Abstract

Non-orthogonal multiple access (NOMA) is a new technique proposed in the 5G communication system, because it can improve the spectrum efficiency. Based on NOMA, a cooperative NOMA technique is designed, where the users in better condition acts as relays to help users in poorer condition. However, this technique would speed up the energy consumption. So wireless power transfer (WPT) is joined to support the relay users for energy harvesting (EH).

This paper focus on the combination of WPT and NOMA in a single cell, and a network is modeled based on simultaneous wireless information and power transfer (SWIPT) to NOMA. To research the effect of WPT, two choices of optimal power splitting coefficient are discussed in the paper. The performance of network in terms of outage probability and system throughput are modulated to demonstrate the impact of path loss, choice of optimal power splitting coefficient and energy harvesting efficiency.

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1. Introduction

1.1. Motivation

The fourth generation mobile communication system (4G) is the latest commercial system, which is based on orthogonal frequency division multiple access (OFDMA) technique. The transmission data rate of OFDMA can reach to 100Mbps and even 1000Mbps, and this technique will be used in current and future period of time.

However, OFDMA cannot satisfy the demand of the application in mobile communication all the time. The development of communication system will meet many issues and challenge.

(1) The amount of devices connected to the network is increasing rapidly. In the future, the global devices connected to mobile communication network will exceed 10 billion, which means more accesses and higher data rate are required.
(2) Recent communication system is a user-oriented system, which focus on offer better service for users. So the speed of running system and no sense of latency will be a metric of quality of system.
(3) The kinds of application in communication system are various, and the difference among them maybe great. It requires communication system with high flexibility and reliability.
(4) Recently, the mobile communication is also need at some remote areas, such as forests and mountain areas, or some areas where signal is hard to arrival, such as underground and tunnel. So the greater scalability and coverage are required.
(5) The frequently transition of small packages would cause resource consumption, which require high capacity of channel.
(6) In some higher-speed mobile environment, such as car, subway and high-speed rail, car, the better mobility of system should be considered.

The next generation communication system– the fifth generation communication system (5G) are demanded to solve these problems. It is requires wireless networks with higher spectrum efficiency, higher data rate and greater capacity. Among these demands, the spectrum fficiency in 5G is 5 or 15 times higher than that in 4G. Therefore, new and more advanced techniques should be proposed in 5G, which are evaluated by the data rate, density of devices, latency form node to node, mobility and sum data rate.

The non-orthogonal multiple access (NOMA) technique is mentioned in 5G. Compared to conventional orthogonal multiple access technique, NOMA can differentiate users in the power domain. NOMA can allocate the resource to more users simultaneously in a channel with same frequency, which can improve the spectrum efficiency. And it has been confirmed that the throughput of system in NOMA can be improved around 50%. Therefore, NOMA is a promoting technique in the 5G.

To solve some problems in NOMA or improve the performance of system, some existing techniques can work with NOMA. In this paper, we mainly focus on wireless power transfer

(WPT) technique and heterogeneous cellular network (HetNet). These techniques are used widely in previous systems, which perform well in terms of increased spectrum efficiency, increased energy efficiency and higher capacity.

In collusion, combination of NOMA with WPT and HetNet would contribute to the development of the 5G communication system.

1.2. Scope of project

This project is to research the wireless power transfer in non-orthogonal multiple access enhanced heterogeneous cellular network. In this paper, the single cell network and multiple cells network have both been made some research, aiming at NOMA enhanced heterogeneous. Some techniques to mitigate the intra-cell and inter-cell interference are discussed according to proposed protocol.

Since the research core of this project is wireless power transfer, this paper primarily focus on WPT in a single cell. Based on that, a network is modeled in this project and the working flow of this network is derived in detail. To demonstrate and analyze the performance of this network, outage probability and system throughput are modulated in this paper.

1.3. Organization

Section 2 (Background) provides some knowledge of wireless power transfer, heterogeneous cellular network and non-orthogonal multiple access technique. The first three subsections are the introductions of WPT, HetNet and NOMA respectively in terms of the theory and some techniques used in them. The forth subsection is the review of literature about the combination of WPT and NOMA and NOMA enhanced HetNet.

Section 3 (Network analysis) models the network and derives the transmission process. The next three subsections discuss three elements in the network, including optimal power splitting coefficient, outage probability and system throughput.

Section 4 (Simulation and performance analysis) simulates the performance of the network by MATLAB, in terms of outage performance and system probability. In this suction, the impact of path loss, choice of optimal power splitting coefficient and energy harvest efficiency are discussed.

Section 5 (Conclusion) includes a conclusion of this project and some further challenges based on this project are advised.

2. Background

2.1. Wireless Power Transfer

Traditional energy transmission and most electronic devices transfer energy by wire, which is limited by space. On the other hand, wireless power transfer (WPT) transmit thorough air gap without wires, supporting both small-range and large-range transmissions. As the development of global telecommunication and remote transmission, WPT has been applied more and more frequently and extensively.

At the transmitter in WPT, power source –direct current (DC) is converted into alternating current (AC), which then flows in coil and produces an oscillating magnetic field. When receiver receives power over air gap, the coil generates AC which then is converted back into DC. This is the process of how wireless power transfer work.

2.1.1. A brief history

In 1888, German physicist Heinrich Hertz theorized the possibility of inductive power. Hertzconfirmed the existence of electromagnetic radiation. The electromagnetic waves was generated by a VHF or UHF "radio wave" spark gap transmitter. A small spark also could be observed by a microscope at the receiver.

Since then, two engineers made a significant contribution to the development of wireless power transfer, who are Nikola Tesla and William C. Brown.

Since 1891, the idea of wireless transfer has been discussed. Serbian American inventor and engineer Nikola Tesla followed Hertz's work and was absorbed in his experiments by duplication of them.

In 1891, the supply or exciter powered by radio frequent wave was improved by Tesla. He had exploited a high-tension induction coil called "System of Electric Lighting", which was used to demonstrate wireless power transfer.

In 1893, the wireless illumination was firstly demonstrated by Tesla, which was a practical application at that time. And then, he demonstrated his technology to some national authority organization such as American Institute of Electrical Engineers.

In 1894, Tesla wirelessly lighted lamps at two laboratories on after another in New York City. It was achieved by "electro dynamic induction" or wireless resonant inductive coupling.

In 1896, Tesla had increased the range to transmit signals over 48 kilometers (30 miles). Then in 1897, he submitted his first patent application, specifically dealing with wireless transmission.

In1901, the Wardenclyffe tower was started building. This tower was designed to broadcast the wireless waves. However, it was a time-consumption and fund-consumption project, which was demolished in 1917.

50 years after that, there was no significant development of wireless power transfer until William C. Brown published an article about microwave power transmission in 1961.

In 1964, Brown demonstrated a helicopter model named Walter Cronkite on CBS news. This helicopter could harvest microwaves to charge its battery from a microwave beam, which is a significant step of the application of wireless power transfer.

Between 1969 and 1975, Brown was the technical director of aJPLRaytheonprogram, which had broadcast 30 kW over a distance of 1 mile at 84% wireless transmission efficiency.

2.1.2. Categorization of WPT

WPT is mainly categorized into non-radiative (near-field) techniques and radiative(far-field) techniques.

(1) non-radiative (near-field) techniques
As for near-field techniques, power is transmitted by inductive coupling, resonant inductive or and capacitive coupling. Coupling is an important technique in WPT, which is basically consisted of two coils.

(2) radiative(far-field) techniques: AS for far-field techniques, the transfer mediums are RF radio, microwave or laser. These beams of electromagnetic radiation are able to be matched with receiver through long-distance transmission.

In Table.1, some wide used WPT technique are listed and are compared with each other.

Table.1 Types of WPT technique [1]

WPT technique	Field region	Propagation	Effective distance	Efficiency	Applications
RF energy transfer	Far-field	Radiative	Depend on distance and frequency and the sensitivity of RF energy harvester(typically meters--kilometers)	0.4%(40dBm) >18.2%(20dBm) >50%(5dBm)	Wireless sensor network, Wireless body network
Resonant inductive coupling	Near-field	Non-radiative	millimeters—centimeters	5.81%-57.2% (frequency: 16.2kHz-508kHz)	Passive RF identification (RFID) tags, contactless smart cards, cell phone charging
Magnetic resonance coupling	Near-field	Non-radiative	centimeters--meters	30%~90% (distance: 0.75m~2.25m)	PHEV charging, cell phone charging

2.1.3. Energy harvesting

Energy harvesting (EH) is a process to convert the energy in the environment to electric power by devices. The power harvested by EH would be used to change the batteries or transmit messages [1]. Conventional energies are from nature, such as solar energy, air flow energy and thermal energy. These energies are limited by the condition of nature environment and are hard to control. Therefore, other controllable and alternative energy are expected to be employed more frequently. Some exiting EH techniques are listed in Table.2 .

Table.2. A comparison of exiting EH techniques [1]

Technique	Power density	Energy-harvesting device
Solar energy harvesting	$15mW/cm^2$ in outdoor applications 100 mW/cm^2 under direct sunlight in outdoor applications $100\mu W/cm^2$ at $10W/cm^2$ light density	Mini solar panel(photovoltaic models)
Vibration energy harvesting	$500mW/cm^2$(piezoelectric method) 4 $\mu W/cm^2$(electromagnetic method) $3.8mW/cm^2$(electrostatic method)	Piezoelectric converters Electromagnetic converters Electrostatic converters
Air flow energy harvesting	$3.5mW/cm^2$(wind speed of 8.4m/s) 3.5 $\mu W/cm^2$(air flow speed less than 1m/s)	Micro wind turbines Oscillating wings Flapping wings
Radio frequency energy harvesting	$315mW/cm^2$(with a transmitted power of 2-3W at frequency at a frequency of 906MHz at a distance of 30 cm)	RF harvesting circuits
Electromagnetic wave energy harvesting	0.26 $\mu W/cm^2$(from an electric field of 1V/m)	Mini antennas
Thermal energy harvesting	$100\mu W/cm^2$ at 5°C gradient $3.5mW/cm^2$ at 30°C	Thin-film thermoelectric elements
Promising energy harvesting	$960nW/cm^3$(acoustic noise of 100dB) Biochemical0.1-1mW/cm^3	Various devices(e.g. small acoustical devices, biofuel cells)

In this paper, radio-frequency (RF) signal is used to harvest energy in WPT. One remarkable characteristic of this technique is controllable and continuous. The efficiency of EH depends on efficiency of the antennas.

