels established by each terminal node are Rayleigh channels, and noise interference between terminals is not considered, only uplink communication is considered, and the working mode of each node is a half-duplex mode. Set the three parameters of the utility function to $\alpha = \beta = \gamma = {}^{1}\!/_{3}$, indicating that the three values of trust, centrality, and similarity share the same proportion. First,

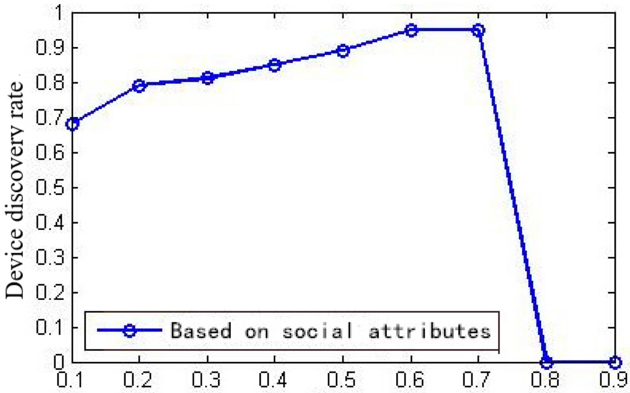

Fig. 3. The threshold value of the utility function

we determine the threshold of the utility function according to the simulation, as shown in Fig. 3:

With the increase of the preset threshold, the communication success rate of the scheme slowly increases to 95%, at this time the threshold is 0.6 or 0.7. After that, it quickly decreased to 0. The reason is that as the threshold increases, candidate terminals that do not meet the conditions are gradually eliminated, and the remaining terminals in the candidate list are more and more in line with the destination terminal, so the success rate of communication is also higher and higher. However, if we continue to increase the threshold, it indicates that the similarity between the two devices is getting higher and higher. At this time, the terminal that meets the conditions may no longer exist. Therefore, as shown in the figure, we set the threshold of the utility function to 0.7. After that, we compare this solution with OEE routing scheme [19] and random routing scheme. The path loss index and the distance from the source terminal to the destination terminal are used as independent variables. The performance comparison is shown in Fig. 4 and Fig. 5:

From the above simulation results, it can be seen that as the path loss index and the distance between the two terminals continue to increase, the energy consumed by the three schemes is increasing. Under a specific path loss index, it can be seen that the energy consumption of the OEE routing scheme is less than the random routing scheme, and the routing scheme based on social attributes needs to go further on the basis of the OEE routing scheme to achieve the predetermined goal.

4.2 Resource Allocation Stage

In the process of resource allocation, D2D will reuse the channel resources of cellular users. We assume that there are three RRU coverage areas in a scenario, where RRU1 is temporarily unable to provide services due to failures. It is set to use channel resources under RRU coverage. There are 6 groups of users, including 3 ordinary users and 3 pairs of D2D users. The link between D2D users has been successfully established. In the

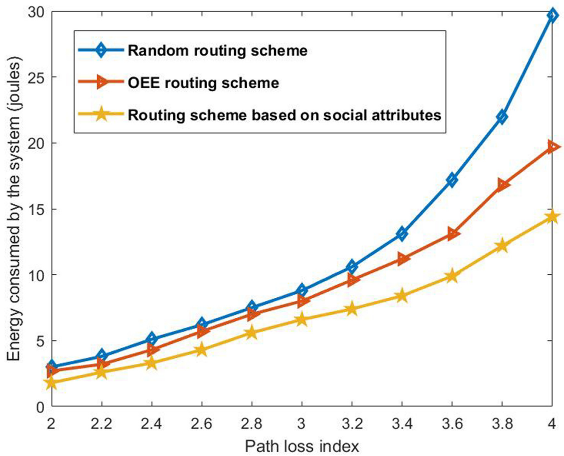

Fig. 4. Comparison of energy consumption of the three schemes

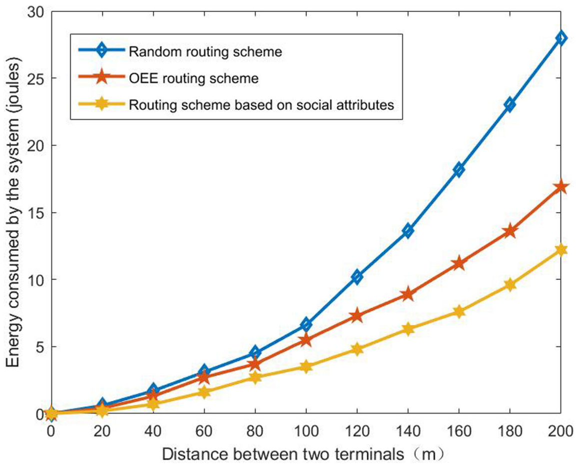

Fig. 5. Comparison of energy consumption of the three schemes

network, there are 6 available channels that are orthogonally allocated to each group of users. The simulation scene diagram is shown in Fig. 6:

According to the configuration of the system simulation parameters, the average communication rate of ordinary users and D2D-to-users in the current environment is 427kbit/s and 438kbit/s, respectively, and it is assumed that the channels of the two communication users in different time periods The rates meet the Rayleigh distribution with mean values of 427 kbit/s and 438 kbit/s respectively . The overall rate of the system is obtained by Eq. 25, where V_{al} is the overall rate of the system, $V(u)$ is the channel

