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Fast Joint Power Control Algorithm for D2D Communication System

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Abstract. D2D (Device to device) communication is a key technology of 5G which allows two end users in similar positions to communicate with each other directly by multiplexing the resources of cellular users. It can improve spectrum utilization and access rate of the cellular system while reducing the burden of the network. However, the sharing of spectrum resources will bring co-channel interference to the system, and the 5G standard raises new requirement of communication latency, new interference suppression method with good real-time performance is urgently needed. In this paper, based on joint power control algorithm, a fast joint power control algorithm is proposed, it increases the flexibility of the power adjustment by improving the calculation of power adjustment step size. In [1]addition to reducing the co-channel interference in the system, the new method can satisfy User's QoE (Quality of Experience) rapidly while ensuring the stability of it. Experimental simulation shows that the fast joint power control algorithm can reduce the power adjustment iterations while improve the throughput of cellular system, it improves algorithm speed and the signaling resources can be saved.

Keywords: D2D communication, power control, throughput, adjustment speed.

1. Introduction

With the explosive growth of communication services and flow, the number of global intelligent end devices has exceeded 6 billion. The continuous evolution of 5G and IoT (Internet of things) technologies has brought huge communication demands between countless devices, presenting new challenges [1]. D2D communication technology can enable UE (User Equipment) pairs with close geographical location to communicate with each other directly, the data doesn't have to flow through the base station and core network. It has the advantages of high spectrum utilization, low energy consumption and short delay. However, the introduction of D2D technology will bring co-channel interference to the cell and lower the efficiency of communication. Furthermore, user may move at any time in the cell, its location and channel status may change all the time, to ensure the stability of the communication quality of the system, the adjusting speed of each user's transmit power must be increased. Therefore, how to decrease the iterations of the algorithm is a topic worth studying.

In D2D communication system, D2D users and cellular users share uplink and downlink spectrum resources. There are mainly two modes for sharing the resources: overlay and underlay. Overlay means that D2D users and cellular users use mutually orthogonal spectrum resources in the frequency domain, so there is no co-channel interference between these two kinds of users, but in this way, the spectrum efficiency will decrease due to underutilization of the resources when the load of cell is becoming lower. In the underlay mode, D2D users improve the spectrum utilization of cell by multiplexing the frequency resources of cellular users, and it will bring the problem of co-channel interference. This paper mainly studies the D2D communication strategies in underlay mode. In addition, there are two main methods to improve the throughput of multiplexing mode system at present: resource allocation and power control. Resource allocation is a strategy to achieve high channel QoS (Quality of Service) and throughput for the system by allocating appropriate spectrum resources for D2D users. Power control is a method to reduce the co-channel interference in the cell by adjusting the transmit power of each transmitter. Power control is used to ensure QoS of the cell in this paper.

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On reducing co-channel interference in D2D communication, a number of papers give effective methods. [2] improves the power control performance by applying the path loss compensation factor matrix of D2D users and cellular users. In order to adjust D2D transmitters' power dynamically, [3] introduces a global adaptive harmony search algorithm on the basis of channel allocation and mode selection, and it improves the system throughput effectively. Facing the requirements of uRLLC (Ultra-Reliable and Low-Latency Communication) and eMBB (Enhanced Mobile Broadband) in 5G, [4] applies PSO (Particle Swarm Optimization) to jointly constraint the transmit powers of these two kinds of users, and the spectrum resources multiplexing mode of uRLLC users, it can reduce the communication delay while ensuring the communication rate of the eMBB user in the cell. Some technologies of AI (Artificial Intelligence) are used to solve the problems in D2D communication by many scholars. [5] shows that both DQN (Deep Q-Learning) and DDPG (Deep Deterministic Policy Gradient) methods can reduce the interference and improve the throughput in the D2D system. [6] proposes a Q-Learning based joint Spectrum Allocation and Power Control (QLSA-PC) algorithm which considers both spectrum resources allocation and transmit power selection for D2D users, the throughput and Qos of the system are effectively improved.

