Journal of King Saud University – Computer and Information Sciences 34 (2022) 8054–8078

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Journal of King Saud University – Computer and Information Sciences

journal homepage: www.sciencedirect.com

Cooperative Communication Resource Allocation Strategies for 5G and Beyond Networks: A Review of Architecture, Challenges and Opportunities

Wanying Guo [a], Nawab Muhammad Faseeh Qureshi [b,*], Isma Farah Siddiqui [c], Dong Ryeol Shin [a]

[a] Department of Electrical and Computer Engineering, Sungkyunkwan University, Suwon, Republic of Korea
[b] Department of Computer Education, Sungkyunkwan University, Seoul, Republic of Korea
[c] Department of Software Engineering, Mehran University of Engineering & Technology, Jamshoro, Pakistan

A R T I C L E I N F O

Article history:
Received 16 April 2022
Revised 23 June 2022
Accepted 23 July 2022
Available online 12 August 2022

Keywords:
5G cooperative communication
Resource allocation
Relay section

A B S T R A C T

The fifth-generation mobile network (5G) supports Internet of Things (IoT) devices and processes large-scale data volumes through mobile devices. With this facility, we find a novel concept of Cooperative communication that manages massive channels accessibility, heterogeneous networks, complex interference environments and high energy consumption mediums through high signal coverage and capacity among mobile devices. The core of cooperative communication system relies on resource allocation techniques that achieves robust interference management, resource scheduling and user matching. To this extend, we find several strategies that discuss cooperative communication allocation techniques from various technological aspects. This review paper compiles all such strategies and discusses cooperative communication resource allocation techniques in a broader scope. The review is designed in such a systematic way that, at first, we classify cooperative communication process according to the number of relay nodes, signal forwarding mode, and transceiver diversity gain. After that, we discuss the core technologies of cooperative communication that includes channel multiplexing, relay selection, power allocation. Followed by that, we discuss the network model of the 5G cooperative communication system having spectrum sharing, new antenna technology, and NOMA along with the several application case studies. In addition to that, we also brief about the resource allocation algorithms of the 5G cooperative communication system from both the certain and uncertain channel states. Finally, we conclude the review discussing the current applied architecture of 5G cooperative communication resource allocation along with challenges, opportunities and open problems.

Contents

* Corresponding author.
E-mail address: faseeh@skku.edu (N.M.F. Qureshi).

https://doi.org/10.1016/j.jksuci.2022.07.019
1319-1578/

Nomenclature

Abbreviation	**Description**
5G	The fifth Generation Mobile Network
AF	Amplify-and-Forward
AP	Access Point
AMC	Adaptive Modulation and Coding
BS	Base Station
CC	Coded Cooperation
CCFD	Co-frequency Co-time Full Duplex
CMC	Cellular and Mobile Communication
CR	Cognitive Radio
CSI	Channel State Information
CRC	Cyclic Redundancy Check
D2D	Device to Device
DF	Decode-and-Forward
eMBB	Enhanced Mobile Broadband
HetNets	Heterogeneous Networks
IoT	Internet of Things
IRS	Intelligent Reflecting Surface
LAN	Local Area Network
LTE	Long Term Evolution
LOS	Line-of-Sight
MIMO	Multi-Input Multi-Output
MISO	Multi-Input Single-Output
mMTC	Massive Machine Type Communications
mmWave	Millimeter Wave
MPSK	M-ary Phase Shift Keying
MRC	Maximum Ratio Combining
MRT	Maximum Ratio Transmission
NAF	Non-orthogonal Amplify-and-Forward
NCC	Network Coded Cooperation
NOMA	Non-orthogonal Multiple Access
OFDMA	Orthogonal Frequency Division Multiple Access
OPA	Optimal Power Allocation
QoS	Quality of Service
RB	Resource Block
RE	Resource Element
SER	Symbol Error Rate
SIC	Successive Interference Cancellation
SIMO	Single-Input Multi-Output
SINR	Signal to Interference and Noise Ratio
SISO	Single-Input Single-Output
SNR	Signal to Noise Ratio
STCC	Space Time Coded Cooperation
TDMA	Time Division Multiple Access
UAV	Unmanned Aerial Vehicle
Ud-HetNet	Ultra Dense Heterogeneous Networks
UDN	Ultra Dense Network
uRLLC	Ultra Reliable Low Latency Communications
V2V	Vehicle to vehicle
V-MIMO	Virtual Multiple-Input Multiple-Output
WANET	Wireless Ad hoc Network
ZFT	Zero Forcing Transmission

1. Introduction

With the rapid growth of IoT and the sharp growth of big data, the next generation of wireless communication faces explosive traffic growth. Doubling the device access problem, 5G is facing huge growth requirements. The total transmission rate of the 5G communication network is much higher than that of the 4G/LTE network in theory (Chen et al., 2020). Such extremely sharp traffic and variety service causes a huge challenge for the telecom industry (Mahmoud et al., 2021). As shown in fig. 1, we can clearly see the evolution of wireless networks in different time periods (Rost et al., 2016; Multiple, 2019). Based on these, compared with 4G, the application scenarios of 5G communication have more rich engineering requirements. As shown in fig. 2, three important application scenarios based on 5G, eMBB (Enhanced Mobile Broadband), uRLLC (Ultra Reliable Low Latency Communications) and mMTC (Massive Machine Type Communications) (Feng et al., 2021; Popovski et al., 2018) based on 5G have many practical applications like VR (Virtual Reality), UAV (Unmanned Aerial Vehicle), Smart Home, AIoT, and so on. Not only that, 5G mobile communication is also used in emergency rescues like war and other military scenarios. More importantly, now that we are paying more and more attention to the concept of green energy, 5G mobile communication needs to meet the requirements of low energy consumption (Ni et al., 2019; Fan et al., 2020). Due to this, energy efficiency can also be one of the most important system performance indicators.

Actually, it is very difficult to achieve perception, data, and information exchange in long-distance transmission communications (Li et al., 2021). Due to the multi-path fading characteristics and noise of wireless channels, as well as the movement and transmission power of nodes, wireless network systems are difficult to obtain a satisfactory data transmission rate and communication quality (Ullah et al., 2012). Wireless communication technology faces great challenges. Traditional point-to-point wireless communication technology is already approaching the Shannon limit (Chi et al., 2018), and new technologies and solutions must be explored. During the exploration process, the researchers proposed cooperative communication (or relay communication) techniques. This technology originated from the research of Cover T and Gamal A E on the information theory characteristics of relay channels in the 1970s (Cover and Gamal, 1979), and the basic idea is to maximize the system throughput through partial resource sharing of nodes in a wireless communication system. Cooperative communication technology integrates relay transmission technology and cooperative diversity technology, which can be applied in WANET (Wireless Ad hoc Network), CMC (Cellular and Mobile Communication) systems, wireless LAN (Local Area Network), and WSN (Wireless Sensor Network) (Malik et al., 2020).

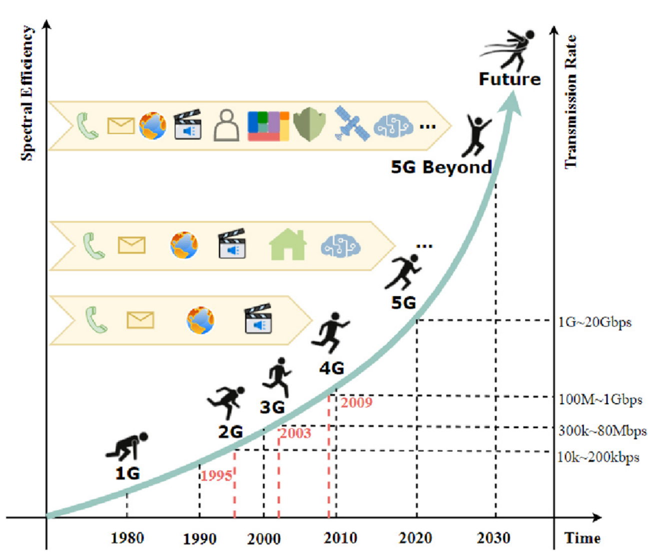


Fig. 1. Evolution of wireless network technique.

Cooperative communication in traditional networks is a technology that conducts assisted transmission through relay nodes, thus improving network coverage and system capacity (Malik et al., 2020). It has been attracting wide attention from industry and academia with its characteristics of assisted transmission. Using a new multi-antenna transmission technology at the relay nodes can provide large-scale concurrent data flow, thus to enhance the system capacity and meet the massive user needs of 5G communications (Ji et al., 2021). Massive MIMO (Multi-Input, Multi-Output) can be seen as a core technology in 5G cooperative communication systems. This technology is mainly used for improving the role of network coverage, user experience, and system capacity (Jijo et al., 2021). At present, this technology has been widely utilized in the domain of wireless communication. For example, communication networks and WiFi hot spots are mainly used in the daily lives of people in the 4G era. Theoretically, the number of antennas bears directly upon the frequency efficiency, transmission rate, and reliability of the communication system (Saleh and Hasoon, 2018). To guarantee the quality of communication services, the communication base station will be fitted out with a massive number of antennas to improve the efficiency of the communication spectrum. The Massive MIMO technology could centralize the communication wave-number in the planning coverage area (Ajewale Alimi et al., 2019), avert the signal interference between different cells effectively, and reduce the transmission power of the communication behaviour (Sharma and Jha, 2021). Besides, the user mostly uses the same relay in the system, causing interference between user pairs. And the new multi-antenna transmission technology can obtain strong interference suppression through simple linear processing. Therefore, combining the relay with the new multi-antenna transmission technology can not only enhance the system capacity but also inhibit the inter-pair interference of the relay network (Li and Baduge, 2020).