2.1.4. Simultaneous wireless information and power transfer

Simultaneous wireless information and power transfer (SWIPT) is the combination of wireless power transfer (WPT) and wireless information (WIP). The principle of WPT and WIT is similar, are both relaying the wireless radio to achieve the transmission of energy and information. As for WPT, it focuses on the energy carried by wireless radio, which is determined by transmission efficiency or spectrum efficiency (SE). on the other hand, WIP concentrates on higher rate of information transmission, transmission reliability and system capacity.

The key idea of SWIPT is to transmit information and energy simultaneously in downlink. So the SWIPY receiver is required the ability of detecting information and harvesting energy. There are four kinds of SWIPT receivers, which are separated receiver, time switching receiver, power splitting receiver and integrated receiver. As power splitting (PS) receiver is used in this paper, we only discuses PS receiver splitting further.

PS is a technique to separate and allocate received power at output. Fig.1 shows the architecture of PS receiver. It is clear that a PS receiver consists of a receive antenna, a power splitter a energy harvester and a information receiver.

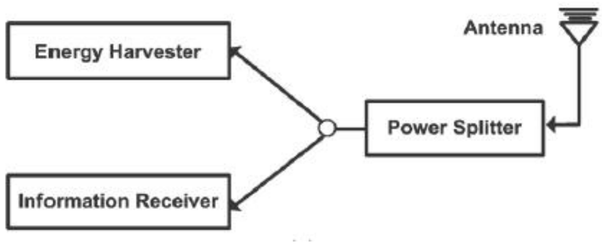

Fig.1 the architecture of PS receiver

Rate-and-energy tradeoff is an important element in SWIPT, which determined how much power from resource is used to decode information or harvest energy. As for WIT, the interference is harmful, which is treated as noise by the receiver it cannot be decoded. On the other hand, for WPT the interference is useful because it can be treated as power from resource and used for energy harvesting. Therefore, it is one reason that the Rate-and energy tradeoff will affect the performance of SWIPT.

A. Time Switching (TS)

If TS is employed, the receiver switches in time between information decoding and energy harvesting [6]. In this case, the signal splitting is performed in the time domain and thus the entire signal received in one time slot is used either for information decoding or power transfer (Fig. 3a). The TS technique allows for a simple hardware implementation at the receiver but requires accurate time synchronization and information/energy scheduling.

B. Power Splitting (PS)

The PS technique achieves SWIPT by splitting the received signal in two streams of different power levels using a PS component; one signal stream is sent to the rectenna circuit for energy harvesting and the other is converted to baseband for information decoding (Fig.3b) [6]. The PS technique entails a higher receiver complexity compared to TS and requires the optimization of the PS factor; however, it achieves instantaneous SWIPT, as the signal received in one time slot is used for both information decoding and power transfer. Therefore, it is more suitable for applications with critical information/energy or delay constraints and closer to the information theoretical optimum.

2.2. Heterogeneous Cellular Networks

As the number of mobile devices and number of applications are increasing rapidly in recent life, the demands of capacity and coverage of internet are growing. Traditional cell networks cannot satisfy these demands; heterogeneous cellular networks (HCN) are more suitable for recent connected structure.

The operators developed the networks by applying different heterogeneous nodes, which are a picocell, a femtocell, a microcell, relays or a remote radio head (RRH). Each cell mainly consists of a base station (BS) and different account of users. These elements are different from each other in terms of transmit power, coverage area and backhaul as shown in Table.3,so that they are suitable for different conditions. For example, a picocells, femrocells and microcells are placed at cities with high population and building density while RRH are more adaptive at remote areas.

Table.3 specifications of different types of HetNet nodes [2]

Type of nodes	Transmit power	Coverage area	Backhaul
Macrocell	46 dBm	Few kilometers	S1 interface
Picocell	23-30 dBm	$\leq$ 300 meter	X2 interface
Femtocell	$\leq$ 23 dBm	$\leq$ 50 meter	Internet IP
Relay	30 dBm	300 meter	Wireless
RRH	40 dBm	Few kilometers	Fiber

Heterogeneous network (HetNet) is consisting of Macro sell and Small Cells with low energy and coverage [2], which improves performance with several benefits:

(1) Efficient usage of spectrum
Compared to mracocell, the number of times that smaller cells reuse the same spectrum has increased.

(2) Enhanced capacity and QoS
In urban areas, the density of devices connected in network is growing. By using multi-standard small cells, the whole capacity of system is improved. Besides, by reducing the scope of services from one BS, the burden is reduced and QoS is improved.

(3) Higher energy efficiency (EE)
HetNet has the potential to reduce the consumption of capacity and coverage. So the nodes with low power in HetNet are allocated with high density, which can help improve the energy efficiency.

(4) Benefits to operators
Marocells in urban areas would produce lot of cost, such as building equipment, power and management. To a certain extent, HCN can help cut the cost.

2.3. Non-orthogonal Multiple Access

With the development of communication systems so far, a fundamental issue that how to satisfy the data demands of users within limited resources still exists. This issue derives from rapid increasing demands of users for high-speed data processing. Moreover, to support this explosive growth, the scarcity of cellular radio resources will still become even more severe. It is foreseeable that the tremendous increase in data traffic and the number of mobile devices may consume the resource of existing cellular networks. In addition, this rapid increase has leaded to high energy consumption in cellular networks.

The fifth generation (5G) communication system is forthcoming in the near future. Regarding the issue above, the 5G is expected with very high data rate, very low latency, energy and cost efficiency, mobility, and ability for very dense crowds of users.

Non-orthogonal multiple access (NOMA) is a prospective technique in 5G communication system. Compared to previous generation communication systems, e.g. frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA), and Long-Term Evolution (LTE), NOMA exploits power domain to implement multiple access (MA). MA techniques are categorized into orthogonal multiple access (OMA) and non-orthogonal multiple access (NOMA).

2.3.1. OMA

In OMA, signals from different users are orthogonal to each other, in other words, their cross correlation is zero. Undesired signals such as noise can be separate from received signals by receiver in OMA technique.

FDMA, TDMA and CDMA are typical OMA techniques used from fist generation (1G) communication system to three generation (3G) communication system. In fourth generation (4G) communication system, orthogonal frequency division multiple access (OFDMA) and single carrier-FDMA (SC-FDMA) are applied in downlink and uplink transmission respectively. In these systems, intra-cell interference are avoidable.

However, with the growth of number users and information, time-domain, frequency-domain, and code-domain resource are becoming in shortage. A more efficient technique should be developed in 5G communication systems, and NOMA is promising.

2.3.2. NOMA

NOMA is divided into power-domain NOMA and code-domain NOMA. In this paper, we mainly consider in power-domain NOMA. Different from OMA, power-domain NOMA allocates disparate power to multiple users in the same frequency/code channel simultaneously in one cell. In other words, except time, frequency and code, signals are distinguished by power allocation coefficients in NOMA technique, which leads to higher spectral efficiency.

According to the condition of users, NOMA allocates transmission power in different level. The ideal is that users in poor conditions have more opportunity to gain more power. These users only process their own messages with higher power level. The users in better conditions will process messages by using successive interference cancellation (SIC).

Compared to OMA where the amount of users is controlled by the number of channels, NOMA serves much more users at the same time. As shown in Fig.2, each user in OMA occupied one slot while more users share one slot in NOMA. The transmission bandwidth for each user in NOMA is wider than that in OMA.

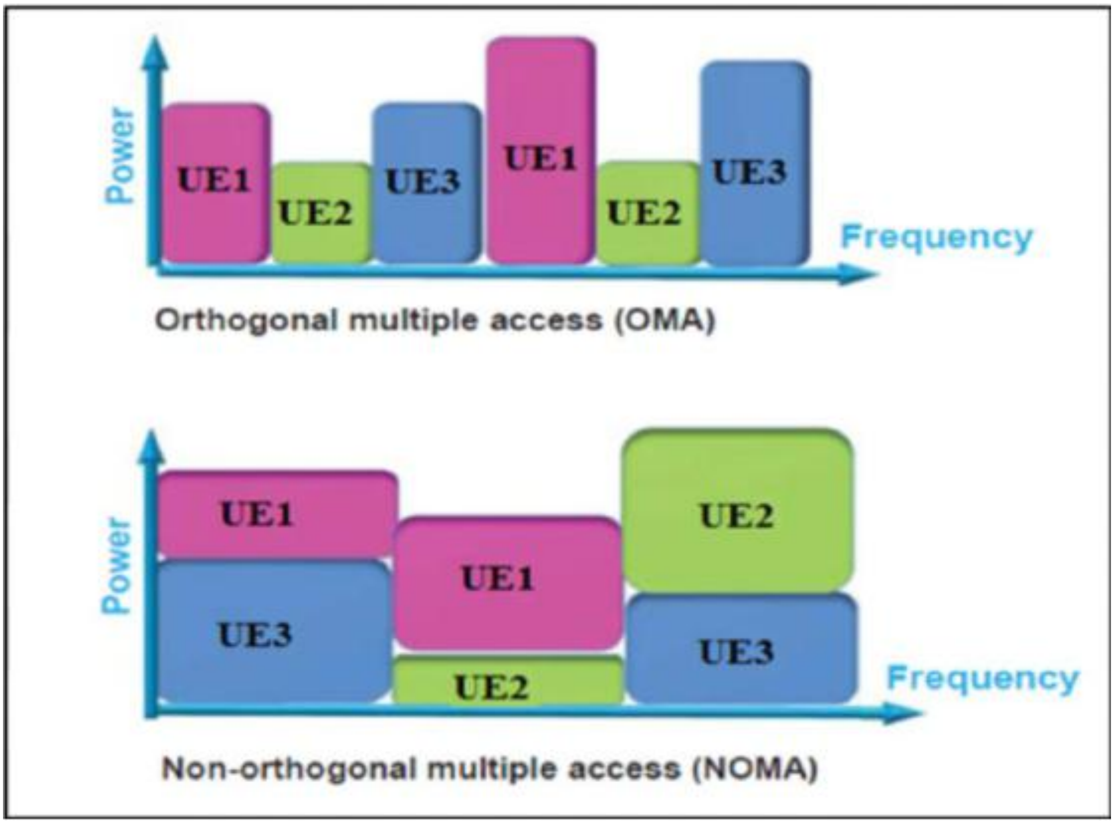

Fig.2 Illustration for OMA and NOMA in the power as well as frequency domain [3]