However, some of the methods may run slowly due to their complicated programs, these methods are inapplicable in actual situations. With the uRLLC proposed by 5G standard, the requirement for communication response speed has raised to 1ms level, running speed has become a significant indicator for evaluating an algorithm. In this paper, a fast joint power control algorithm is proposed to solve the problem of co-channel interference in D2D system and improve the running speed of algorithm at the same time. By improving the setting of transmit power adjustment stepping in the joint power control algorithm [7], new power control method makes UEs' transmit power to be rapidly adjusted to a stable level while receivers have stable signal-to-noise ratio (SINR). Compared with traditional fixed adjustment step size scheme, the proposed method has fewer iterations and better stability.

2. D2D System Model

In underlay mode, D2D users can multiplex both uplink and downlink communication resources of cellular users. Due to the receiving ends of the downlink are cellular users of strong mobility, their interference is difficult to control, and in cellular network the utilization rate of the uplink spectrum resources is always lower than it of the downlink, this article mainly studies the problems that arise while D2D users multiplex the uplink spectrum resources of cellular users.

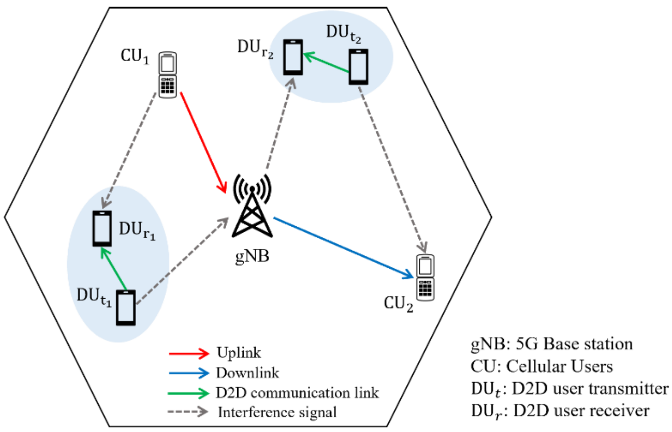

Fig. 1: Signal and interference model of D2D communication system.

This paper studies the spectrum resources multiplexing scheme of single cell. In the D2D system model shown in Figure 1, the cell is a regular hexagon, and the 5G base station named gNB manages user ends of whole cell in the center of the area. M pairs of cellular users $CU_1, \dots, CU_m, \dots, CU_M$ and N cellular users$\left(DU_{t_1}, DU_{r_1}\right), \dots, \left(DU_{t_n}, DU_{r_n}\right), \dots, \left(DU_{t_N}, DU_{r_N}\right)$ distributed in the cell randomly. After gNB allocates the spectrum resources for cellular users, then D2D users can use the resources to communicate with their matched users directly.

The paper adopts ITU-R micro-city standards as the path loss model, if i-th pair of D2D users uses spectrum resource of j-th cellular user, the path loss can be calculated as follow:

$$Loss_{D2D_i} = 38.47 + 20\lg\left(d_{D2D_i}\right) \tag{1}$$

$$Loss_{CUE_j} = 35.24 + 35\lg\left(d_{CUE_j}\right) \tag{2}$$

Where d_{D2D_i} represents the distance between users of the i-th D2D pair, and d_{CUE_j} represents the distance between the j-th cellular user and the base station.

Supposing that the transmit power of the i-th pair of D2D users is set to PT_{D2D_i}, path loss of the D2D receiver is $Loss_{D2D_i}$. When the noise index of all UEs is N_{UE} and the shadow fading is N_{sf}, the receiving power RP_{D2D_i} can be calculated as follows:

$$PR_{D2D_i} = PT_{D2D_i} - Loss_{D2D_i} - N_{UE} - N_{sf} \tag{3}$$

The transmit power of the j-th cellular user is set to PT_{CUE_j}, the power of signal received by gNB is PR_{CUE_j}, and the path loss is $Loss_{CUE_j}$. When the noise index of gNB is N_{gNb}, the power of signal received by gNB can be calculated as follows:

$$PR_{CUE_j} = PT_{CUE_j} - Loss_{CUE_j} - N_{gNB} - N_{sf} \tag{4}$$

In the uplink of the communication, the j-th cellular user will cause co-channel interference to the receiver of the i-th pair of D2D users. When the path loss is $Loss_{CUE_j - D2D_i}$, the power of interference signal at this D2D receiver can be calculated as follows:

$$I_{CUE_i} = PT_{CUE_j} - Loss_{CUE_j - D2D_i} \tag{5}$$

There will also be interference between the transmitter of the i-th pair of D2D users and gNB. When the path loss is $Loss_{D2D_i - gNB}$, power of the interference signal I_{D2D_i} at gNB can be calculated as follows:

$$I_{D2D_i} = PT_{D2D_i} - Loss_{D2D_i - gNB} \tag{6}$$

While the thermal noise power is N, the SINR values at receivers of the j-th cellular link and the i-th D2D link can be expressed as:

$$SINR_{CUE_j} = 10\lg\left(\frac{10^{PR_{CUE_j}/10}}{10^{I_{D2D_i}/10} + N}\right) \tag{7}$$

$$SINR_{D2D_i} = 10\lg\left(\frac{10^{PR_{D2D_i}/10}}{10^{I_{CUE_j}/10} + N}\right) \tag{8}$$

The throughput of cellular users and D2D users can be calculated as follows:

$$TO_{CUE_j} = B\log_2\left(1 + SINR_{CUE_j}\right) \tag{9}$$

$$TO_{D2D_i} = B\log_2\left(1 + SINR_{D2D_i}\right) \tag{10}$$

Where B is the spectrum bandwidth allocated by the base station for each cellular user, and it is the value of spectrum resource multiplexed by each D2D user pair as well. In this paper, B=180kHz, and the unit of throughput is kbps.

3. Fast Joint Power Control Algorithm

The joint power control algorithm (JPC) can effectively reduce the co-channel interference and improve the throughput of the D2D system, the basis of the JPC is the closed-loop power control algorithm (CLPC). This paper improves the setting of the power control adjustment step of the CLPC algorithm and proposes a closed-loop control method with variable step size, the method can make the user's SINR quickly approach the target range, so the running speed of the algorithm can be effectively improved.

3.1. D2D open-loop and close-loop power control

In the open-loop power control algorithm (OLPC), the transmitters in the cell are not required to make adjustments according to the receiver's reception. As the principles in 3GPP (3rd Generation Partnership Project) standard for uplink power control technology, the transmit power of UE in OLPC can be calculated as follow:

$$P_o = \min\{P_{max}, P_0 + 10\lg M + \alpha L_P\} \tag{11}$$

In the formula, P_{max} is the maximum transmit power of UE, and its value is determined by the UE level. P_0 is the rated power, it is a cell-specific parameter and its value range is generally [-126dBm,23dBm], the value of P_0 in this paper is -78dBm. M represents the number of resource blocks allocated to each user in the cell. In this paper, the number of resources each user get is 1, so M=1; α is the path loss compensation coefficient, its value ranges in {0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0}, generally be selected in 0.5~0.9 in the actual experiment; L_P is the path loss, which is calculated according to the detection result of the reference signal by UE. So (11) can be simplified to:

$$P_o = \min\{P_{max}, P_0 + \alpha L_P\} \tag{12}$$

The parameter α determines the degree of path loss compensation of users. When $\alpha = 0$, the users will not be compensated for transmit power; when $\alpha = 1$, it called a full power compensation control which compensates all path loss; when α is other value, partial path compensation will be performed for users. The base station first broadcasts preset α and P_0 to all UEs in the cell, then each UE sets its own value of initial transmit power based on these two parameters and its own measured L_P.