Recently, NOMA (Non-orthogonal Multiple Access) technologies have raised concerns about 5G. Unlike OFDMA (Orthogonal Frequency Division Multiple Access), which we are familiar with in 4G cooperative communication systems, 5G cooperative communication uses NOMA (Ligwa and Balyan, 2022). Multiple users transmit the signal on the same sub-frequency band, extremely improving spectrum utilization, but also produce the same frequency interference problem. However, the SIC (Successive Interference Cancellation) can be used to effectively eliminate this interference (Zhang et al., 2020). Due to the emergence of NOMA technology, it is expected to satisfy the requirements of ultra-low cost, ultra-low power consumption, as well as massive packets in massive connected mMTC application scenarios in the future (Tanwar et al., 2019), and to meet the real organizing and low delay and power consumption requirements under the burst of small packets randomly in the application scenarios of eMBB and uRLLC (Sharma and Wang, 2019). In traditional cellular networks, to increase the system throughput with decreasing energy consumption, the concept of micro cell was proposed (Gui et al., 2020), which is inevitable with more intensive heterogeneous cellular deployment and a more complex wireless interference environment. Optional architectural design is of great importance for the gradually expanding coverage area. The relay system model assists the cell edge user transmission with the characteristics of the auxiliary transmission and can reduce the inter-layer interference by reducing the transmit power (Mao et al., 2017). Reference (Ge et al., 2016) presents that with the enhanced mobility, the

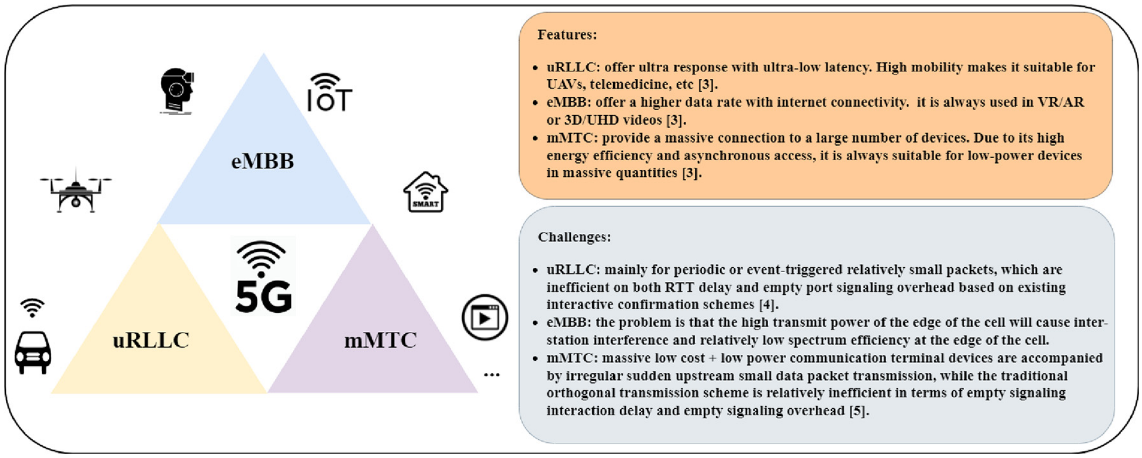


Fig. 2. Three 5G application scenarios-features and challenges.

performance of 5G ultra-dense heterogeneous networks gradually decreases, the relay cooperation (adjacent micro cell base stations as relay) collaborates to transmit back-haul services to guarantee the system performance. In traditional cellular communication networks, only some users with good channel state can obtain services directly from the base station. Using D2D (device-to-device) short-distance transmission technology, users with good channel status perform short-distance transmission as relay nodes, so that users with poor channel state can access services (Maraqa et al., 2020). Cooperative transmission based on inter-device communication improves system spectrum utilization and service quality, while reducing the burden and power consumption of base stations (Jameel et al., 2018). At the same time, 5G cooperative communication systems require high data rates to support the growing traffic demand of emerging applications (Chien et al., 2020), so the relay nodes adopt CCFD (Co-frequency Co-time Full Duplex) technology to meet this demand.

The 5G cooperative communication system has the characteristics of massive access, heterogeneity, diversity, complex interference environment and high energy consumption (Vaigandla and Venu, 2021; Ni et al., 2018; Gkonis et al., 2020), which produces many problems absent from the traditional cooperative communication systems, such as more flexible relay selection, cache optimization, task unloading, node selection, network security, etc.

This paper reviews the current situation of 5G mobile communication research and the resource allocation problems of relay cooperative communication networks. First, cooperative communication systems are classified into different dimensions, and then several common relay network models are detailed. Secondly, the application scenarios, key technologies, and existing problems are detailed. Then, the resource allocation problems of ultimate selection and power distribution under these models are summarized. And finally, the existing issues of the present development are indicated and the future research direction of 5G is reviewed.

2. What is cooperative communication networks?

2.1. Basic Concept

Cooperative communication refers to the transmission between users through cooperation with each other. The source node not only transmits the signal to the destination node but also transmits the signal to the relay node. Then, the relay node transmits to the next relay node or destination node through different relay transmission protocols (Hossain et al., 2019).

It is a technology that uses mobile relay nodes to increase specific user capacity. This principle means that the system can be divided into three types of nodes: source node (base station), destination node (node of specific users), and relay node (other user terminals) (Peng et al., 2011). In this system, all the relay nodes will be considered as sending and receiving antennas for specific user nodes. Therefore, we can think of the network as the same as a multi-input and multi-output (MIMO) antenna system, called a virtual multiple-input and multiple-output antenna (V-MIMO) system, which could guarantee the specific capacity of specific users (Kothari and Ragavendran, 2021). To sum up, we call this kind of technology "cooperative communication".

In normal situation, most cooperative communication system involve 2 transmission phases:

- Phase I: In this phase, the users will share the source data along with the control messages with the destination or other users (Hong et al., 2010).
- Phase II: In this phase, the users re-transmit the messages to the destination cooperatively (Hong et al., 2010).

The basal relay system is always composed of 2 users transmitting to an ordinary destination node. One user plays the role of the source node and another user plays the role of the relay node. Besides, both of the 2 users can exchange their roles to be the source node or the relay node at different instants of time (Ibrahim et al., 2008). As described above, in Phase I, information will be broadcast to the relay node, as well as the destination node, by the source node user. And in the following Phase II, the relay node can complete data self-forwarding or co-forwarding with the source node to advance the reception at the destination node. In cooperative systems, coordination is extremely necessary because the antennas are supplied to different terminal devices distributively, instead of centralized MIMO systems (You et al., 2010). Too much extra coordination will decrease system bandwidth, but the cost will always be compensated by the large diversity gain under high SNR (Hong et al., 2010). In detail, coordination could be realized not only by direct user-to-user communication but also by feedback from the destination. On the basis of the messages achieved by coordination, cooperating partners would calculate and transmit messages to decrease the transmission cost or increase the detection nature of the receiver. However, the coordination cost could be raised by the quantity of cooperating users. So, a high-efficient user-to-user or feedback communication strategy must be designed for more meaningful cooperation (Hong et al., 2010; Khan et al., 2018).

2.2. The application of cooperative communication in the mobile communication network

2.2.1. In normal mobile communications

In the traditional cellular network system, to enhance the quality of user service effectively, a cell will be upgraded again to several microcells, and there should be a BS (base station) set up in the center of the microcells. When cooperative communication is utilized in a cellular communication system, the mobile station and the BS are connected in the coverage range of the BS, and all the users can realize the communication behavior directly through the BS. But when it is in the coverage range of the relay station, the communication of the mobile station uses collaboration to connect with the BS nearby, thus forming a multi-jump link, and realizing the communication behavior. During cooperative communication, not only can the communication behavior between mobile stations and BSs be achieved by the relay station, but also the cooperation between mobile stations, BSs, and relay stations can achieve the communication behavior.

The most important point about this is that system design concentrates on reducing the cost of collaboration, or on enhancing technical requirements. In mobile communication systems, cooperative communication technology is utilized. The relay station is connected with a lot of mobile stations, and the BS is connected with many relay stations. The resources in the whole range are under the control of the BS, while the relay station uses a certain function to control the actual allocation of resources. The relay station can use the AF mechanism, and the relay station could achieve the information sent from the BS at a certain time slot and frequency. If this is the case, the relay station can effectively broaden the coverage of the BS. Besides, the relay station could also utilize the mechanism of coding forwarding, under which the relay station could encode the information transmitted by the BS firstly, and then remodulate or error correction code to send the information out. Then, the quality of service could be effectively improved.

2.2.2. In emergency mobile communications

There are times when cooperative communication could improve the robustness of the system effectively. Besides, it sometimes also supports partial communication behavior if the BS is paralyzed. In emergency communication, when in a certain area, the BS breakdowns, it becomes paralyzed and fails in communicating normally. If the cooperative communication system is set up, even if the BS fails in normally work, the communication users within the coverage can still communicate through the RS (Relay Selector). At this moment, the RS can be considered as a simple BS. If users in the region want to communicate with users outside the region, they can use multi-hop RS, or use multi-hop RS to connect with the BS to achieve communication behavior. However, this communication mode also has some faultiness. That is, the capacity is limited, and we can only use the priority to expand the controlling to guarantee the communication behavior of the users with high priority, while the relatively low priority will only be given up. Under different situations of various serious natural disasters (like earthquakes), the local BSs may be largely paralyzed. Under these circumstances, RS can be utilized to guarantee the communication from the paralyzed area to normal areas. Through the cooperative communication system, between the paralyzed area and the outside areathe communication behavior could be guaranteed, and some significant information from the area suffered from a disaster can be gotten at the beginning of disaster resistance to guarantee the smooth flow of important communication.

3. Classification of cooperative communication networks

Compared with traditional relay networks, the structure of 5G cooperative system is more complex due to the high user diversity, network density and heterogeneity as fig. 3 shows. Then, we mainly classify the cooperative communication networks by

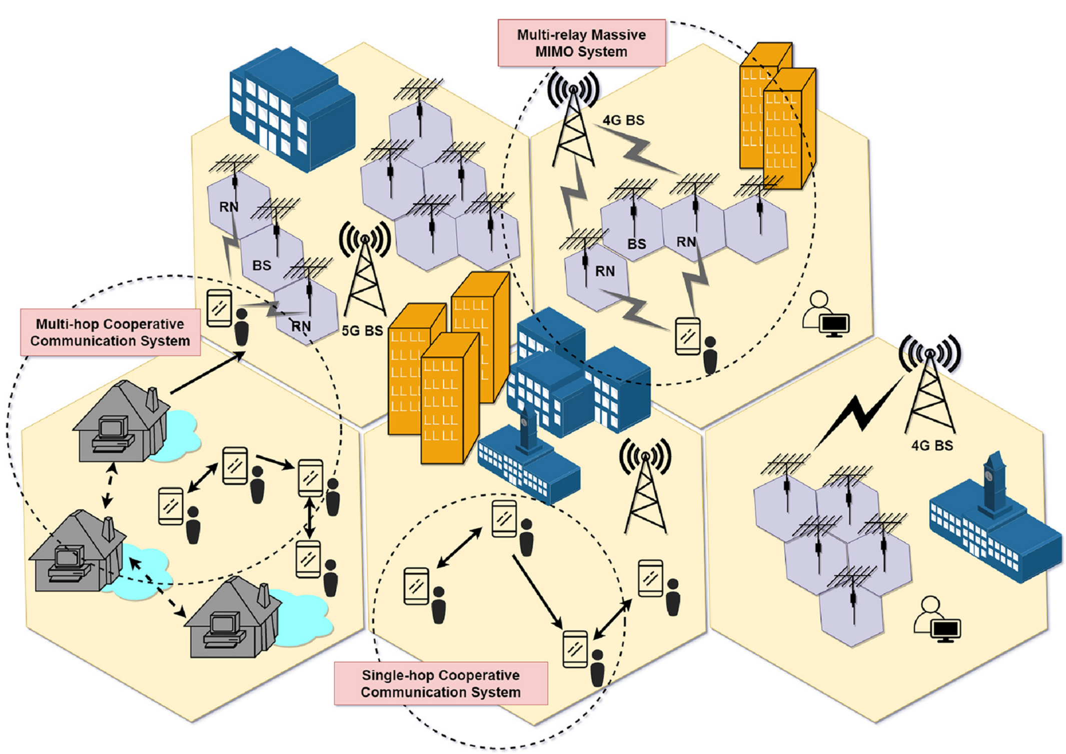


Fig. 3. 5G Cooperative Communication System.

several aspects, the number of relay nodes, signal forwarding methods, as well as the transceiver diversity gain.