Hence, we can conclude some advantages of NOMA:

1) High spectrum efficiency (SE) and capacity: NOMA allows more users connected simultaneously in channel with same frequency and these users are distinguished by different allocation of power. And with SIC technique, the SINR of the system has been improved.

2) Fairness-throughput tradeoff: Under the guarantee of advanced system throughput, the base station allocates power to users against their channel condition, which leads to improved fairness compared to conventional OMA.

3) Low transmission latency: when users want to transmit information to the base

station, there is no scheduling request needed.

2.3.3. Main techniques in NOMA

1) Power Division Multiplexing (PDM)

Unlike other multiple access techniques, power division multiplexing (PDM) is firstly used by NOMA. Different from simple power control, the power is allocated by the base station, following associated algorithm.

As the same as conventional division multiplexing, which divides the communication channel into several logical, The transmit power is divided into several power segments at the transmitter. These power segments can carry different simultaneously information in a same channel. By allocating different user with different transmit power, the system throughput can be improved.

2) Superposition coding(SC)

When a transmitter wants to send information to several receivers, the superposition coding technique is applied. SC technique can offer communication superposed way, which means the base station can send messages to multiple users simultaneously.

However, the condition and ability of the users are various. To achieve the SC in practice, the transmitter is required to encode the information of each user connected to it.

3) Successive Interference Cancellation(SIC)

Successive Interference Cancellation (SIC) is an important and essential technique used in NOMA. It is algorithm for multiuser receivers with low complexity, which can sequentially recover the user data form combined signals. The matched filter is used at the receiver.

As shown in fig.3, combined signals are transmitted to users. Assume the power allocated to messages of user 2 is more than that of user 1 in Figure, that means the condition of user 2 is better than that of user 1. SIC allows user 2 decode its own messages primarily while the other signals with weak power are regarded as interference. Then the signals of user 2 are removed and the remained signals are detected by user 1.

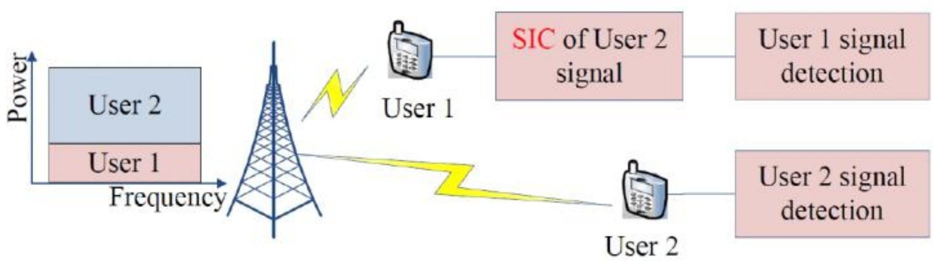

Fig.3 SIC at receiver [4]

To explain the influence of SIC, [4] has compared the channel capacity in system without SIC and one with SIC. Assume two transmitters T_1 and T_2 transmit two massages to a receiver R with signal power S_1 and S_2 respectively at the same time, with $S_1 > S_2$. The channel bandwidth is B and the noise in channel is N_0.

When SIC is not considered, S_1 and S_2 cannot be received by R simultaneously. Hence, the capacity of channel is $C_1 = \max\{B\log_2\left(1+\frac{S_1}{N_0}\right)\ ,\ B\log_2\left(1+\frac{S_2}{N_0}\right)\}$.

When SIC is considered, S_1 and S_2 cannot be received by R simultaneously. According to the theory of NOMA, R will decode S_1 firstly, treating S_2 as interference. Then when R decodes S_2, the S_1 will be removed. Therefore, the capacity of channel is $C_2 = B\log_2\left(1+\frac{S_1}{S_2+N_0}\right) + B\log_2\left(1+\frac{S_2}{N_0}\right) = B\log_2\left(1+\frac{S_1+S_2}{S_2+N_0}\right)$.

Compare C_1 and C_2 , the capacity of channel with SIC is better than one without SIC.

2.3.4. Cooperative non-orthogonal multiple access

The most outstanding characteristic of NOMA is that users are allocated different levels of power, depending on their channel condition. Users in better channel can decode their information by using SIC[5], and prior messages of other users can be known by these users. [5] proposes an non-orthogonal multiple access (C-NOMA) scheme. The ideal is that users in better channel will decode the messages of users in poor channel, acting as relays. This paper has approved that C-NOMA performances better than conventional NOMA in terms of capacity and reliability.

In [5], C-NOMA consists of two phases called direct transmission phase and cooperative phase. In the first phase, the BS transmits k messages, following $\sum_{n=1}^{K} p_n x_n$, to users direct, where x_n is the message to n-th user and p_n is the power allocation coefficient with $\sum_{n=1}^{K} |p_n|^2$. As for cooperative phase, users connect to each other by short-range communication channels, such as Bluetooth. It has ($K-1$) time slot, where successive detection is used. At the k-th time slot (1<k<(K-1)), the (K-k+1)-th user will broadcast the combination of (K-1) time slots[5]. As more time slots are required to retransmit messages form user with better condition, user pairing is used to reduce the system complexity.

2.3.5. User pairing

Via user pairing, users are divided into several groups. In this scheme, NOMA is applied within each group while OMA is applied between groups [6]. This hybrid network can help reduce the limitation of interference compared to simplex NOMA.

[6] proposes two kinds of user pairing based NOMA systems. For NOMA with fixed power allocation (F-NOMA) ,where users are allocated fixed power from BS, [6] has proved

that the sum rate of F-NOMA is larger than conventional OMA. The another scheme is cognitive-radio-inspired NOMA (CR-NOMA), which can guarantee the QoS of users in poor condition channel. Therefore, [6] summarizes that F-NOMA is more suitable for users with better conditions while CR-NOMA are preferred by users with poor conditions.

2.4. Relative literature review

2.4.1. The application of wireless power transfer to NOMA

Wireless power transfer can break the restriction of user allocation. On the other hand, NOMA allows multiple users connection simultaneously. Besides, energy harvesting technique in WPT also can used in NOMA to promote the connection. Hence, the application of WPT to NOMA is a promising challenge in the 5G.

A new protocol called SWIPT NOMA is proposed in [7], which considered cooperative non-orthogonal multiple access with simultaneous wireless information and power transfer. As mentioned before, in the C-NOMA techniques, the user in poorer condition can be helped by user in better condition, which acts a relay. However, this technique would increase the burden of user in better condition and shorten the battery lifetime of this user. Hence, SWIPT used in [7] can support user in better condition for harvesting energy from the base station, and then harvested energy can be used to charge battery or decode information. And in [7], there are three user selection schemes proposed, which are random near user and random far user (RNRF) selection, nearest near user and nearest far user (NNNF) selection, and nearest near user and farthest far user (NNFF) selection. Following by [7], a best near user and best far user selection scheme based on SWIPT NOMA is proposed in [8]. In [8], decode and forward (DF) technique, amplifier and forward (AF) technique and hybrid of DF and AF technique are used at the relay user. And in [9], a new PS protocol is considered in SWIPT NOMA, which has been certified better performance of system, compared to [7]. Based on [7], a transceiver for SWIPT NOMA is designed in [9], and the achievable rate region for DF, AF and combine of DF with AF is calculated in [10].

Except the coordination wireless power transfer with cooperative NOMA, there also are some applications of WPT to other NOMA project. For example, the harvest-then transmit protocol is used in [11] as a receiver cannot harvest energy and decode information at the same time in practice. So in [11], the user firstly harvests energy from the BS in the downlink and the send the information to the BS by NOMA theory in the uplink. To reduce the influence of double near-far problem in Wireless Powered Communication Network (WPCN), [13] characterizes the optimal allocations of the BS transmit power and the duration of the energy harvesting and information transmission phases in the uplink.

2.4.2. NOMA Enhanced HetNet

A heterogeneous network (HetNet) is a wireless network consisting of nodes with different transmission powers and coverage [6].As mentioned before, HetNet can improve the spectrum efficiency and energy efficiency. Since HetNet and NOMA have a common goal in terms of increasing EE and SE. Besides, the base station is closer to users because of high cell density, which can cause higher SINR by SIC technique. Therefore, the cooperation NOMA and HetNet is also aN important direction and subject in 5G.

In [6], NOMA is adopted into small sells in massive MIMO enabled HetNets. It proofs that NOMA-based HetNets performs better than OMA-based HetNets. Besides, it comes to a conclusion that NOMA-based HetNets can achieve high spectrum efficiency, high compatibility, low complexity and fairness-throughput tradeoff.