In OLPC method, the transmit power of users will only be allocated once, it cannot dynamically adjust the transmit power of UEs in time according to the suddenly changes of channels to guarantee users' communication quality. Furthermore, it is unable to guarantee the accuracy of user UE's transmit power without a further adjustment when users set their target range of SINR.

Closed-loop power control algorithm (CLPC) is also called the dynamic power control algorithm. In CLPC, D2D users can adjust their transmit power due to the status of channels in real time, the method can guarantee their requirements of SINR while keeping the co-channel interference they brought to cellular users at a low level. The CLPC adds a feedback term $f(\Delta)$ on the basis of OLPC. The transmit power of user in CLPC is as follows:

$$P_c = \min\{P_{max}, P_0 + \alpha L_P + f(\Delta)\} \tag{13}$$

In the formula, Δ is the power adjustment factor, it is to adjust the transmit power of UEs when circuit errors and channel state changes occur, so that the SINR of the D2D UEs can be guaranteed. $f(k)$ is the cumulative function, whose value will be constantly adjusted to be relatively stable. In the CLPC, the base station sends appropriate power control signaling to UE according to the user parameters, channel environment, target SINR range and other information, then UE will adjust up or down P units of transmit power as the instruction of the received signaling. We set the upper limit of SINR $SINR_H$, and the lower limit $SINR_L$. The upper limit of $f(k)$ is $f(k)_H$, and the lower limit is $f(k)_L$.

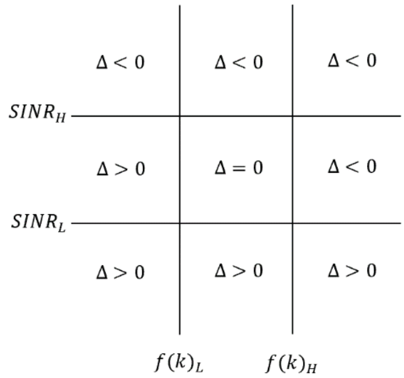

Fig. 2: The relationship between Δ and 0 in all cases.

As shown in Figure 2, when the user UE's SINR is less than $SINR_L$, $\Delta > 0$, the transmit power increases for ensuring the quality of D2D communication; If the user UE's SINR is greater than $SINR_H$, so $\Delta < 0$, UE decreases its transmit power for reducing the co-channel interference and power loss ; when user SINR is between $SINR_L$ and $SINR_H$, it means channel is in good condition, transmit power of UE does not need to adjust.

3.2. D2D fast close-loop power control algorithm

The cumulative function $f(\Delta)$ of the k-th UE in (13) can be calculated as follow:

$$f(\Delta)_k = \sum_{i=1}^{\infty} \Delta_{k_i} \tag{14}$$

And the power adjustment factor Δ in traditional CLPC can be presented as:

$$\Delta_{k_i} = \begin{cases} P & SINR_{k_i} < SINR_L \\ -P & SINR_{k_i} > SINR_H \\ 0 & else \end{cases} \tag{15}$$

Where P is always positive.

However, the adjustment with fixed step size has the problem of poor flexibility. If P is set to be small, there will be so many iterations that the adjusting time will be relatively long; if P is set to a large value, power adjustment stepping of large size will causes fluctuation in the user's SINR adjustment, besides, when $SINR_L$ and $SINR_H$ have similar values, the user UE's SINR will vibrate, then user's QoE and the system Qos will be unstable, so it is not advisable to set P to a large value.

This paper proposed the fast closed-loop power control algorithm (FCLPC), and it makes an improvement on the calculation of Δ. In FCLPC, the power adjustment factor $\Delta_{F_{k_i}}$ for the k-th user in the i-th adjustment can be calculated as:

$$\Delta_{F_{k_i}} = \beta e_{k_i} \tag{16}$$

Where e_{k_i} is defined as follow:

$$e_{k_i} = \begin{cases} SINR_L - SINR_{k_i} & SINR_{k_i} < SINR_L \\ SINR_H - SINR_{k_i} & SINR_{k_i} > SINR_H \\ 0 & else \end{cases} \tag{17}$$