3.1. The number of relay nodes

In terms of the quantity of relay nodes, cooperative communication networks can be categorized as single-relay cooperative communication networks and multi-relay cooperative communication networks (He et al., 2018).

In a single-relay cooperative communication network, there is only one relay node used to forward the signal. The network has a simple structure and limited information transmission efficiency. It is a two–hop communication system usually applied in a close-up communication system without direct transmission (Lv et al., 2019), as fig. 4 shows.

As shown in fig. 4, the source node can not directly transmit the effective information to the destination node, and it needs to communicate through two hops with the assistance of the relay node. Moreover, the information from the source node to the destination node may be regarded as a harmful interference to the receiver (Qiao et al., 2012).

In a multi-relay cooperative communication system, multiple relay nodes forward and re-transmit information to achieve high-reliable communication and far-coverage transmission (Zhang et al., 2019). In this type of network model, network transmission scenarios are particularly complex because the information is also transmitted among multiple relay nodes. It is reflected in the changeable of relay selection, channel distribution, as well as power distribution (Ding et al., 2020).

From the perspective of information transfer and transmission, the multi-relay cooperative communication system can be segmented into two types: two–hop-based multi-relay cooperative communication networks and multi-hop-based multi-relay cooperative communication network (SB, 2018). According to the different transmission modes of the signal, the two–hop cooperative communication system can be categorized as time-division system or a frequency-division system like fig. 5 shows. In a time division system scenario, information is relay transmitted through different time slots and eventually reaches the destination node. Only one signal is allowed to be transmitted at the same time. In frequency division system scenarios, the signals can be transmitted on different sub-bands at the same time. Thus, the signal transmission efficiency can be improved.

In the multi-hop multi-relay cooperative communication system (the number of relay nodes is greater than or equal to 2), the information from the source node finally reaches the destination node through the forwarding of multiple relay nodes (Liu et al., 2012). One method is a multi-relay serial transmission mode without relay selection like fig. 6(a) shows. The multi-relay serial transmission mode is to let each relay node merge all the signals from all previous relays and source nodes. Its network structure is very complex, with a large time delay (Liu et al., 2009). The other

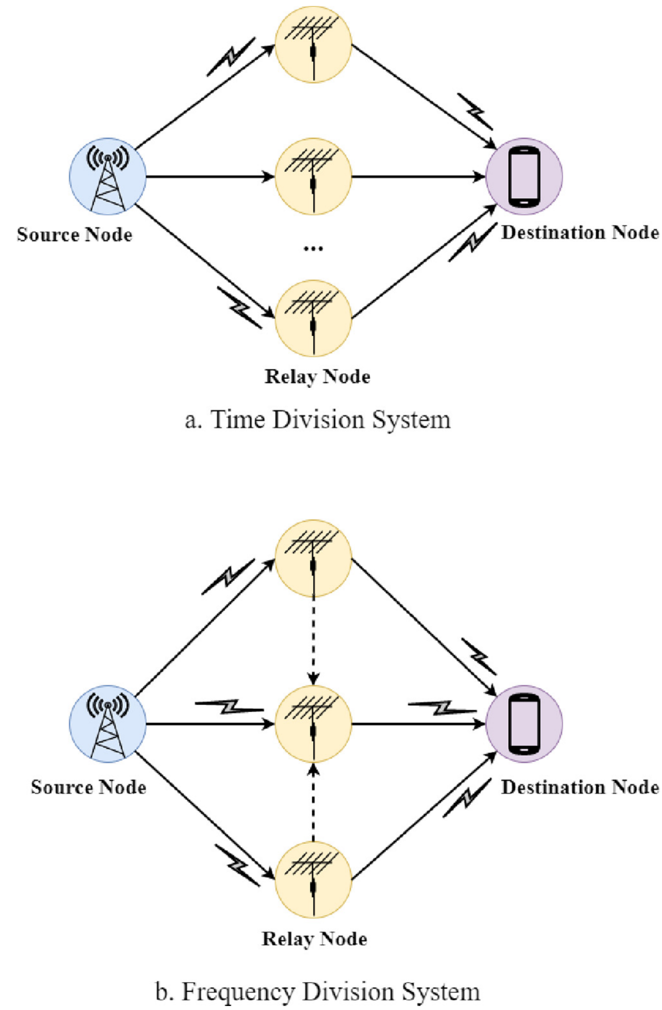


Fig. 5. 2-hop multi-relay cooperative communication.

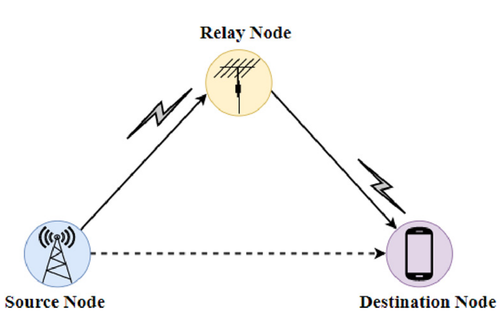


Fig. 4. Single-relay cooperative communication.

is a multi-relay transmission mode based on channel selection. It can judge and determine the transmission link, selected by the first or second jump, by the channel state of the relay node. This transmission mode can effectively utilize the channel fading characteristics to select the node with the best channel state for transmission each time, as shown in fig. 6(b). It can be found throughout whole fig. 6 that multi-relay cooperative communication could obtain a diversity gain relative to single-relay cooperative communication, but the overall design complexity of the system will be very high (Lu et al., 2020). Therefore, the selection of the number of relay nodes needs to be well optimized and designed.

3.2. Signal forward methods

If the signal forwarding method sent by the source node is classified by the relay node, it can be divided into amplify-and-forward (AF), decode-and-forward (DF), and coded cooperation (CC) (Khan et al., 2018). The system schematic is shown in Fig. 7.

- Amplify-and-Forward (AF): As Fig. 7 a (1) shows, the power of relay node amplifies the signal which received from the source node to supplement the power loss in the transmission and then transmits the signal to the next node (Sanguinetti et al., 2012). Among lots of AF protocols, non-orthogonal AF (NAF) protocol is significantly better than other AF protocols in error

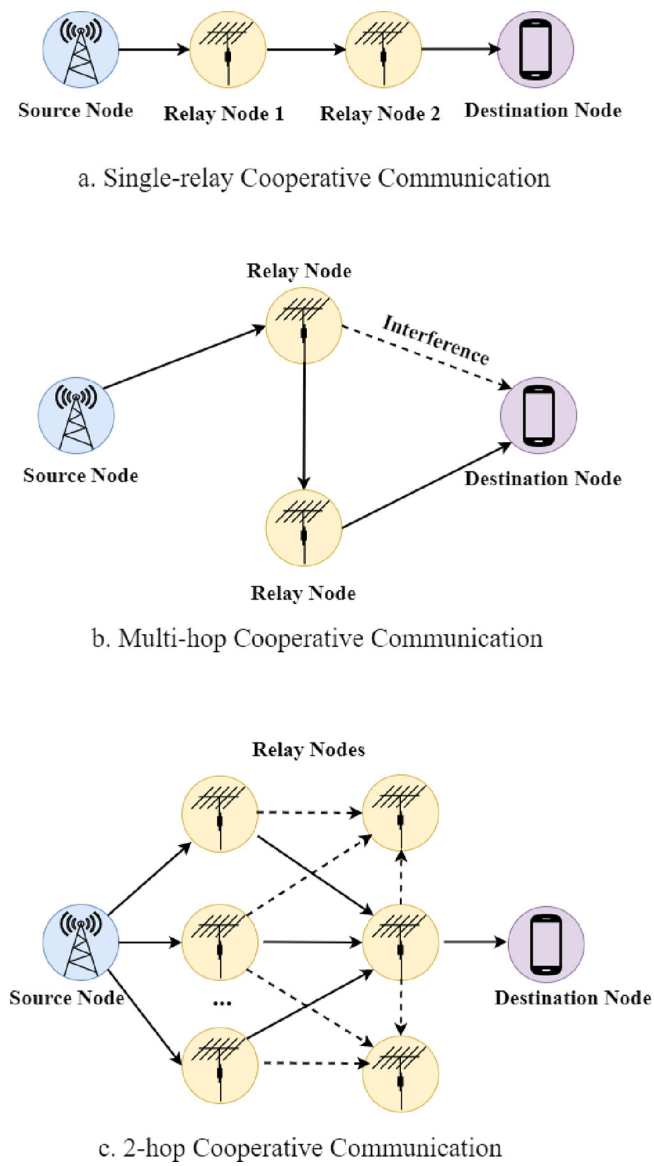


Fig. 6. Multi-relay cooperative communication.

performance and capacity (Nabar et al., 2004). To overcome high receiver complexity, Fig. 7 a (2) gives a joint liner AF model, not only improve the bit error rate (BER) performance, but also gets both symbols achieve same diversity order (Ahmed et al., 2014).

- Decode-and-Forward (DF): The relay node demodates, decodes and judges the received signal, then encodes the judgment data and transmits it to the next node. If a relay node can not decode properly, it will result in a sharp decline in the system performance, so decoding forwarding is suitable for better SR (source-relay) channels (Wang et al., 2007).
- Coded Cooperation (CC): The source node sends information not only to the relay nodes but also to the destination nodes, which re-encode it to the destination node after receiving the information from the source node. And then the destination node merges the information received from the source and relay nodes and performs the decoding judgment (Başaran et al., 2016).

Actually, AF and DF are more commonly used. Here, the characteristics of AF and DF forwarding methods are shown in Table 1.

According to the table, the transmission characteristics of the source node to the relay node channel have a great influence on the DF mode. Without CRC (Cyclic Redundancy Check), the SER (Symbol Error Rate) of DF is even worse than direct transmission; with CRC, DF can overcome this disadvantage and achieve slightly better performance than AF. The complexity of the AF mode is lower than that of the DF. If the complexity and performance are considered comprehensively, the AF mode can be used in low SNR (Signal Noise Ratio), and the DF mode can be used in high SNR. The transmission power distribution scheme of DF mode with CRC is similar to AF mode and is applicable to DF mode without CRC.

To sum up, AF and DF have advantages and disadvantages, and it is too one-sided to think that whoever is superior is inferior. In practice, you can choose according to different priorities.

To offer a greater connection, we summarize the resource problems on relay-forward in Table 2. From this table, relay node selection and power allocation should be the two important problems in cooperative communication where we will discussed in the following section.