[2] proposes a strategy cooperative NOMA with HetNet. The aim of this strategy is to increase the throughput ant mitigate the inter-cell interference. With this new strategy, both the spectrum utilization and system capacity are improved.

In [15], a two-cell scenario is modeled. In the network, [15] propose a EE-SE co-design NOMA, and to reduce the inter-cell interference, a pre-code solution across the adjacent cells is considered. This solution has been certified to improve the EE and SE in network.

2.5. Summary

In the fifth generation communication system, NOMA is a promising scenario with high SE, higher cell-edge throughput and other benefits for the system. As for SWIPT and HetNet, they have widely adopted in many field of communication network. Both these two techniques have improved the performance of the system, which will meet some challenge in the next generation communication system. The combination of SWIPT and HetNet with NOMA is a significant subject in the future.

As mentioned before, many previous jobs focus on researching such networks, and which have gained advanced achievement in terms of single cell or multiple cell theoretically. Hence, how to implement these techniques practically is also a main step to commercialize them in 5G.

3. Network analysis

As mentioned before, this paper focuses on the combination of wireless power transfer and non-orthogonal multiple access in a single cell. In such network, we consider a base station and users with single antenna in random allocations. [7] proposes a new cooperative non-orthogonal multiple access with simultaneous wireless information and power transfer (SWIPT NOMA) protocol. In this protocol, the near users with better conditions do not only complete the process in proposed C-NOMA in [6] but also harvest energy to help the far users with poorer conditions. As for the issue of selection of near user and far user, there are three selection schemes are proposed: random near user and random far user (RNRF) selection, nearest near user and nearest far user (NNNF) selection and nearest near user and farthestfar user (NNFF) selection. In this paper, we consider the same network model as in [7] in a single cell.

3.1. Network model and working flow

To model the network in [7], there are some elements need to be considered:

(1) Devices allocation and user pairing: In a single sell, user pairing technique is used to divide users into two group far users $\{F_i\}$ and near users $\{N_i\}$. This two groups are distinguished geographically by three circles with radius R_1, R_2 and R_3 respectively, which is assumed that $R_1 > R_2 \gg R_3$. These circles have a same center, where base station is placed. Between circle with radius R_1 and circle with radius R_2, the group $\{F_i\}$ is the far users with poor conditions. On the other hand, in circle with radius R_3, the group $\{N_i\}$ is the near users with better conditions. The allocation of these users obeys homogeneous Poisson point process with densities λ_{ϕ_F} for far users and λ_{ϕ_N} for near users, which is showed in Fig.4.

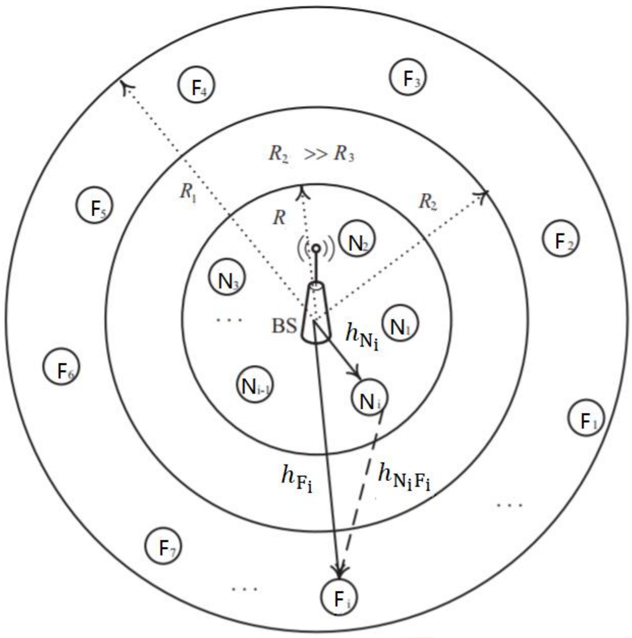

Fig.4 Allocation of the BS and users

(2) Channel conditions: The channels between BS and users as well as users and users are constant with Rayleigh fading. $h_{\mathrm{N_i}}$, $h_{\mathrm{F_i}}$ and $h_{\mathrm{N_iF_i}}$ model the small-scale Rayleigh fading from the BS to $\mathrm{N_i}$, the BS to $\mathrm{F_i}$ and $\mathrm{N_i}$ to $\mathrm{F_i}$ separately, The unwanted noise in channel is additive white Gaussian noise (AWGN) with mean zero and variance σ^2, where $\sigma^2 = 1$.

(3) Relaying scheme: In this network, decode-and-forward (DF) scheme is used by near users. The main ideal of DF scheme is to decode messages from the source and then forward the re-encoded massages to the destination.

3.2. Transmission process

As mentioned above, C-NOMA has two phases: direct transmission phase and cooperative transmission. In SWIPT-CNOMA near users $\{N_i\}$ specially harvest RF energy from BS to help far users $\{F_i\}$. Following NOMA characteristic, the power allocated to far users $\{F_i\}$ is lower than power allocated to users $\{N_i\}$; $|P_{N_i}|^2$ and $|P_{F_i}|^2$ are the power allocation coefficients, with $|P_{N_i}|^2 < |P_{F_i}|^2$ and $|P_{N_i}|^2 + |P_{F_i}|^2 = 1$. The transmission power at BS is written as P_S.

3.2.1. Direct transmit phase

At the first time slot, BS transmit combined message $p_{N_i}x_{N_i}+p_{F_i}x_{F_i}$ to selected $\mathrm{N_i}$ and $\mathrm{F_i}$ respectively at the same time.

As for near users, the received signal to interference plus noise ratio (SINR) at F_i to detect its own message $\mathrm{x_{F_i}}$ is expressed as

$$\gamma_{S,F_i}^{x_{F_i}} = \frac{\rho|h_{F_i}|^2|p_{F_i}|^2}{\rho|h_{F_i}|^2|p_{N_i}|^2+1+d_{F_i}^{\alpha}}, \tag{1}$$

where $\rho = \frac{P_s}{\sigma^2}$ is the transmit power to signal ration (SIR) of BS, $\mathrm{d_{F_i}}$ is the distance from the BS to $\mathrm{F_i}$, and α is the path loss exponent.

As for far users, to achieve energy harvesting, power splitting approach is used. Power splitting coefficient β_i is defined to decide how much power is used for EH. On the other words, full EH and full DF happen when $\beta_i = 1$ and $\beta_i = 0$ respectively. N_i firstly decodes the message $\mathrm{x_{F_i}}$ of F_i, and the received SINR at N_i to detect message $\mathrm{x_{N_I}}$ from the BS is expressed as

$$\gamma_{S,N_i}^{x_{F_i}} = \frac{\rho|h_{N_i}|^2|p_{F_i}|^2(1-\beta_i)}{\rho|h_{N_i}|^2|p_{N_i}|^2(1-\beta_i)+1+d_{N_i}^{\alpha}}, \tag{2}$$

where $d_{N_i}^{\alpha}$ is the distance from the BS to N_i.

After successfully decoding x_{F_i}, N_i will forward re-encoded x_{F_i} by using harvested energy toF_i. Because of the implement of SIC, the component of x_{F_i} will be removed, then the interference caused by F_i will not be considered. Therefore, the received SNR at N_i to detect its own message x_{N_i} from the BS is expressed as

$$\gamma_{S,N_i}^{x_{N_i}} = \frac{\rho|h_{N_i}|^2|p_{N_i}|^2(1-\beta_i)}{1+d_{N_i}^{\alpha}}. \tag{3}$$

In [7], it has given the harvested energy as

$$E_{N_i} = \frac{T\eta P_S\beta_i|h_{N_i}|^2}{2(1+d_{N_i}^{\alpha})}, \tag{4}$$

where T is the whole transmission period and η is the energy harvesting coefficient. As there are two time slot during one transmission period, which are assumed with same duration $T/2$, the transmit power atN_i is given by

$$P_t = \frac{\eta P_S\beta_i|h_{N_i}|^2}{1+d_{N_i}^{\alpha}}. \tag{5}$$

3.2.2. Cooperative transmission phase

At the second time slot, N_i forwards re-encoded x_{F_i} to F_i. The received SNR at F_i to detect re-encoded message x_{F_i} from N_i is expressed as

$$\gamma_{N_i,F_i}^{x_{F_i}} = \frac{p_t|h_{N_iF_i}|^2}{(1+d_{N_iF_i}^{\alpha})\sigma^2} = \frac{\eta\rho\beta_i|h_{N_i}|^2|h_{N_iF_i}|^2}{1+d_{N_iF_i}^{\alpha}}, \tag{6}$$

where $d_{N_iF_i}^{\alpha}$ is the distance from N_i to F_i.

After receiving the messages from the BS and N_i, F_i use maximal-ratio combining (MRC) to combine these two messages. The received SINR at F_i is expressed as

$$\gamma_{N_i\_MRC}^{x_{F_i}} = \frac{\rho|h_{F_i}|^2|p_{F_i}|^2}{\rho|h_{F_i}|^2|p_{N_i}|^2+1+d_{F_i}^{\alpha}} + \frac{\eta\rho\beta_i|h_{N_i}|^2|h_{N_iF_i}|^2}{1+d_{N_iF_i}^{\alpha}}. \tag{7}$$

3.3. Optimal power splitting coefficient

As mentioned above, power splitting coefficient β_i determines the amount of power used for EH. To guarantee the prior detection of far user's message x_{F_i} at near user N_i, according to (2), an achievable date rate to complete this process is given in[7] as

$$R_{N_i}^{x_{F_i}} = \frac{1}{2}log_2(1+\frac{\rho|h_{N_i}|^2|p_{F_i}|^2(1-\beta_i)}{\rho|h_{N_i}|^2|p_{N_i}|^2(1-\beta_i)+1+d_{N_i}^{\alpha}}). \tag{8}$$

Before discuss the power splitting coefficient, we note that R_{t1} and R_{t2} are the target rates, determined by the QoS of the far user and the near user, which N_i can successfully detect x_{F_i} and x_{N_i} respectively. In [7], optimal β_i is defined as the maximum amount of power harvested by relay user N_i, which needs to satisfy $R_{t1} \le R_{N_i}^{x_{F_i}}$. Hence, the optimal power splitting coefficient based on (8), determined as β_i', can be expressed as

$$\beta_i' = max\{0,1 - \frac{\varepsilon_{F_i}(1+d_{N_i}^{\alpha})}{|h_{B_i}|^2}\}, \tag{9}$$

where $\varepsilon_{F_i} = \frac{\tau_{t1}}{\rho(|p_{F_i}|^2 - |p_N|^2\tau_{t1})}$ with $|p_{N_i}|^2 - |p_{F_i}|^2\tau_{t1} > 0$.