$|e_{k_i}|$ represents the deviation value of current SINR of user UE from the target range $[SINR_L, SINR_H]$. The parameter β is the proportional coefficient, (16) shows that the size of power adjustment step is determined by the difference between the current user UE's SINR and the target SINR range. When user UE's SINR deviates greatly from the target range, $|\Delta|$ will become relatively large to increase the adjustment speed; On the contrary, if the value of current user SINR is close to the target range, $|\Delta|$ will be relatively small to make the adjustment stable. In addition, the value of β determines the size of every adjustment step. When β increases, each step size of the adjustment will increase and the speed of user UE's SINR reaching to the target range becomes faster, vice versa. The selection of β depends on the actual application. System block diagram of the FCLPC is shown in Figure 3.

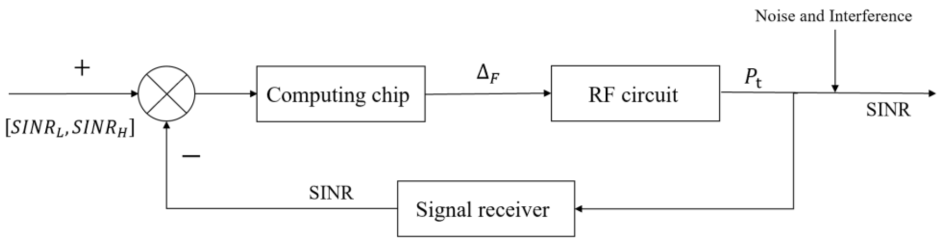

Fig. 3: System block diagram of the FCLPC.

3.3. Fast joint power control algorithm

Some of the traditional D2D power control methods only consider the co-channel interference generated when D2D multiplexes communication link resources of cellular users, and perform closed-loop power control only on D2D users. However, cellular users also produce co-channel interference to D2D users conversely. The JPC considers the control of the transmission power of both D2D users and cellular users, it not only ensures the SINR of D2D users and cellular users, but also improves the total throughput and Qos of the system. The FJPC proposed in this paper is an improvement of JPC method, it replaces the traditional CLPC method with the FCLPC method in the way of controlling transmit power of D2D user UEs and cellular user UEs, the method reduces the iterations of the algorithm while maintaining other performances of the JPC algorithm.

The FJPC algorithm owns good dynamic characteristics in the cell where users' locations and accessing status change frequently, and it improves the real-time performance of the power control method in the D2D communication system. The transmit power of D2D users and cellular users in FJPC can be presented as follow:

$$P_{c,D2D_i} = \min\{P_{max}, P_0 + \alpha_{D2D_i} L_P + f(\Delta_{F_i})\} \tag{18}$$

$$P_{c,cell_j} = \min\left\{P_{max}, P_0 + \alpha_{CUE_j} L_P + f\left(\Delta_{F_j}\right)\right\} \tag{19}$$

Where Δ_{F_i} is the power adjustment factor of the FCLPC. The path loss compensation α may have different values due to the different requirements of D2D users and cellular users.

4. Experimental Simulation and Analysis

In this paper, the simulation experiment is carried out on the MATLAB platform. We first compared and analyzed the total throughput of the system while using OLPC, CLPC and FJPC methods, and then the adjustment iterations of user UE's transmit power using CLPC and FCLPC methods are simulated and compared. Finally, FJPC and JPC are applied to the system, the number of system adjustment iterations is compared and analyzed.

4.1. System simulation parameters

We assume that the radius of the cellular cell is 500m, 50 cellular users and 20 D2D users randomly distribute in the cell, the maximum distance between users of each D2D pair is 50m, and the multiplexing mode of the channels is random allocation. Table 1 shows some of the main parameters during the simulation.