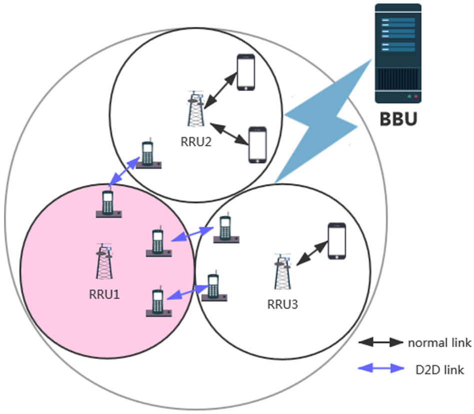

Fig. 6. Simulation scene diagram

transmission rate of ordinary users), $V(d, d)$ is the channel transmission rate of D2D users.

$$Val = \sum_{k=1}^{3} V(u_k) + \sum_{i=1}^{3}\sum_{j=1}^{3} V(u_i, v_j)\beta_i \tag{24}$$

We then set up two communication scenarios. The communication success rates of the three sets of D2D pairs are $P_1 = 0.3$ $P_2 = 0.5$ $P_3 = 0.7$. At this time, the average communication success rate is $\alpha = (P_1+P_2+P_3)/3 = 0.5$, then their resource allocation priorities are $\beta_1 = 0.6$, $\beta_2 = 1.0$, $\beta_3 = 1.4$. The success rates of the three sets of D2D pairs in scene 2 are $P_1 = 0.1$ $P_2 = 0.5$ $P_3 = 0.9$, then the average communication success rate is $\alpha = (P_1 + P_2 + P_3)/3 = 0.5$, then their resource allocation priorities are $\beta_1 = 0.2$, $\beta_2 = 1.0$, $\beta_3 = 1.8$.The total transmission rate of the system in two scenarios is shown in Fig. 7 and Fig. 8:

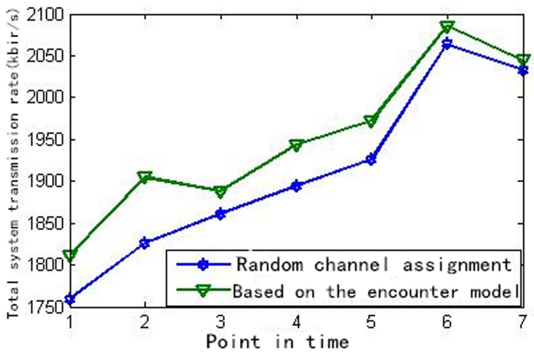

Fig.7. The total system transmission rate of the two schemes in scene one

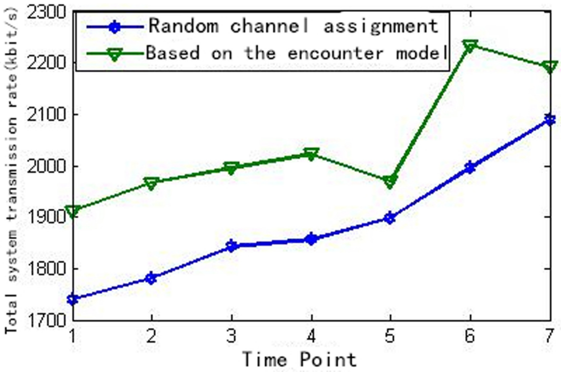

Fig. 8. The total system transmission rate of the two schemes in scene two

Through Fig. 7 and Fig. 8 we can conclude that the resource allocation method using the encounter model will increase the overall transmission rate of the system. However, in scenario two, the increase in system rate is more obvious, because in scenario two, the distribution variance of the success rate of the D2D pair connection is larger, so that a better channel is allocated to a better D2D time band The greater the revenue, the better performance.

5 Conclusion

This paper mainly studies the scheme of using D2D technology for fast network compensation for the edge area of the network covered by RRU after the 5G C-RAN network is interrupted. Different from the traditional scheme of changing the base station inclination or network parameters for optimization and compensation, fully taking into account the portable characteristics of D2D devices, introducing social network attributes, adding social attributes and encounter models to the two D2D connection processes of routing and resource allocation can fully avoid The problem of unnecessary network loss due to user selfishness is of great significance for reducing the waste of system power resources and channel resources.

However, there are still some imperfect work in this article, which only considers the D2D connection method of single-hop unicast. In reality, a D2D terminal with a good geographic or social location may undertake the transmission of multiple pairs of D2D pairs. Devices with relatively remote locations may require multi-hop D2D pairs to complete network compensation. Moreover, this article ignores the mutual interference of various D2Ds in communication. In a complex network, signal interference is one of the problems that must be solved.

The next work will focus on solving the signal interference problem in the D2D connection process, and at the same time investigate and explore the network topology more realistically, and explore the difficulties and possibilities of multi-hop multicast D2D technology. At the same time, since the D2D technology has a relatively small range of network compensation, in the case of a large-scale network failure, it is also the direction of efforts to explore more autonomous solutions with lower energy consumption and better compensation effects.

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