However, if only x_{F_i} is decoded but x_{N_i} is not decoded by N_i, the outage probability at N_i constantly equals to 1, which may lead to sever path loss in the system. In the other words, [7] only discussed the condition of case $\varepsilon_{F_i} \ge \varepsilon_{N_i}$. In [16], a new PS protocol is proposed, where the detection of near user's own message x_{N_i} at N_i also should be guaranteed. Hence, the achievable data rate to complete this process is given by

$$R_{N_i}^{x_{N_i}} = \frac{1}{2}log_2(1 + \frac{\rho|h_{N_i}|^2|p_{N_i}|^2(1-\beta_i)}{1+d_{N_i}^{\alpha}}). \tag{10}$$

According to this protocol, both x_{F_i} and x_{N_i} can be decoded successfully at N_i. Namely, in this protocol, the optimal β_i should satisfy both $R_{t1} \le R_{N_i}^{x_{F_i}}$ and $R_{t2} \le R_{N_i}^{x_{N_i}}$. Therefore, based on (8) (9)(11) the optimal power splitting coefficient can be expressed as

$$\beta_i'' = \begin{cases} max\left\{0,1 - \frac{\varepsilon_{F_i}\left(1+d_{N_i}^{\alpha}\right)}{|h_{N_i}|^2}\right\}, & \varepsilon_{F_i} \ge \varepsilon_{N_i} \\ max\left\{0,1 - \frac{\varepsilon_{N_i}\left(1+d_{N_i}^{\alpha}\right)}{|h_{N_i}|^2}\right\}, & \varepsilon_{F_i} < \varepsilon_{N_i} \end{cases}. \tag{11}$$

3.4. Outage probability

In this subsection, only the RNRF selection scheme is derived in detail. The NNFF selection scheme and NNNF selection scheme are derived in [7] while the BNBF scheme is derived in [8].

For the near user N_i, the outage happens when N_i cannot detect message x_{F_i} of the far user F_i or when N_i can detect message x_{F_i} but cannot detect its own message x_{N_i}. Then the outage probability of the near user N_i can be written in [7] as

$$P_{N_i} = pr\left(\gamma_{S,N_i}^{x_{F_i}} < \tau_{t1}\right) + pr\left(\gamma_{S,N_i}^{x_{F_i}} \ge \tau_{t1}, \gamma_{S,N_i}^{x_{N_i}} < \tau_{t2}\right), \tag{12}$$

where $\tau_{t1} = 2^{2R_{t1}} - 1$ and $\tau_{t2} = 2^{2R_{t2}} - 1$.

For the far user F_i, the outage happens when the near user N_i can detect x_{F_i} but the combined SINR cannot complete the process of forwarding re-encoded x_{F_i} from N_i to

F_i and re-decode at F_i, or when neither N_i nor F_i cannot detect x_{F_i}. Then the outage probability of the far user F_i can be written in [7] as

$$P_{F_i} = pr\left(\gamma_{N_i\_MRC}^{x_{F_i}} < \tau_{t1}, \gamma_{S,N_i}^{x_{F_i}}|_{\beta_i=0} > \tau_{t1}\right) + pr\left(\gamma_{S,F_i}^{x_{F_i}} < \tau_{t1}, \gamma_{S,N_i}^{x_{F_i}}|_{\beta_i=0} < \tau_{t1}\right). \quad (13)$$

Based on (11), there are two conditions should be considered respectively: case $\varepsilon_{F_i} \geq \varepsilon_{N_i}$ and case $\varepsilon_{F_i} < \varepsilon_{N_i}$. To further discussion and simplify the expression of formula, we define $X_i = \frac{|h_{F_i}|^2}{1+d_{F_i}^{\alpha}}$, $Y_i = \frac{|h_{N_i}|^2}{1+d_{N_i}^{\alpha}}$ and $Z_i = \frac{|h_{N_iF_i}|^2}{1+d_{N_iF_i}^{\alpha}}$, and $f_{X_i}(x) = (1+d_{F_i}^{\alpha})e^{-\left(1+d_{F_i}^{\alpha}\right)x}$, $f_{Y_i}(x) = (1+d_{N_i}^{\alpha})e^{-\left(1+d_{N_i}^{\alpha}\right)x}$ and $f_{Z_i}(x) = (1+d_{N_iF_i}^{\alpha})e^{-\left(1+d_{N_iF_i}^{\alpha}\right)x}$. The performance in terms of outage probabilities at near user and far user in these two cases are explained hereinafter.

- **Case $\varepsilon_{F_i} \geq \varepsilon_{N_i}$:**

At near user, it can be recognized that if all the power are used to decode message x_{F_i} but the near user N_i still cannot detect the massage successfully, the outage occurs. Hence, to simplifythe process of calculate,$\beta_i" = 0$ is considered in the calculation. According to (12), the outage probability of N_i when $\varepsilon_{F_i} \geq \varepsilon_{N_i}$ is expressed as

$$P_{1N_i} = pr\left(Y_i < \varepsilon_{F_i}\right) + pr\left(Y_i > \varepsilon_{F_i}, \varepsilon_{F_i} < \varepsilon_{N_i}\right). \quad (14)$$

At the far user, it also can be recognized if the most power is used for energy harvesting to help far user but it is not enough to support the target rate, outage occurs. Hence, based on (11) we use the power splitting coefficient with $\beta_i" = 1 - \frac{\varepsilon_{F_i}\left(1+d_{N_i}^{\alpha}\right)}{|h_{N_i}|^2}$. Then the outage probability of F_i when $\varepsilon_{F_i} \geq \varepsilon_{N_i}$ is expressed as

$$P_{1F_i} = pr\left(Z_i < \frac{\tau_{t1} - \frac{\rho X_i|p_{F_i}|^2}{\rho X_i|p_{N_i}|^2+1}}{\eta\rho(Y_i - \varepsilon_{F_i})}, Y_i > \varepsilon_{F_i}\right) + pr\left(X_i < \varepsilon_{F_i}, Y_i < \varepsilon_{F_i}\right). \quad (15)$$

Note that the far users and near users are both distributed as homogeneous PPPs, which are the points modeled as independently and identically distributed (i.i.d.) with the donation of W_{k_i} where $k \in \{N,F\}$. The distribution information of the near user N_i and F_i is included in W_{N_i} and W_{F_i} respectively, and the probability density functions (PDFs) of the near user and the far user are separately written as

$$f_{W_{N_i}}\left(\omega_{N_i}\right) = \frac{1}{\pi {R_3}^2}, \quad (16)$$

and

$$f_{W_{F_i}}\left(\omega_{F_i}\right) = \frac{1}{\pi({R_1}^2 - {R_2}^2)}. \quad (17)$$

Then specially, when the path loss exponent $\alpha = 2$, in the free space the outage probability of the near user can be written as [7]

$$P_{1N_i}|_{\alpha=2} = 1 - \frac{e^{-\varepsilon_{F_i,}}}{R_3{}^2\ \boldsymbol{\varepsilon}_{\mathbf{F_i}}} + \frac{e^{-(\mathbf{1}+R_3{}^2)\ \boldsymbol{\varepsilon}_{\mathbf{F_i}}}}{R_3{}^2\ \boldsymbol{\varepsilon}_{\mathbf{F_i}}}, \tag{18}$$

while the outage probability of the far user can be written as [7]

$$P_{1F_i}|_{\alpha=2} = P_A + P_B, \tag{19}$$

Where

$$P_A = pr\left(Z_i < \left.\frac{\tau_{t1} - \frac{\rho X_i |p_{F_i}|^2}{\rho X_i |p_{N_i}|^2 + 1}}{\eta\rho\left(Y_i - \varepsilon_{F_i}\right)}\right|_{\alpha=2}, Y_i > \varepsilon_{F_i,}|_{\alpha=2} \right) =$$

$$\int_{R_3}\int_{R_1}\int_0^{\boldsymbol{\varepsilon}_{\boldsymbol{F_i}}}\int_{\boldsymbol{\varepsilon}_{\boldsymbol{F_i}}}^{\infty}\left(1 - e^{-(\mathbf{1}+R_2{}^2)\frac{\tau_{t1} - \frac{\rho X_i |p_{F_i}|^2}{\rho X_i |p_{N_i}|^2 + 1}}{\eta\rho\left(y - \varepsilon_{F_i}\right)}}\right) f_{Y_i}(y)\, dy f_{X_i}(x) dx f_{W_{F_i}}\left(\omega_{F_i}\right) d\omega_{F_i} f_{W_{N_i}}\left(\omega_{N_i}\right) d\omega_{N_i},$$

$$P_B = pr\left(X_i < \varepsilon_{F_i}|_{\alpha=2}, Y_i < \varepsilon_{F_i}|_{\alpha=2}\right)$$
$$= \left(1 - \frac{e^{-(1+R_2{}^2)\ \boldsymbol{\varepsilon}_{\boldsymbol{F_i}}}}{\boldsymbol{\varepsilon}_{\boldsymbol{F_i}}(R_1{}^2 - R_2{}^2)} + \frac{e^{-(1+R_1{}^2)\ \boldsymbol{\varepsilon}_{\boldsymbol{F_i}}}}{\boldsymbol{\varepsilon}_{\boldsymbol{F_i}}(R_1{}^2 - R_2{}^2)}\right) \times \left(1 - \frac{e^{-\ \boldsymbol{\varepsilon}_{\boldsymbol{F_i}}}}{\boldsymbol{\varepsilon}_{\boldsymbol{F_i}} R_3{}^2} + \frac{e^{-(1+R_3{}^2)\ \boldsymbol{\varepsilon}_{\boldsymbol{F_i}}}}{\boldsymbol{\varepsilon}_{\boldsymbol{F_i}} R_3{}^2}\right).$$