3.3. Transceiver diversity gain

Due to the rapid progress of communication technology, multi-antenna technology can enhance the effective signal of the receiver and obtain a large diversity gain. It is thus widely used in the field of cooperative communication. Diversity gain means dividing the same signal into multiple copies, sent at different times, at different frequencies, or space, and then merged at the receiver. The core idea of diversity is that the probability of synchronous deep fading of each signal is really low. Thus, the probability of deep fading of the synthetic signal is greatly reduced, as shown in fig. 8. This technique does not improve the average SINR of the receiver, but can stabilize the SINR.

The single-antenna cooperative communication system, as discussed above, is one in which the transmitter, relay node, and receiver all have only a single antenna. The system can only send or receive one signal at a time. Therefore, it requires the use of complex MODM techniques and large amounts of spectral resources to achieve high-quality communication over channels of arbitrary conditions (Liu et al., 2019).

In a multi-antenna cooperative communication system, the multi-antenna antenna can be distributed at any location within the source node, relay node, and destination node. That is, a system in which anyone or more nodes of the transmitter, the relay node, and the receiver have multiple antennas (Garg et al., 2013). The system can transmit or receive more signals simultaneously at one time. In contrast to single-antenna cooperative communication systems, it not only reduces the processing complexity of the receiver device, but can also effectively inhibit channel fading, increase the coverage of wireless systems, and improve spectral utilization (Rajatheva et al., 2020). The cooperative communication system model for different numbers of antennas is shown in fig. 9.

4. Key technologies in cooperative communication

Traditional relays usually utilize the depth shadow fading area to improve wireless coverage. Now, cooperative relay transmission has evolved into an advanced frontier technology. A wireless cooperative communication system is not just a simple multi-hop transmission, but can achieve ubiquitous high data rate coverage and traffic at a low cost network architecture (Correia et al., 2010), which is different from the traditional direct transmission system and needs to be solved. Specific for:

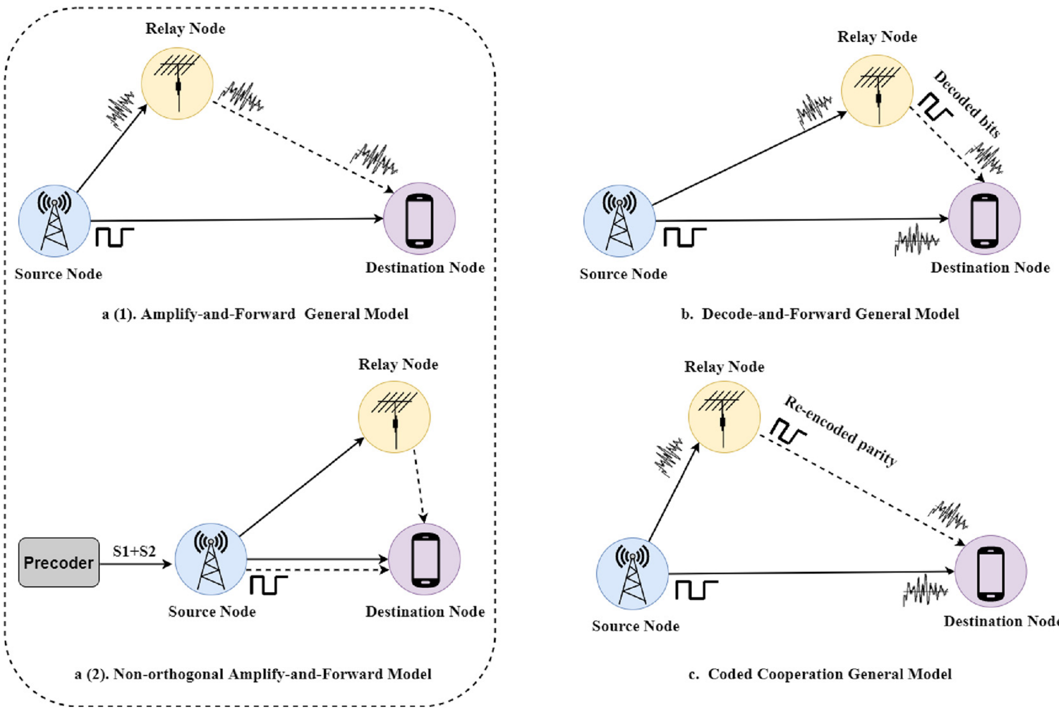


Fig. 7. The model of signal forward methods.

Table 1
Characteristics of AF and DF

	Characteristics of AF and DF	
	AF	**DF**
Signal processing mode	The relay node only needs to amplify the source node signal and forward it out. It can be regarded as a way of analog signal processing (Nguyen et al., 2019; Laneman et al., 2004)	The relay node needs to detect the accepted signal and forward it after the valuation. It can be regarded as a kind of digital signal processing (Liu et al., 2018; Laneman et al., 2004)
Complexity	Low	High
Noise	Do not transmit the noise, but easy to cause decoding error (Ali et al., 2019)	Transmit expected signal, also transmit the noise (Ali et al., 2019)
Power distribution scheme (MPSK modulation, OPA scheme)	$\begin{cases} P_s = \frac{\sigma_{s,r}+\sqrt{\sigma_{s,r}^2+8\sigma_{r,d}^2}}{3\sigma_{s,r}+\sqrt{\sigma_{s,r}^2+8\sigma_{r,d}^2}}P \\ P_r = \frac{2\sigma_{s,r}}{3\sigma_{s,r}+\sqrt{\sigma_{s,r}^2+8\sigma_{r,d}^2}}P \end{cases}.$	$\begin{cases} P_s = \frac{\sigma_{s,r}+\sqrt{\sigma_{s,r}^2+8(\frac{C^2}{D}\sigma_{r,d}^2)}}{3\sigma_{s,r}+\sqrt{\sigma_{s,r}^2+8(\frac{C^2}{D}\sigma_{r,d}^2)}}P \\ P_r = \frac{2\sigma_{s,r}}{3\sigma_{s,r}+\sqrt{\sigma_{s,r}^2+8(\frac{C^2}{D}\sigma_{r,d}^2)}}P \end{cases}.$
SER	Without the CRC, the DF performance is much lower than AF With CRC, the DF performance is slightly higher than AF (Huo et al., 2014)	
Overall	AF is used in low SNR situation, but DF is used in high SNR situation (Popovski et al., 2018)	
	$Note^* : \begin{cases} C = \frac{M-1}{2M} + \frac{\sin\frac{2\pi}{M}}{4\pi} \\ D = \frac{3(M-1)}{8M} + \frac{\sin\frac{2\pi}{M}}{4\pi} - \frac{\sin\frac{4\pi}{M}}{32\pi} \end{cases}.$	
	while $M = 2^k$. σ^2 is the channel variance (Su et al., 2005)	

Table 2
A summary of resource allocation on relay-forward.

	Scenes	Forward Method	Objectives	Methods
single-relay	2-hop single-user with antennas	**AF**	maximum SINR	power allocation
	2-hop single-user without antennas	**DF-CC hybrid**	maximum sum-rate	
multi-relay	two–hop single-user	**DF**	maximum energy efficiency	time allocation, power allocation
	two–hop multi-user		maximum sum-throughput	power allocation
			maximum sum-rate	RB allocation, power allocation
			maximum energy efficiency	cell selection, power allocation
			minimum sum-power	relay selection, power allocation
			minimum sum-power	
			maximum sum-throughput	
	multi-hop multi-user		maximum sum-rate	

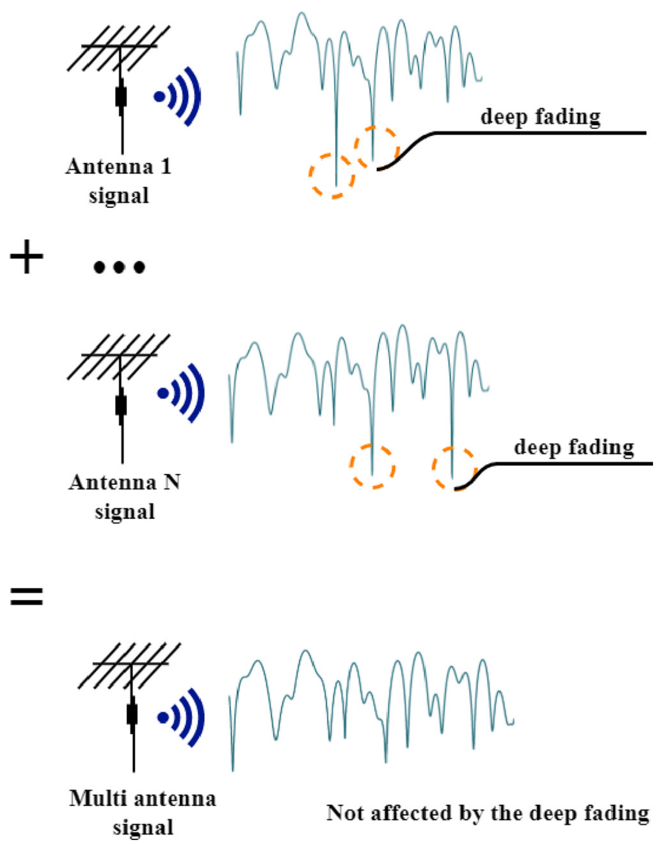


Fig. 8. Diversity Technique.

- Channel multiplexing problem. Relay nodes need to occupy channels when forwarding information, while it is unrealistic to reserve channels for relay nodes in advance. Nowadays, TDMA (Time Division Multiple Access) is mostly used in cooperative communication, which will undoubtedly reduce the utilization rate of channels. Therefore, it is particularly important to choose the right collaboration time (Spencer et al., 2004).
- Problems caused by the way the relay nodes handle. As mentioned above, AF can cause error propagation noise enhancement, and its front and rear channels are related. DF can cause error accumulation. These will make relay channels different from traditional wireless channels and increase the complexity of the analysis (Su et al., 2008).
- Mobility of the relay nodes. In the cooperative communication systems now, the relay nodes are often constantly moving, such as mobile phone users in cellular networks. Therefore, it is not reasonable to assume that the relay node is fixed and does not conform to the actual situation, while the existing literature rarely involves the situation of the relay terminal movement. Therefore, it is extremely important to choose the appropriate motion model (Tsai and Chan, 2015).
- Selection of the relay node. Relay selection is similar to the problem of collaboration timing. In a cooperative communication system, the composition of the relay set is adjusted according to certain parameters, and the most appropriate relay nodes are selected for the optimal combination to participate in the collaboration communication, which will obtain a great collaboration gain. At the same time, the mobility of the relay also aggravates the difficulty of the relay selection (Hwang and Ko, 2007).
- Power allocation issues. Cooperative communication at the beginning of the research, most of the researchers consider that the source and relay nodes, although this way is simple, but many studies show that it is obviously not optimal, can maximize the overall system performance, so it is necessary to construct an effective power distribution scheme (Wang et al., 2016).
- Combination with other technologies.

Among the key technologies in cooperative communication, relay selection and power allocation are the most concerning.