Table 1: Simulation Parameters

Main Simulation Parameters	
Parameter	***Value***
Cell radius/m	500
Number of cellular users	50
Number of D2D users	20
Maximum spacing between D2D user pairs/m	50
Minimum distance between cellular users and gNB/m	25
Resource block bandwidth/kHz	180
Path loss model between users	$38.47 + 20\lg D$
Path loss model between users and gNB	$35.24 + 35\lg D$
Shadow fading standard deviation/dB	8
Thermal noise power/dBm	116
User noise index/dBm	9
Base station noise index/dBm	5
Rated power P0/dBm	-78
Maximum transmit power for user/dBm	24
α_{D2D},α_{CUE}	0.8
β	1

4.2. The throughput of system

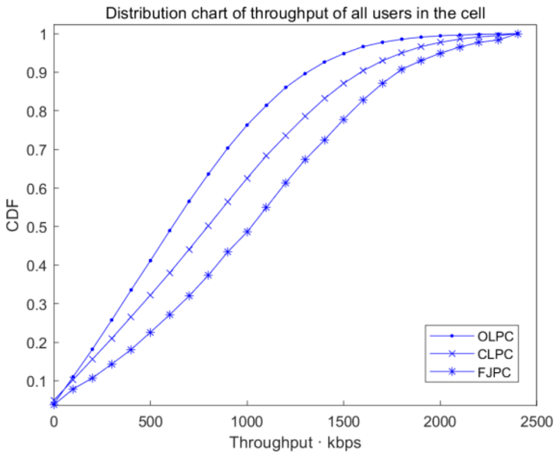

Fig. 4: Distribution of average system throughput in different methods.

Figure 4 shows the cumulative distribution of the average system throughput of OLPC, CLPC and FJPC methods in the cell, when CDF=0.5, the average throughput of the 3 methods are 634kbps, 741kbps and 894kbps. It can be seen from the curve that the throughput distribution of the CLPC is greater than OLPC, that is because the CLPC can dynamically adjust the transmit power of transmitters to reach the user's target SINR range. At the same time, the throughput result of FJPC is better than it of CLPC because FJPC considers the power control of both D2D users and cellular users, so that the communication quality of both cellular users and D2D users are guaranteed and the system throughput is improved.

4.3. Speed of the methods

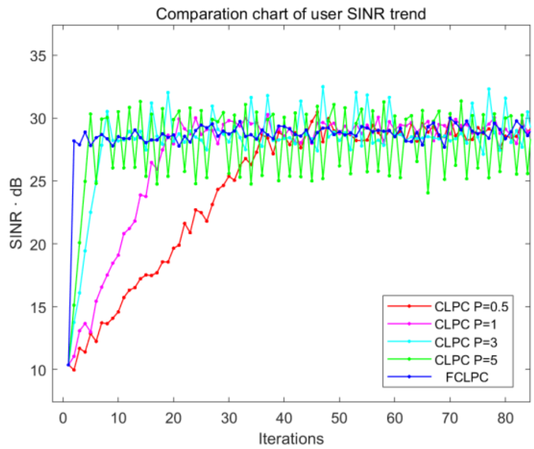

Fig. 5: Trend of user UE's SINR using CLPC and FCLPC methods.

We randomly selected one D2D pair (No.8) in the cell to simulate the experiment on power adjustment iterations, we carried out the experiment with CLPC (P equals to 0.5, 1, 3 and 5 respectively) and FCLPC, the target SINR range is [28,30] and the standard deviation of the noise is 0.5. As shown in Figure 5 and 6, when α is 0.8, the initial transmit power of the D2D transmitter is -25.7573dBm, and the initial SINR of the receiver is 10.376dB, which is obviously insufficient for the compensation of transmit power. It can be seen from Figure 5 that while using CLPC method of P=0.5 and P=1, the adjustment iterations the user UE required to reach the target SINR range is about 34 and 18, and when P=3 and P=5, although both curves approach the target SINR range quickly, due to the excessive adjustment step size near the range, they have severe vibrations, and it will make user's SINR unable to be stabilized in such an accurate target SINR range. When FCLPC is used, the curve can quickly approach the target SINR range and keep relative stable, it only takes about 3 iterations of adjustment to keep the user UE's SINR in a small range with no excessive vibration.