- **Case $\boldsymbol{\varepsilon}_{\mathbf{F_i}} < \boldsymbol{\varepsilon}_{\mathbf{N_i}}$:**

At the near user, as the same as in case $\varepsilon_{F_i} \geq \varepsilon_{N_i}$, we consider the power splitting coefficient with $\beta_i" = 0$. Hence, the outage probability of $\mathrm{N_i}$ when $\varepsilon_{F_i} < \varepsilon_{N_i}$ is expressed as

$$P_{2N_i} = pr\left(Y_i < \varepsilon_{F_i}\right) + pr\left(\varepsilon_{F_i,} < Y_i < \varepsilon_{N_i,}\right), \tag{16}$$

At the far user, depending on (11) and the reason mentioned before, we calculate with $\beta_i" = 1 - \frac{\varepsilon_{N_i}\left(1 + d_{N_i}^{\alpha}\right)}{|h_{N_i}|^2}$. Then the outage probability of F_i when $\varepsilon_{F_i} < \varepsilon_{N_i}$ is expressed as

$$P_{2F_i} = pr\left(Z_i < \frac{\tau_{t1} - \frac{\rho X_i |p_{F_i}|^2}{\rho X_i |p_{N_i}|^2 + 1}}{\eta\rho(Y_i - \varepsilon_{N_i})}, Y_i > \varepsilon_{N_i,} \right) + pr\left(X_i < \varepsilon_{N_i}, Y_i < \varepsilon_{N_i}\right). \tag{17}$$

As the same as (18) (19) in the case $\boldsymbol{\varepsilon}_{\boldsymbol{F_i}} < \boldsymbol{\varepsilon}_{\boldsymbol{N_i}}$, when $\alpha = 2$, (17) can be written as [16]

$$P_{2N_i}|_{\alpha=2} = 1 - \frac{e^{-\varepsilon_{N_i},}}{R_1{}^2\ \boldsymbol{\varepsilon}_{\mathbf{N_i}}} + \frac{e^{-(1+R_1{}^2)\ \boldsymbol{\varepsilon}_{\mathbf{N_i}}}}{R_1{}^2\ \boldsymbol{\varepsilon}_{\mathbf{N_i}}}, \tag{18}$$

and (17) can be written as[16]

$$P_{1F_i}|_{\alpha=2} = P_A{}' + P_B{}' \quad ,(19)$$

where

$$P_A^{'} = pr\left(Z_i < \left.\frac{\tau_{t1} - \frac{\rho X_i |p_{F_i}|^2}{\rho X_i |p_{N_i}|^2 + 1}}{\eta\rho(Y_i - \varepsilon_{N_i})}\right|_{\alpha=2} ,Y_i > \left.\varepsilon_{N_i}\right|_{\alpha=2} \right) =$$

$$\int_{R_3}\int_{R_1}\int_0^{\varepsilon_{N_i}}\int_{\varepsilon_{N_i}}^{\infty} (1 - e^{-(1+R_2{}^2)\frac{\tau_{t1} - \frac{\rho X_i |p_{F_i}|^2}{\rho X_i |p_{N_i}|^2 + 1}}{\eta\rho(y - \varepsilon_{N_i})}}) f_{Y_i}(y)\, dy f_{X_i}(x) dx f_{W_{F_i}}(\omega_{F_i}) d\omega_{F_i} f_{W_{N_i}}(\omega_{N_i}) d\omega_{N_i},$$

$$P_B{}' = pr\left(X_i < \left.\varepsilon_{N_i}\right|_{\alpha=2}, Y_i < \left.\varepsilon_{N_i}\right|_{\alpha=2}\right)$$

$$= \left(1 - \frac{e^{-(1+R_2{}^2)\,\varepsilon_{N_i}}}{\varepsilon_{N_i}(R_1{}^2 - R_2{}^2)} + \frac{e^{-(1+R_1{}^2)\,\varepsilon_{N_i}}}{\varepsilon_{N_i}(R_1{}^2 - R_2{}^2)}\right) \times \left(1 - \frac{e^{-\varepsilon_{N_i}}}{\varepsilon_{N_i} R_3{}^2} + \frac{e^{-(1+R_3{}^2)\,\varepsilon_{N_i}}}{\varepsilon_{N_i} R_3{}^2}\right)$$

3.5. System throughput in delay-sensitive transmission

System throughput is a significant criterion to measure the performance of a network. In this network model, the base station transmit the combination message to the near user and the far user simultaneously at fixed target rate R_{t1} and R_{t2} respectively. Hence, the system through is determined by the outage probabilities of the near user and the far user.

For the case $\boldsymbol{\varepsilon}_{\mathbf{F_i}} \geq \boldsymbol{\varepsilon}_{\mathbf{N_i}}$, the system throughput can be expressed as

$$T_1 = (1 - P_{1N_i})R_{t2} + (1 - P_{1F_i})R_{t1}. \tag{20}$$

And for the case $\boldsymbol{\varepsilon}_{\mathbf{F_i}} < \boldsymbol{\varepsilon}_{\mathbf{N_i}}$, the system throughput can be expressed as

$$T_2 = (1 - P_{2N_i})R_{t2} + (1 - P_{2F_i})R_{t2}. \tag{21}$$

4. Simulation and performance analysis

In this section, the performance in terms of outage probabilities and throughput are simulated. We assume that the radiuses of these three circles are $R_1 = 12$, $R_2 = 10$ and $R_3 = 3$ respectively; the power allocation coefficients of near user and far user are $|P_{N_i}|^2 = 0.2$ and $|P_{F_i}|^2 = 0.8$ respectively.

4.1. Impact of path loss

In this subsection, the outage probabilities of the near user and the far user and the system throughput with the path loss exponent of $\alpha_1 = 2\alpha_2 = 3$ and $\alpha_3 = 4$ are modulated respectively to demonstrate the impact of path loss. Besides, we set that energy harvesting coefficient $\eta = 0.7$ and the target rates are $R_{t1} = 1$ and $R_{t2} = 1$. As the RNRF selection scheme is considered, the performance of near user and the far user are both affected by the path loss.

As showed in Fig.5, the overall trend of the outage probability is inverse to the growth of SNR. The near user performs better than the far user as the outage probability the of near user in less than that of the far user in the same path loss exponent. Additionally, it is clear for the near user or the far user, the outage probability is higher with a larger value of path loss exponent.

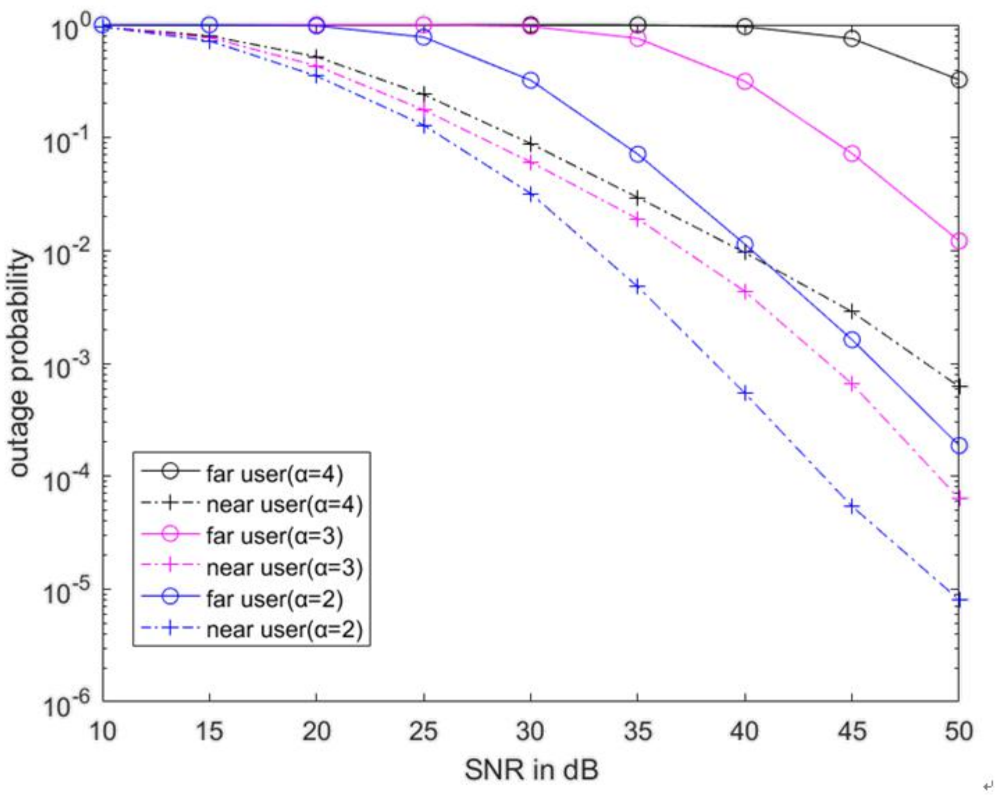

Fig.5 The outage probability of far user and near user with different path loss exponent

System throughput is another important element to evaluate the performance of network. Fig.6 expresses the tendency of the system throughput in RNRF, which go up with the increasing of SNR. In addition, the system throughput with α_3 grows below the system throughput with α_2 which is under the system throughput with α_1 in a range of small SNR. However, when the SNR exceeds a certain value, the impact of path loss becomes weak. With a large SNR, the values of system throughput with these three path loss exponent almost reach to a same level. On the other words, the difference of system throughput impact by disparate path loss is only showed in a range of SNR.