4.1. Relay selection

In the current multi-user cooperative communication system, there are multiple alternative potential collaborative relay nodes simultaneously. Relay selection or partner selection is the most appropriate choice among these users to participate in the collaborative communication process and obtain the maximum collaborative gain. In a sense, relay choice is equivalent to collaboration timing. The best scheme of relay selection should adjust the composition of the cooperative relay set according to the channel state information, and make the optimal combination (Lin and Liu, 2015), rather than participating all idle users in the cooperative communication, which will cause a huge waste of resources. Therefore, relay selection is an important issue in cooperative communication systems, which should determine which users to collaborate with, how long to redistribute the collaborative users, etc.

4.1.1. Classification according to the channel status

Relay selection can be classified based on instantaneous or statistical CSI (channel state information).

The relay selection scheme based on the instantaneous CSI needs to know the instantaneous information between users (Bletsas et al., 2006), and this instantaneous information changes in real-time, which not only requires the real-time tracking of the channel information, but also the algorithm complexity is quite high. Therefore, it is only suitable for relaying over stationary networks and is not practical.

Relay selection scheme based on statistical channel transmission characteristics can also be considered based on location information; that is, the distance between the source relay node and source relay node needs to be known. Under the coding collaboration approach, Lin et al. (2004) gave the concept of a region-user collaboration area that benefits collaborative users. With the location information of each mobile terminal and destination known, the user collaboration area determines the distance from the source node to the destination node and is a circle centered on the destination node. The user benefits from collaboration if only if the user's partner is in this circle; otherwise, the user does not transmit in collaboration mode. The scheme requires many prerequisites and is very small. The relay selection scheme based on location information requires the system to have a distance estimation structure (such as the GPS receiver installed at each terminal), which is a difficult problem to solve (Sayed et al., 2005).

4.1.2. Classification according to the presence and absence of central control nodes

According to the function of centralized control nodes, relay selection can also be divided into two kinds: centralized and distributed.

Nosratinia et al. (2004) proposes a centralized relay selection scheme based on the greedy algorithm, which is only locally optimal. Then lots of other algorithms for relay selection were proposed. But the computation quantity for the algorithms is very large.

At present, there are few distributed relay selection methods. Wang et al. (2007) gives a distributed relay selection algorithm with game theory. Moreover, the difficulty of distribution lies in

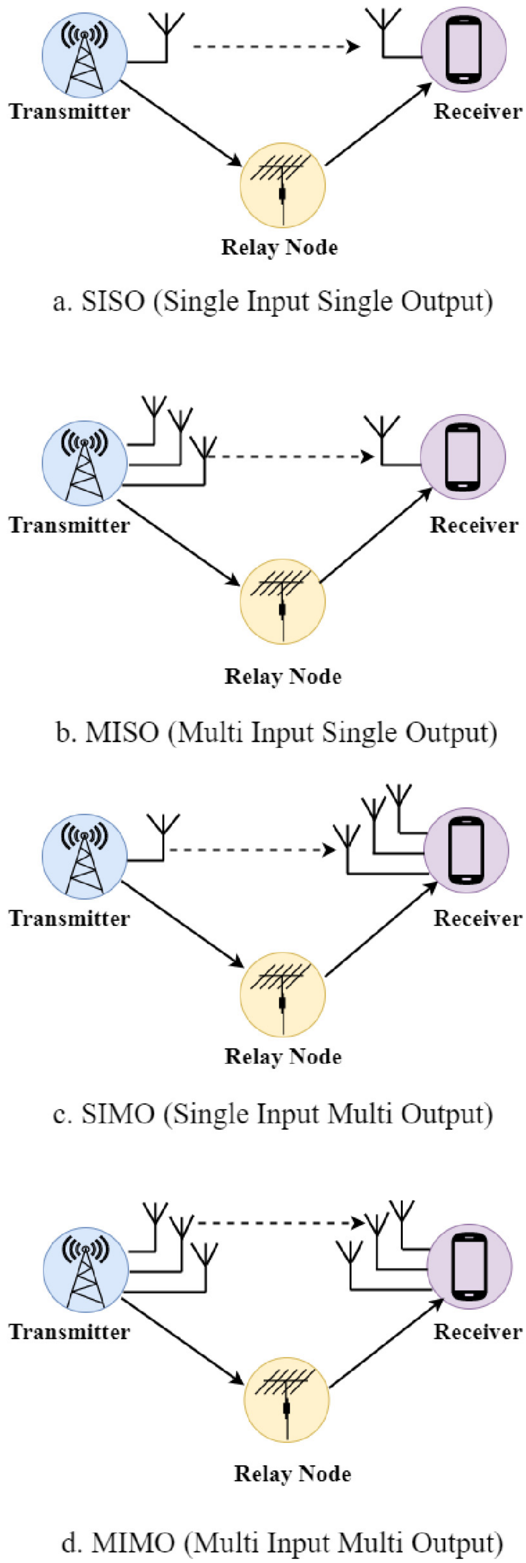


Fig. 9. Single and multi antenna cooperative communication system model.

how to ensure the fairness of all users without adding additional system resources.

It should be pointed out that DF mode has natural advantages in relay selection. For example, CRC can be added to the information of the source node, and only the potential relay that can correctly demodulate can forward the information as the partner of the source node. This solution has a small complexity and can achieve very good performance (Kwon et al., 2010).

4.2. Power allocation

Power control acts a really important role in the resource management of wireless communication system. For the white interference system, this problem is more important. Its goal is to provide acceptable level of service quality for each user while reducing its interference to other users (Hossain et al., 2014).

4.2.1. Classification according to the objective function

According to the different objective functions, the power allocation scheme in the cooperative communication system can be divided into two categories to improve the reliability or effectiveness.

Most power allocation schemes with the purpose of improving reliability choose outage probability or SER as the target function, and their algorithms are completely similar and generate similar conclusions. For example, in the AF way, this power allocation scheme is only related to the relevant channel transmission characteristics of the relay node, but not to the node channel of the source, which shows that no matter what the channel situation of the direct transmission link is, the relay node is always involved in the cooperative communication process and does not involve the problem of collaborative timing. If the rate is compared with SER performance, the former analyzes the problem from the point of view of information theory. Although it has a certain guiding significance, it cannot accurately measure the coding modulation performance in the actual communication system. From this point of view, the power distribution scheme based on SER performance is superior.

Most power allocation schemes choose the maximum average mutual information and traversal capacity as the objective function. Unlike the reliability-based power allocation scheme, which involves the problem of cooperative timing, the relay nodes participate in the cooperative communication process if and only if certain conditions are met. This processing method can significantly improve the data transmission rate of collaborative communication in half-duplex mode, and it also contributes to improved reliability.

In conclusion, power distribution schemes aimed at improving effectiveness are superior to those aimed at improving reliability (Du and Zhang, 2018).

4.2.2. Classification according to the channel state information

According to the different channel transmission characteristics, the power allocation scheme in the cooperative communication system can be divided into two categories based on the transient or statistical channel transmission characteristics.

The objective function of the power allocation scheme based on the instantaneous CSI can be selected as the maximum average mutual information, the instantaneous receiving SINR, etc. Through the channel estimation algorithm and the independent feedback channel, the source and relay nodes could obtain the channel information of the first and second jumps in each transmission time slot, such as path loss and fading factors. In this way, the system will fully understand the channel state and can adjust the transmission power of the source nodes and the relay nodes at each signal transmission time slot, so that the system is always in the optimal state (Cai et al., 2008). It can be seen that the scheme based on the instantaneous CSI will have the best system performance, along with the highest system complexity.

The objective function of the power allocation scheme based on statistical CSI can be selected as traversal capacity, the average received SNR, outage probability, SER performance, etc. Because the instantaneous CSI is difficult to obtain in real-time in actual communication, the channel information in a time period can be statistically analyzed to obtain the statistical characteristics of the channel, such as the mean and variance of channel fading, and the statistical information of the channel as the parameter of resource allocation, so that the channel has the best performance in the average sense. This scheme is easier to implement because the complexity of the algorithm and channel estimation is much lower than that based on the instantaneous CSI, and its system performance is not based on the instantaneous CSI, so there is little difference between them.

In conclusion, considering both the system performance and the algorithm complexity, the power distribution scheme based on statistical channel state information (CSI) is better than that based on instantaneous channel state information (Wang et al., 2017).

4.2.3. Classification according to the presence and absence of central control nodes

According to the function of central control nodes in the network, the power allocation scheme in the cooperative communication system could be separated into centralized and distributed types (Youssef et al., 2019).

The centralized power allocation scheme is only applicable to networks with central control nodes, such as a cellular network that calculates the power allocation factor and then notifies the source node and the relay node using the feedback channel. The scheme will get the optimal solution for the system's performance, but it will undoubtedly increase the burden of the central control nodes and easily cause the vulnerability of the network (Wang et al., 2008). Therefore, it is only applicable for theoretical analysis, and it can also provide theoretical guidance for the distributed power allocation strategy. Most of the power allocation in the existing cooperative communication is centralized.

The distributed power allocation strategy is flexible and equally suitable whether there is a central control node in the network. However, at this time, the power allocation factor is no longer calculated by the central control node, but by the source node and each relay node itself, which requires far less information than the centralized scheme, but also, because of this, its algorithm time is longer than the centralized node. A distributed scheme is more suitable for practical communication situations, but the research on collaborative communication is only in its infancy. Wang et al. (2008) gives a distributed scheme using the game theory that gives us good inspiration. Now, more deep learning is being used here.

Most centralized power allocation schemes, as the optimal theoretical analysis, can guide distributed schemes and are not suitable for practical communication systems. However, distributed schemes are in their infancy, and efforts should be made to construct more ideal algorithms.

4.2.4. According to the number of relays

Depending on the quantity of relays in cooperative communication network, it can be divided into a power distribution scheme based on a system with a single relay and a system with multiple relays (Huang et al., 2008). The two schemes are essentially identical, but the latter has a much higher level of complexity than the former. In the early days of the study, most were limited to systems with only a single relay. At present, power distribution schemes in systems with multiple relays are mostly based on point-to-point communication between source and relay nodes and lack a multi-user network, which is still an unsolved problem.

5. A 5G mobile communication network model based on relay cooperation

Introducing cooperative communication in the 5G mobile communication network will further improve the overall performance of the system and meet the communication needs of 5G application scenarios. Key technologies in 5G networks include spectrum sharing, new multi-antenna transmission, NOMA (non-orthogonal multiple access), ultra-dense networks, and D2D (device-to-device) (Jijo et al., 2021), etc. The combination of relay cooperative technologies and key 5G technologies will be detailed below.

5.1. Spectrum sharing

As demand for the wireless communications business grows, the available spectrum becomes extremely scarce. However, many of the already assigned spectra are used only for specific regions or specific time slots, and this allocation policy creates a substantial waste of spectral resources. The very low spectrum utilization rate seriously restricts the development of the communication industry. In order to improve this situation and achieve super-reliable communication at any time and place, people use advanced communication technology and theory to try to realize the sharing of non-renewable spectral resources, and cognitive radio (CR) technology arises at this historic moment.