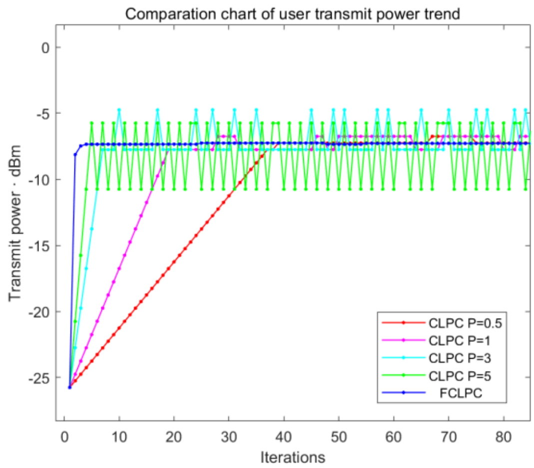

Fig. 6: Trend of user transmit power using CLPC and FCLPC methods.

Figure 6 shows the adjustments of user's transmit power in the above process. It can be seen that the adjustment in FCLPC has advantages of both rapid speed and good stability. Furthermore, when FCLPC is used to control the transmit power of UE, more signaling resources will be saved due to the less adjustments.

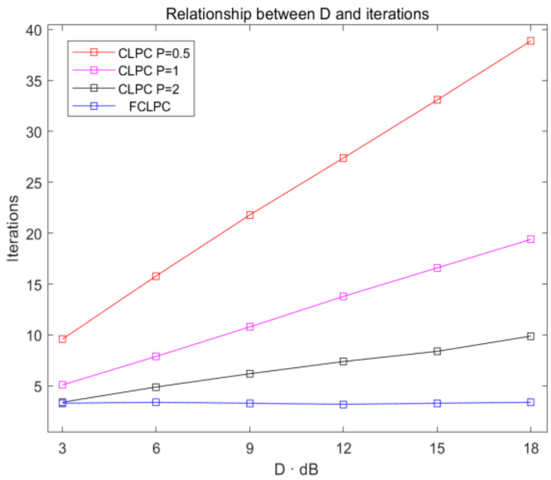

Fig. 7: The relationship between D and the iterations of algorithms.

In order to conveniently present the difference between the user UE's current SINR and the target SINR range, we defined D value, which can be calculated as follow:

$$D = \begin{cases} SINR_i - SINR_H & SINR_i > SINR_H \\ SINR_L - SINR_i & SINR_i < SINR_L \end{cases} \tag{20}$$

Where $SINR_i$ is the initial SINR of the user UE in this adjustment.

Figure 7 is the chart of the relationship between D and the iterations of power adjustment. The size of target range $(SINR_H - SINR_L)$ is 2dB. The average value of iterations for 20 D2D users to reach the target SINR range is calculated in this simulation. It can be seen from the figure that as D increases, the iterations number of traditional CLPC method increases, and the relationship between the two is roughly proportional.

Besides, CLPC of P=2 has a better performance than it of P=1 in speed because of lower iterations, and the result of CLPC of P=1 is better than it of P=0.5. In FCLPC, the average value of the algorithm iterations is less affected by the value of D, which is always maintained at about 3.3. We can see from above that the FCLPC method can rapidly finish an adjustment on user UE's transmit power. The average value of iterations is almost independent of the setting of user's target SINR range, furthermore, we can infer from it that the larger D is, the FCLPC can save more running time than CLPC.