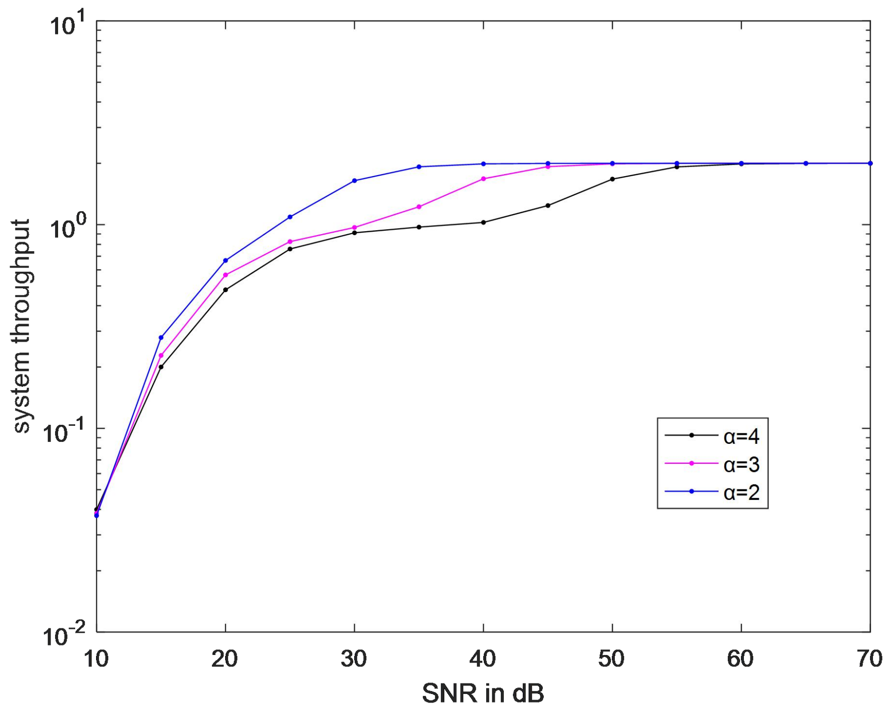

Fig.6 The system throughput with different path loss exponent

4.2. Impact of the choice of optimal power splitting coefficient

In this part, to compare the performance affected by the choice of optimal power splitting coefficient, only case $\varepsilon_{F_i} < \varepsilon_{N_i}$ is discussed. To illustrate the performance of them, the outage probability and system throughput are considered. The three groups of target rate are assumed as $R_{t1} = 1$, $R_{t2} = 2$; $R_{t1} = 0.5$, $R_{t2} = 1$ and $R_{t1} = 0.3$, $R_{t2} = 0.5$; the energy harvesting coefficient is set as $\eta = 0.7$; the pass loss exponent is set as $\alpha = 2$.

Fig7demonstrates the outage probability of near user changed with SNR. It is clear that the optimal the power splitting coefficientβ_i' proposed in [7] is not suitable for case $\varepsilon_{F_i} < \varepsilon_{N_i}$, becausethe outage probabilities of near are constantly one. Besides, with different groups of target rate, the system performs disparately.

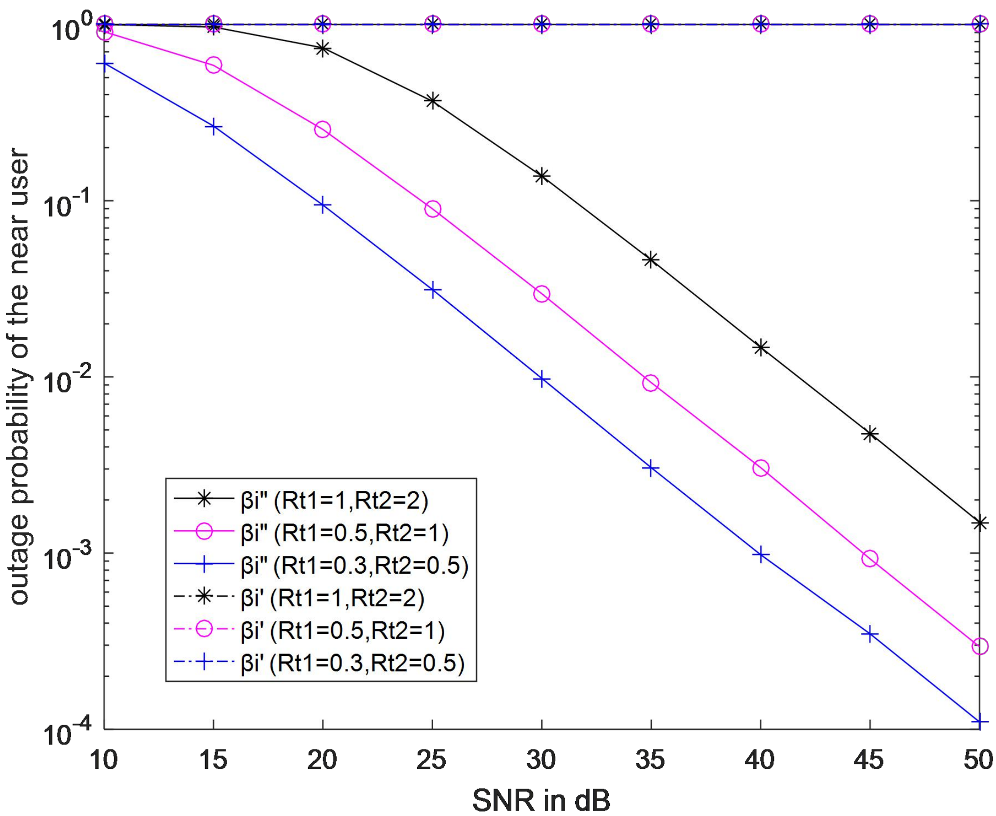

Fig.7 The outage probability of the near user with different target rate in two selection of optimal splitting coefficient

The fig.8 demonstrates the outage probability of far users. For the far user, it is obvious that with the same target rate, the two lines almost coincide together, which express the outage probability of far users with β_i' and β_i''. Hence, for far users, there is no obvious impact by choice of optimal power splitting coefficient.

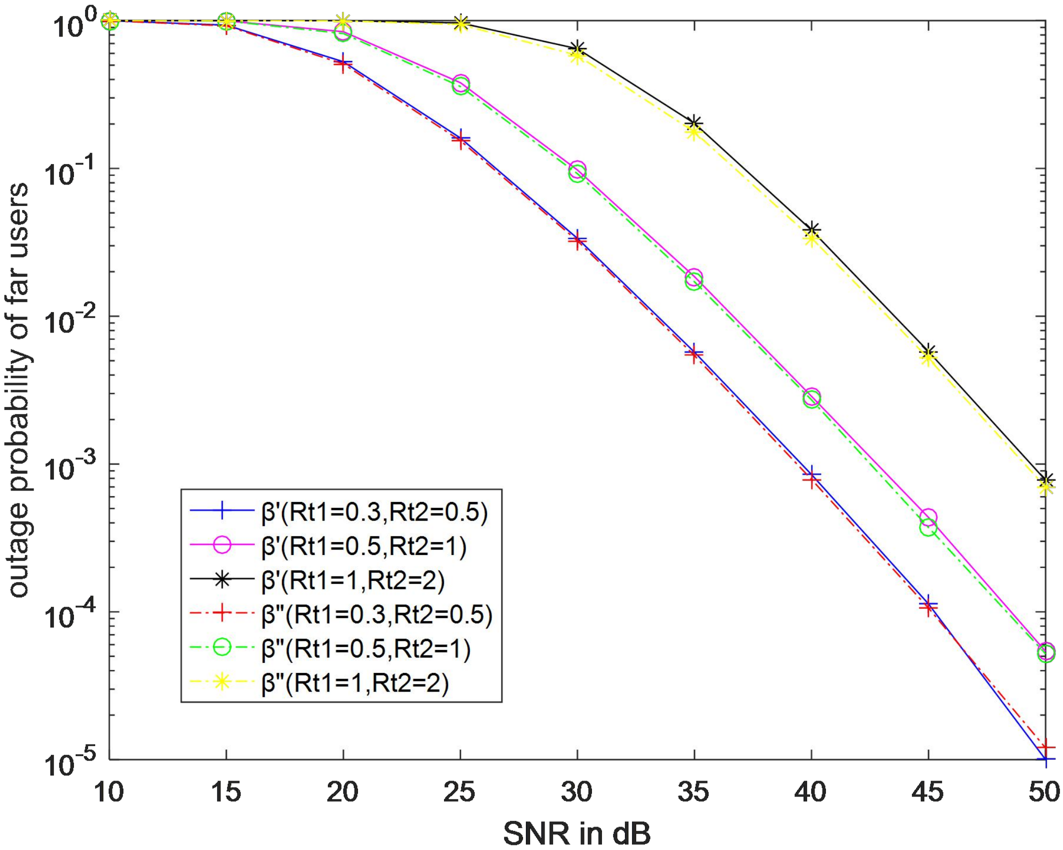

Fig.8 The outage probability of the far user with different target rate in two selection of optimal splitting coefficient

In Fig.9, the system throughput changed with SNR is demonstrated. As same as the conclusion above, the values of system throughput reach to constant level with a high SNR, which are distinguished by different groups target rate. However, the system throughput with the same target rate reaches to different level when different optimal power splitting coefficient. The network with β_i'' performs better than network with β_i' at the same target rate. Besides, aim at a network with each optimal splitting coefficient, with the growth of value $|R_{t2} - R_{t1}|$, the performance has improved.