A simple principle diagram is given in fig. 10. The up-link band uses the reserved blank RE (Resource Element) resources and samples environmental signals to identify the interference signals in the up-link band, block the disturbing spectrum in the up-link communication with the terminal, and make full use of the RB (Resource Block) resources of the undisturbed spectrum. In the presence of down-link interference, the base station receives channel quality feedback from the terminal and no longer uses seriously interfered sub-bands. In the remaining sub-bands, using a flexible scheduling strategy, in the terminal communication quality, in the terminal number, guarantees the overall system capacity. In the presence of down-link interference, the spectrum can be maximized.

The access to massive equipment in 5G mobile communication requires sufficient spectrum resources, and the fixed spectrum allocation can no longer meet the spectrum demand in reality. The CR can adjust the spectral dynamic allocation of the unused transmission coefficient according to the needs of different multimedia devices. Secondly, in the traditional understanding of radio networks, sub-users cannot simultaneously sense and transmit information, which limits the throughput of sub-user networks. With the improvement of self-interference suppression technology, cognitive radio networks are based on co-frequency co-time full duplex to improve the system throughput. Thus, spectrum sharing is an important means to meet 5G development, while CR is the core technology of spectrum sharing. Typical models of cognitive systems based on relay cooperation (Hu et al., 2018) are shown in fig. 11.

5.2. New multi-antenna transmission

The finiteness of spectral resources and the increase in data rate requirements make improving spectral efficiency the most important problem. The new multi-antenna technology transmits rates on the same spectrum through multiple antennas, which greatly improves the spectral efficiency. It is noted in the (Telatar, 1999) that the effects of fast fading in channels can be effectively eliminated when the number of transmitter antennas in MIMO is sufficient. Recently, massive MIMO becomes one of the most important techniques in new multi-antenna transmission.

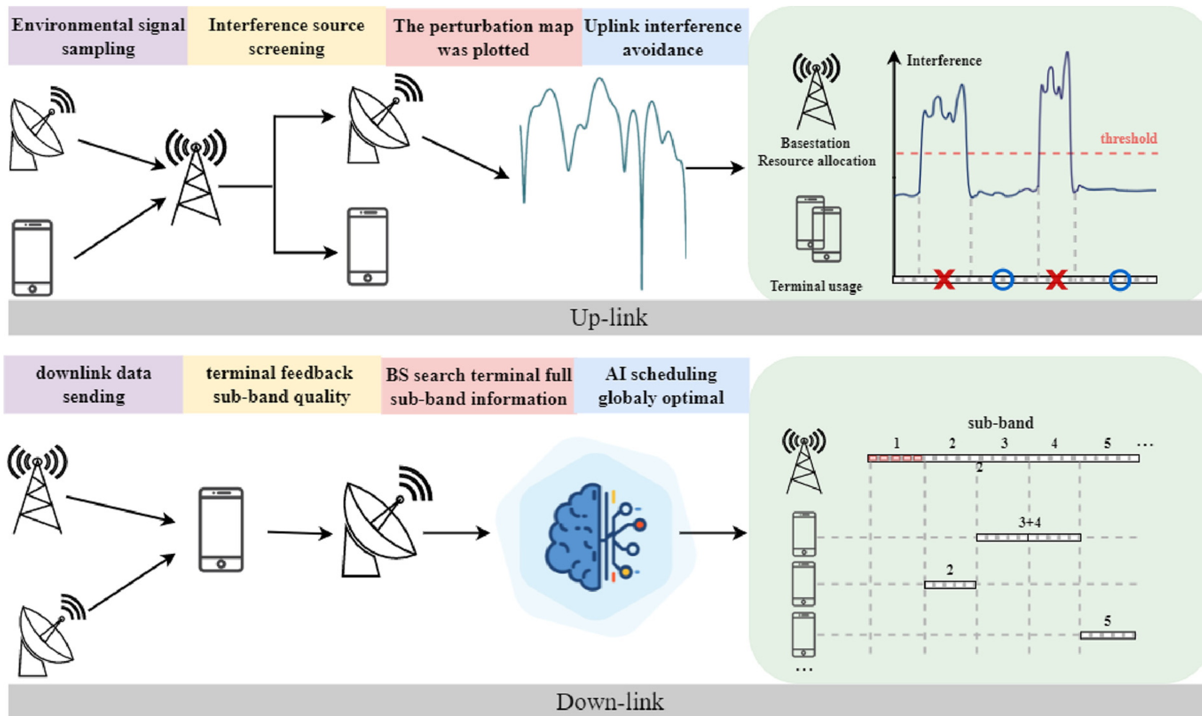


Fig. 10. Example of principle of application of cognitive radio.

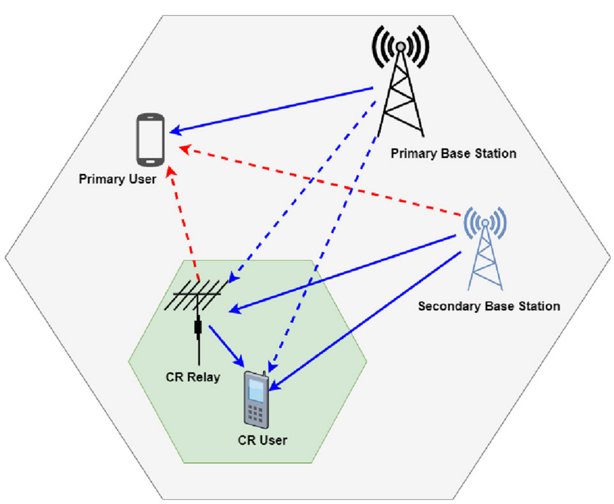


Fig. 11. Cognitive relay system.

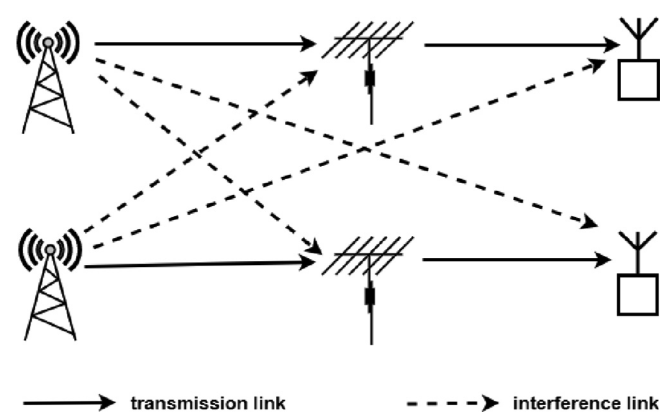


Fig. 12. Massive MIMO relay system.

Even with many advantages, there are still problems for massive MIMO that need to be solved. For massive MIMO, the improvement in system capacity is limited by the interference from same frequency band users in other cells. That is, pilot pollution. And relay cooperative technology can effectively eliminate the pilot pollution caused by massive antennas. He and Gitlin (2016) demonstrates that collaboration between adjacent cells in massive MIMO networks will substantially improve the performance of cell edge users, while (Sharma et al., 2018) indicates that massive MIMO can effectively eliminate loop interference problems in full-duplex relay systems.

Therefore, the combination of relay collaboration with massive MIMO will greatly improve the system's performance. And the massive MIMO model based on relay cooperation is shown in fig. 12.

5.3. NOMA

In the orthogonal frequency division multiplexing access (OFDMA) technology used in 4G technology, an orthogonal resource allows access to only one user, greatly limiting the system capacity and spectrum utilization (Quality, 2017). At this point, non-orthogonal multiple access (NOMA) technology introduces new dimensions. In this technique, the transmitter performs non-orthogonal superposition transmission, actively introduces interference information, and the receiver achieves correct demodulation through SIC technology. NOMA technology achieves higher spectral efficiency by increasing receiver complexity. Therefore, NOMA is considered the most viable access technology for 5G mobile communication.

We give a comparison between NOMA and OFDMA as fig. 13 and Table 3. In the traditional OFDMA case, different user signals are transmitted with different frequency resources. In contrast to

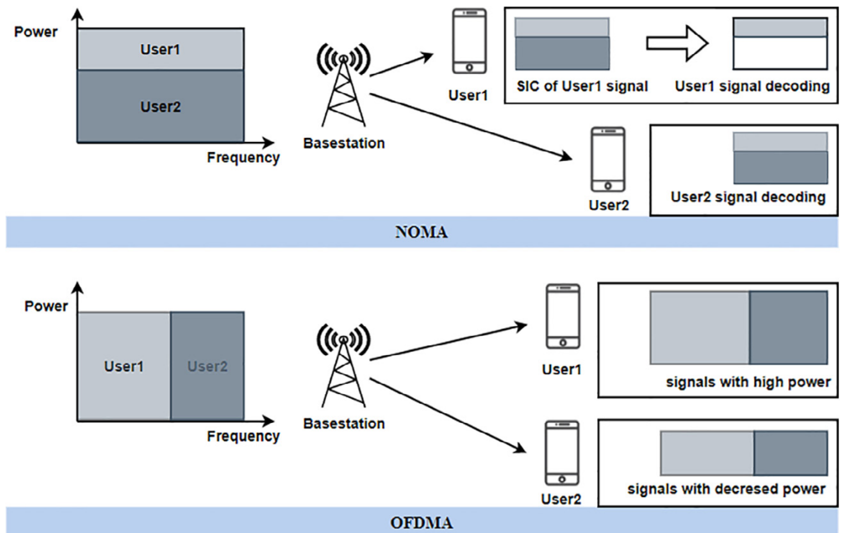
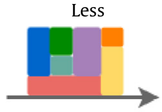
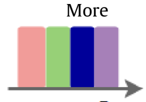


Fig. 13. NOMA v.s OFDMA.

Table 3
Comparison between NOMA and OFDMA.

	NOMA	OFDMA
Technique	Non-Orthogonal Multiple Access	Orthogonal Frequency Division Multiple Access
Adaptive Technology	AMC + Power Allocation	AMC
Spectrum Efficiency	High	Low
Capacity	Less	More
Frequency Spectrum		

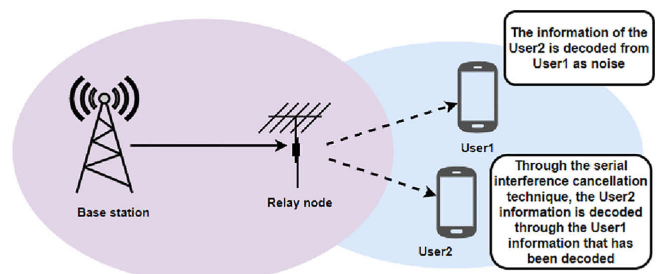


Fig. 14. Cooperative NOMA model.