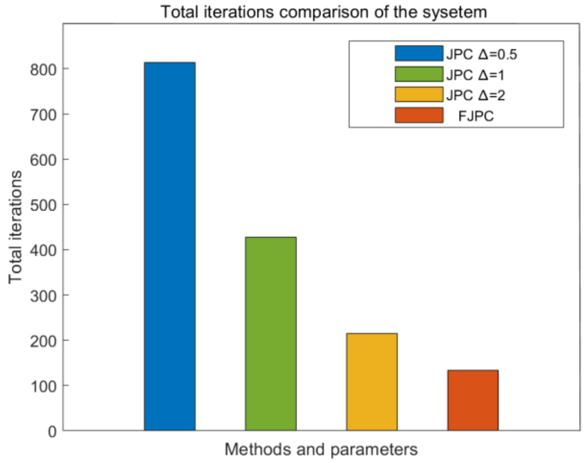

Fig. 8: Total iterations of the system using FJPC and JPC methods

Finally, we applied the FJPC algorithm to the D2D system and compared it with the traditional JPC method in total system iterations. As shown in Figure 8, in using JPC method, if P=0.5, the total power adjustment iterations are 813 (including D2D users and cellular users), and the number when P=1 is 427, P=2 is 215. When FJPC is used, the total iterations are 133, the adjustment speed of the method is 221% faster than it using JPC when P=1 and 60% faster than it when P=2. It is obvious that FJPC has faster running speed than the traditional JPC.

5. Conclusion

As a key technology of 5G, D2D communication can improve the spectrum utilization, increase the number of accessed devices, and reduce the load of the base station in the cell. As uRLLC, one of the application scenarios of 5G, raises new requirements for the speed of the communication. In terms of user UE's transmit power adjustments when it accesses the system and adapts to the channel changes, the problem that the traditional JPC algorithm needs too many adjustment iterations of transmit power has emerged, it will cause a lack of real-time performance of the algorithm. The FJPC algorithm proposed in this paper improves the calculation method of the power adjustment factor Δ of the JPC, and it makes the adjustment rapid and stable by allowing Δ to dynamically change according to the difference value between the current user UE's SINR and the target SINR range. In the experimental simulation, we verified that the improvement in FJPC can increase the speed of the algorithm while keeping the system throughput in a good level. In addition, signaling resources can be saved.

6. References

[1] J. Khan and L. Jacob, "Link Adaptation for Multi-connectivity Enabled 5G URLLC: Challenges and Solutions," 2021 International Conference on COMmunication Systems & NETworkS (COMSNETS), 2021, pp. 148-152, doi: 10.1109/COMSNETS51098.2021.9352811.

[2] X. P. Zhai, L. Gong, N. Zhang. "Adaptive Joint Power Control Algorithm Based on Compensation Factor for Device-to-Device Communication." Journal of Applied ciences, vol. 37, no.1, pp. 1-11, January 2019.I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[3] G. B. Zhuo Model, J. S. Tang, X. X. Zhang, H. X. Yang, M. L. Lu. selection and channel allocation for D2D communication in cellular networks[J]. INFORMATION & COMMUNICATIONS, 2019(10):193-197.

[4] Y. Zhu, M. Gao, F. Hu and K. Jiang. Maximizing Throughput Efficiency for Direct and Relay Transmission Protocolsin Cooperative System[C]. Shenzhen: 2019 Computing, Communications and IoT Applications (ComComAp), 2019, 112-116.

[5] Liu, Z. Li, Z. Hu and Y. Li, "Distributed Reinforcement Learning for Quality-of-Service Routing in Wireless Device-to-device Networks," 2018 IEEE/CIC International Conference on Communications in China (ICCC Workshops), 2018, pp. 282-286, doi: 10.1109/ICCChinaW.2018.8674510.

[6] Chen W, Zheng J, A Multi-Agent Reinforcement Learning based Power Control Algorithm for D2D Communication underlaying Cellular Networks, in Proc. of 2019 EAI International Conference on Artificial Intelligence for Communications and Networks(AI-CON), Harbin, China.

[7] J. Ren, L. Du, P. Zhong, X. Wang, G. Zhang and W. Lu, "D2D Joint Power Control Algorithm Based on Two Factor Power Compensation," 2021 International Wireless Communications and Mobile Computing (IWCMC), 2021, pp. 382-387, doi: 10.1109/IWCMC51323.2021.9498752.