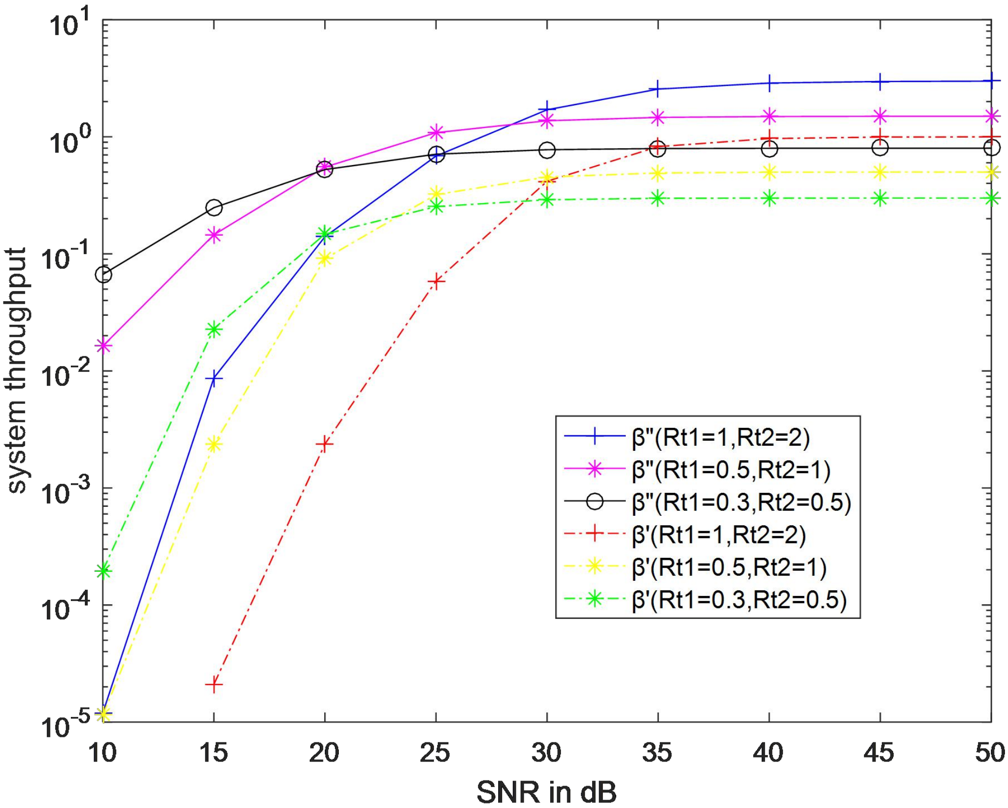

Fig.9 The system throughput with different target rate

in two selection of optimal splitting coefficient

4.3. Impact of energy harvesting efficiency

As this paper mainly researched the WPT in the network, we consider impact of energy harvesting coefficient η, which determines the efficiency of energy harvesting. We assume $\eta = 0.4, 0.6, 0.8$ and Fig.10 has showed the outage probabilities with different value of η. It is clear that it has not affected much at the near users. On the other hand, η has influence on far users. It is because all of the power harvested by the near user is used to help the far user. With higher energy harvest efficiency, the far user gets lower outage probability.

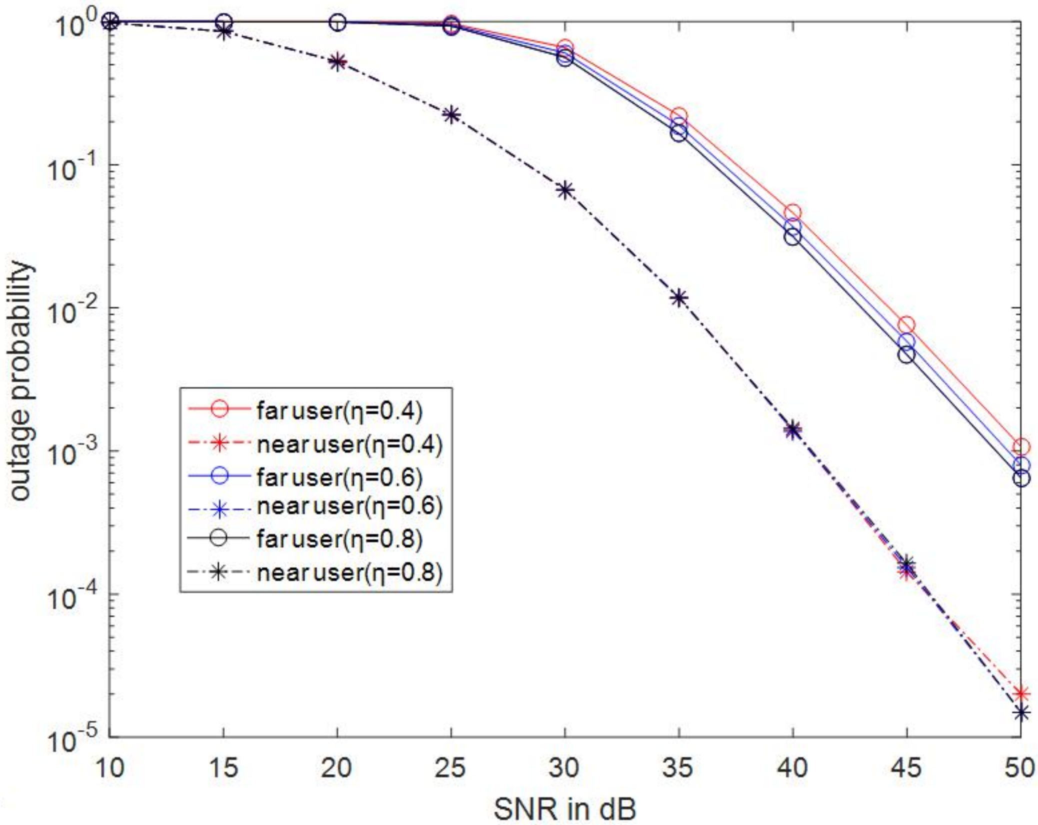

Fig.10 The outage probability with different energy harvest efficiency

5. Conclusion

5.1. Project overview

The communication system is updating and developing constantly to satisfy the demand of market and requirement of users. Current generation communication system would not suitable one day in the. The next generation system would require higher spectrum efficiency, higher data rate and greater capacity.

To meet these demands in the 5G communication system, many new techniques are proposed. Among these techniques, non-orthogonal multiple access is a promising one. The power-domain NOMA can support more users in a channel at the same time. The most significant of NOMA is improved spectrum efficiency. In NOMA, the power division multiplexing (PDM) technique,superposition coding (SC) technique successive interference cancellation(SIC) technique are involved. PDM divides information in power domain at the transmitter; SC supports transmitter send information to multiple user simultaneously; and SIC can help mitigate the interference.

Based on NOMA, some new schemes are advised. Cooperative NOMA scheme is put forward, in which the users in better channel would act as a relay to help the users in poorer channel. However, the relay users would be limited by their lifetime of battery. Hence, the wireless power transfer technique is combined with CNOMA. In SWIPT NOMA protocol, the relay users can harvest energy to charge battery or forward information.

The network in this projection is model on the basis of SWIPT NOMA. In this network, users are divided into two groups by using user pairing technique mentioned in section 2. As for the protocol proposed in [7], the near user only guarantees the detection the massage of the far user. So when the near user cannot decode its own message, the outage probability of the near user equals to one. So another protocol in [16] is proposed, where the near user can guarantee the detection the information of far-user as well as its own message. The difference between these two protocols is the choice of optimal power splitting coefficient, which determine the amount of power used to harvest energy.

In the forth section, these two protocols are compared by simulation. It is confirmed that the network with the second optimal power splitting coefficient (9) performs better than the network with the first optimal power splitting coefficient (11) in terms of the outage probability of near users and system throughput.

Besides, the impact of path loss and energy harvesting is also discussed by modulation. When the impact of path loss is considered, as for the probability, both far users and near users performs better with lower path loss exponent. On the other hand, the difference of system throughput impact by disparate path loss is only showed in a range of SNR. When the impact of energy harvest efficiency is considered, the far user will be affected by energy harvest efficiency while the energy harvest efficiency almost does not affect the near user.

In conclusion, NOMA can satisfy the demand of high spectrum efficiency in 5G. When WPT is added, the energy efficiency can be improved. Hence, the combination of NOMA and WPT will be achievable technique in the future.

5.2. Further work and challenge

As the summary above, this SWIPT NOMA network can achieve some advanced development in the 5G communication system. However, there are still some parts of based on this network model can be improved.

In this network, the user pairing technique is applied to divide into multiple groups, where users are processed by NOMA in each group. However, the location and condition of users are not all the same. As the traffic is quicker than before, the change speed of allocation is also higher. Additionally, the environment of communication becomes more complex, which means the condition of users are more difficult to predict. Hence, a dynamic user pairing technique should be considered in this network.

Moreover, the users in the network are with single antenna. However in practice, a lot of devices are with multiple antennas. Therefore, in the further work, the condition of multiple antennas should be designed in this network. Besides, with the increased complexity of channel, a useful antennas selection scheme should also be considered, which could help choose suitable antenna in difference channel.

Furthermore, this network model is considered in a single sell, but the construct of multiple cells is completed practically. So to generalize the SWIPT NOMA in the future, the muti-cell network should be designed with SWIPT NOMA.

Except the challenges mentioned above, the most important challenge is how to achieve these theoretical techniques in practice and adopt them as commercial business. This is a significant step to achieve 5G communication system.

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