OFDMA, in the case of NOMA, different user signals are transmitted at the same frequency and at different power levels, which depends on the location of the user within the coverage of the cell. Compared with OFDMA, the performance gain of NOMA raises when the disparity in channel gain and the path loss between users becomes large. On the basis of this simple 2-user case, NOMA offers a better sum rate compared with OFDMA. Actually, the cell-center UE gains according to the rate because this user's bandwidth is limited. So it can benefit more from being able to use two times the bandwidth, but it costs much lower transmit power. At the same time, the cell-edge user also gains at a rate due to the fact that it is limited by power. Under NOMA, its transmit power is only reduced a bit while its transmit bandwidth is doubles.

And combining the above mentioned massive MIMO technology with NOMA will improve spectral efficiency (Huang et al., 2018).

However, the practical application of NOMA also faces some difficult problems, such as the high system complexity, the mismatch of power distribution algorithms, and the compatibility of massive MIMO and NOMA technologies (Akbar et al., 2021). It is also important that when allocating resources, most research is currently limited to strong users in allocating less resources as (Riaz et al., 2020) mentioned. How to let the stronger user allocates maximum power while weak user allocates the minimum power is a very urgent need to be addressed.

Unlike other access methods, a very critical characteristic of NOMA is that the user who has good channel quality also has redundant copies of other users. The redundancy technique is applied in cooperative NOMA for increasing transmission reliability and transmission rate. Specifically, users with good channel status act as relays and forward user information with poor channel quality to enhance the reception reliability of users with poor channels (Islam et al., 2016). However, users with good channel quality require the ability to retrieve their data without any other assistance. The NOMA model based on relay cooperation is shown in fig. 14.

5.4. Ultra-dense networks

5G communication network or the future communication network will always evolve towards the direction of diversification, broadband, comprehensive and intelligent intelligence. With the popularity of various terminal equipment, the data flow will show a blowout growth, and while the flow demand is very large, the low power consumption is also very important. Different from the traditional base station deployment strategies, the ultra-dense networks will adopt a scheme of reducing the cell radius and increasing the number of nodes to meet the traffic requirements (Yu et al., 2016). Its advantage is that there are more opportunities for collaboration between adjacent networks, and the system will gain more cooperatively. At the same time, the application of ultra-dense networks is accompanied by corresponding challenges. The dense deployment of irregular cell areas makes the network topology more complex, and the interference between the communities is also more complex. The management of mobility also causes the problem of complex frequency switching due to

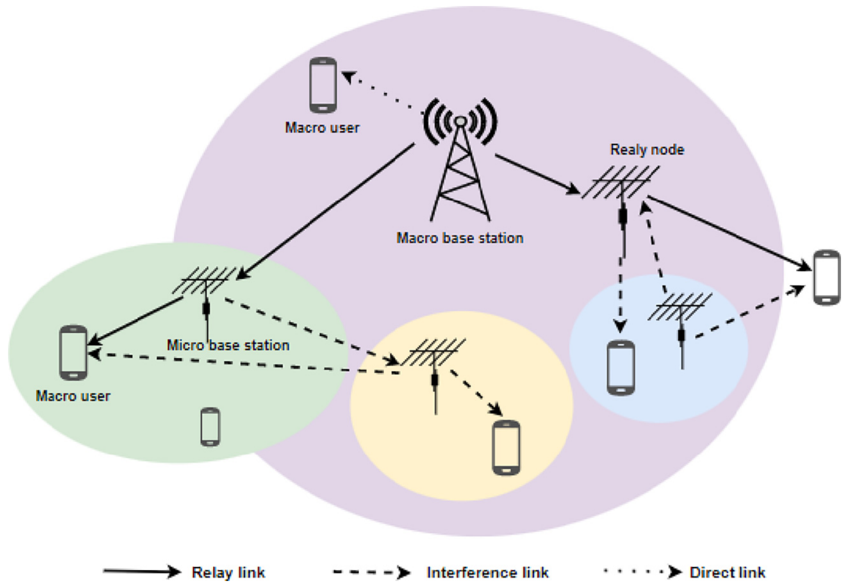


Fig. 15. The model of Ud-HetNet based on Relay cooperation.

the reduction of the cell coverage area (Alsharif and Nordin, 2017). Chang et al. (2017) introduces small cellular networks in heterogeneous networks for relay cooperation to further increase the system capacity, however this cooperation is limited by interference between adjacent cells and the switching in cells. To address the above problems, Chen and Zhao (2017) proposes that relay cooperation between base stations to reduce the switching rate. The ultra-dense heterogeneous network based on relay cooperation is shown in fig. 15.

5.5. Device to Device (D2D)

Unlike conventional cellular communication, the D2D technology can directly realize communication between the short-distance device terminals without the help of a base station (Hussein et al., 2020). The rapid development of a large number of terminal equipment and the Internet of Things makes the communication center equipment unable to carry them. The application of D2D technology can not only reduce the burden of base stations and improve the spectral utilization rate, but also has the advantages of high reliability, high data rate, low delay, low power consumption, and other advantages (Ahad et al., 2019). However, due to the dynamics of the wireless transmission link, it is difficult to guarantee the reliability of the D2D direct transmission link (Tullberg et al., 2016). Therefore, we introduce the relay nodes into the D2D technology to reduce the network interruption probability. The model as fig. 16 shows, is the cooperative D2D system.

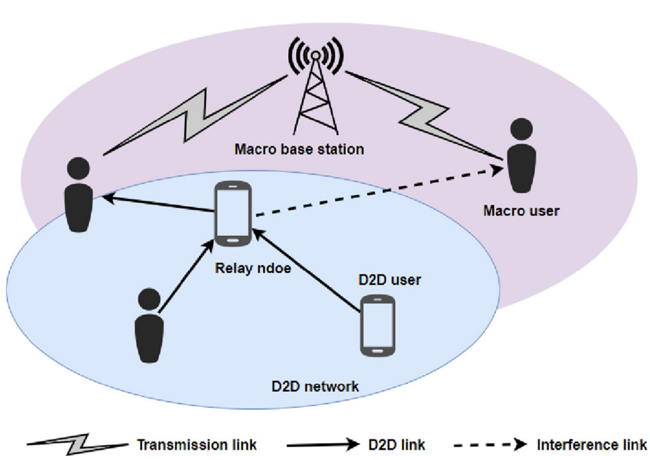


Fig. 16. Cooperative D2D system.

5.6. Co-frequency co-time full duplex

Co-frequency co-time full duplex technology is that both sides of the communication receive and send messages simultaneously on the same spectrum (Gazestani et al., 2019). Using this technique can theoretically double the utilization of the spectrum and make the utilization of the spectral resources more flexible. The system model is shown in fig. 17. In terms of implementation, the biggest obstacle is its self-interference (SI) problem (Li et al., 2017). The

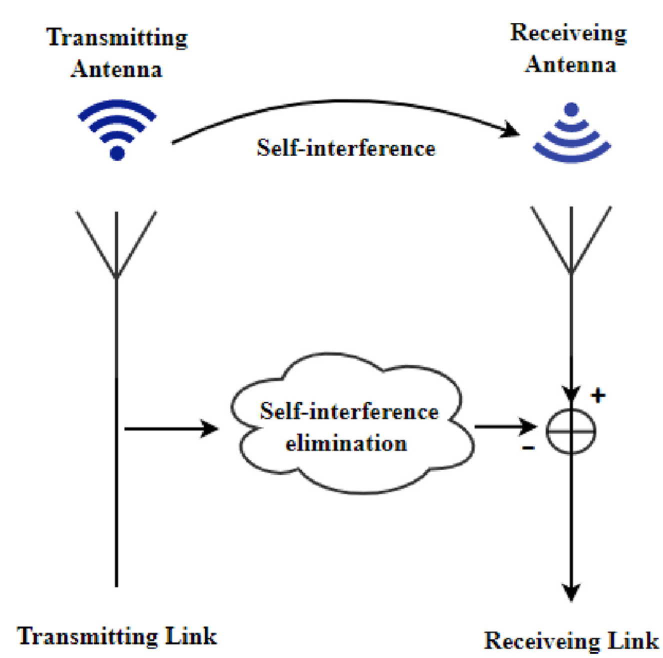


Fig. 17. Wireless co-frequency co-time full duplex system.

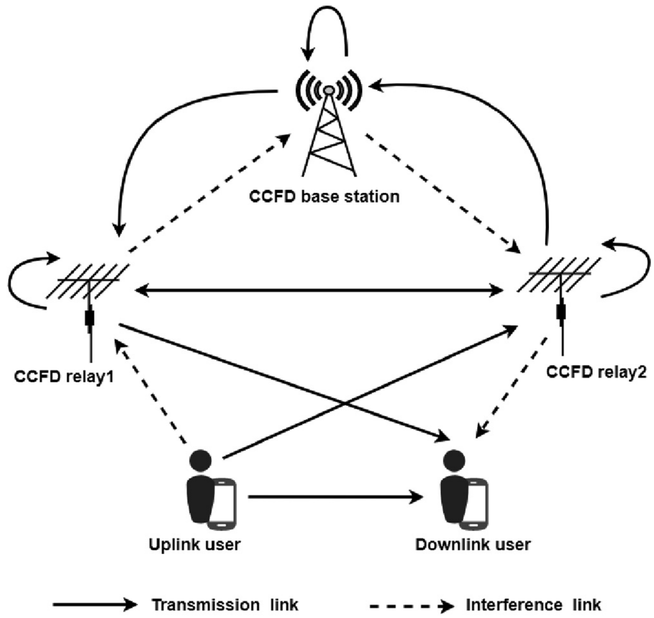


Fig. 18. Cooperative co-frequency co-time full duplex system.

signals transmitted by the proximal transmitter will cause serious interference to the signals received by the proximal receiver.

In 5G mobile communication networks, relay nodes often adopt the co-frequency co-time full duplex forwarding, but there will be loop interference problems in the full duplex system (Gazestani et al., 2019) as fig. 17 shows. Therefore, the application of this technology needs to further solve the above mentioned problem. Its network model is shown in fig. 18.

5.7. Millimeter-wave

5G deployment faces a major challenge: when providing the best sub performance required for many high-level applications and concurrent users, the available Sub-6 GHz spectrum cannot guarantee the required latency and throughput. Fortunately, millimeter-wave (mmWave) technology can solve this problem. It is an electromagnetic wave somewhere between radio and light. The ultra-fast mmWave provides the desired 5G or B5G, with a high working frequency range of 24 to 40 GHz. With transmission rates of up to 5Gbps, a full HD movie can be downloaded in seconds. Although mmWave 5G networks are extremely fast, the range, signal propagation, and LOS (Line-of-Sight) limitations are mmWave's drawbacks. But many techniques such as massive MIMO (multiple-input multiple-output), miniaturized antenna arrays, adaptable beamforming, and smart active repeaters can effectively address these challenges, especially smart active repeaters. As fig. 19 shows, this technique can solve 5G signal propagation challenges by amplifying mmWave signals and extending the range and coverage of mmWave-based networks in indoor and outdoor environment. Active repeaters work by boosting mmWave signals, enabling them to penetrate walls and other blockers and bend around buildings to overcome LOS issues without the need for bulky antenna designs or costly fiber backhaul. When deployed inside a building, a smart repeater amplifies a weak beamed signal and can light up an entire room, improving end user and application connectivity experiences.

5.8. Intelligent Reflecting Surfaces

The intelligent reflecting surface (IRS) considered as a cost-effective technology has attracted much attention in recent research (Renzo M D et al., 2019). An IRS consists of an array of intelligent reflection units, each of which can make certain changes to the incident signal independently as fig. 20 shows. Generally include: phase, amplitude, frequency, and even polarization. So far, numerous studies have shown that only needles consider the phase shift of the incident signal (Basar et al., 2019), so that IRSs do not consume the transmission power. Essentially, when direct channels are of poor quality, the IRS is able to intelligently configure a wireless environment to help the transmitter and receiver transmit messages. Besides, IRS can be easily mounted on walls, building walls, and ceilings (Okogbaa et al., 2022). So IRS is widely acknowledged as a low-cost and high-efficient solution for future

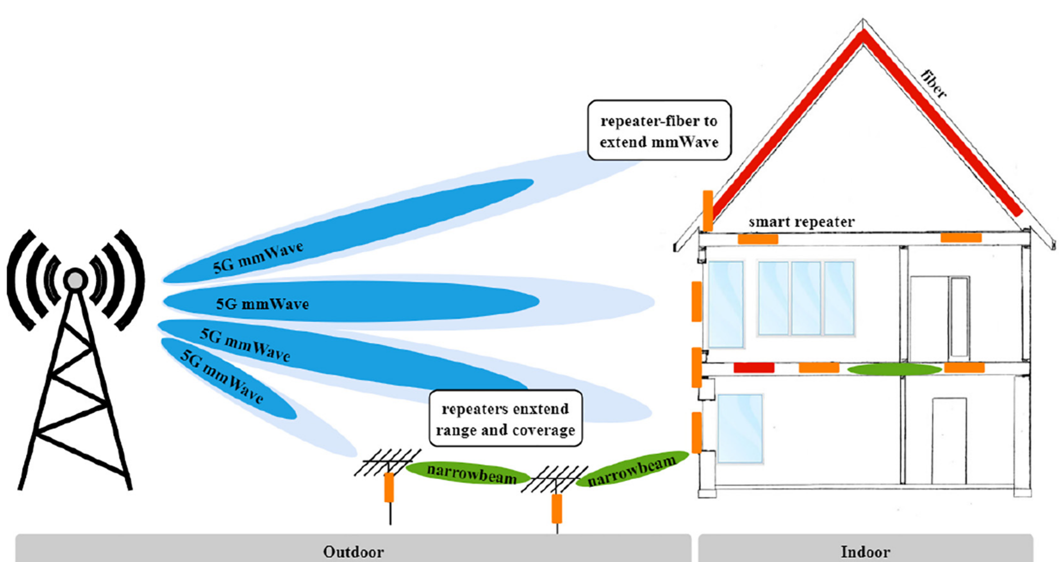


Fig. 19. mmWave networks: indoor and outdoor.

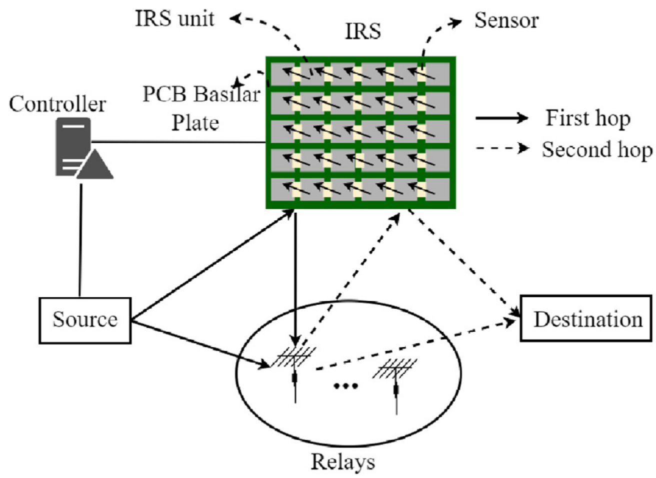


Fig. 20. Cooperative IRS network.

wireless networks. The introduction of IRS can be perfectly combined with other technologies, such as:

1. IRS Channel Estimation: The access point (AP) has perfect channel state information (CSI). The AP receives a pilot signal transmit by user and reflected by IRS. The IRS channel estimation using this method assumes a simple cell-by-cell ON/ OFF-based reflection pattern.
2. IRS Beam Management: In order to solve the occlusion problem of millimeter-wave network, IRS is proposed as a promising green communication technology, which can actively adjust the propagation direction of the incident signal without greatly increasing energy consumption.
3. IRS-aid NOMA: As one of the key technologies of B5G/6G, NOMA is to align the channel vector direction of the near and far users, which can control the channel vector direction through the use of IRS.
4. IRS-aid Physical Layer Security: Physical layer security enables high-quality security performance without the actual allocation of keys, and IRS has potential advantages in enhancing physical layer security in communication links.

5.9. Relay-assisted Handover

Handover (HO) is the mechanism that transfer an ongoing call from one cell to another as a user moves through the coverage area of a cellular system. It is a key element in wireless network to provide continuous connections and user perceived QoS. And Relay Station (RS) is widely used in wireless communication systems for increasing capacity, expanding signal coverage and enhancing weak filed zone. With the introduction of RS in cellular networks, more handover scenarios appears. Fig. 21–25 shows 5 scenarios (Intracell RS-RS Handover, Intracell BS-RS Handover, Intercell RS-BS Handover, Intercell BS-BS Hanover and Intercell BS-RS Handover) under relay-assisted handover. And we also take intercell RS-RS handover to illustrate resource allocation in case

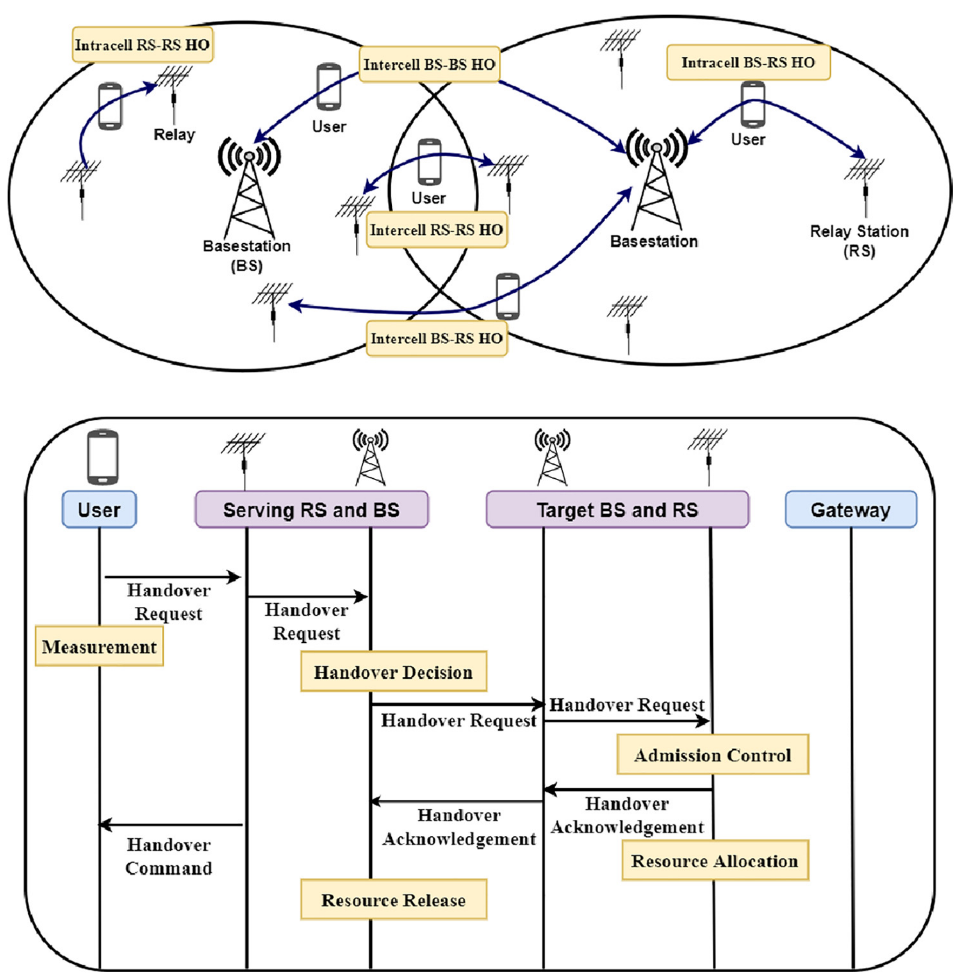


Fig. 21. Relay-assisted handover scenarios and procedure.

Fig. 22. Resource allocation algorithm in 5G.

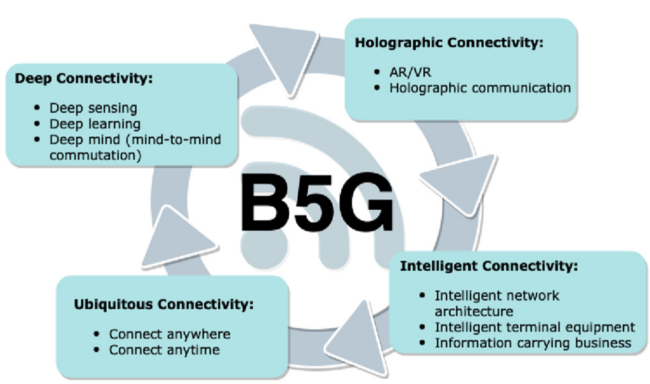


Fig. 23. 5G Beyond Vision.

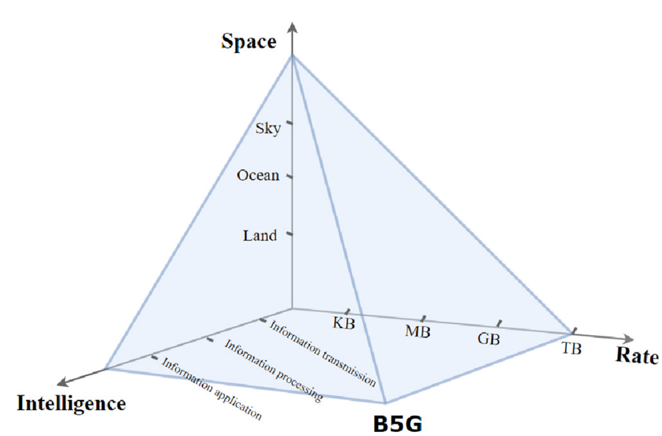


Fig. 24. 5G Beyond Trend Chart.

of handover. In terms of the current complex network environment, the traditional handover management technology based on the user and the network perspective can no longer meet the needs of different types of users. At present, we need to consider not only from the perspective of spectrum resources, but also to consider the influence of channel fading, interference change and other factors on resource allocation and adjustment.

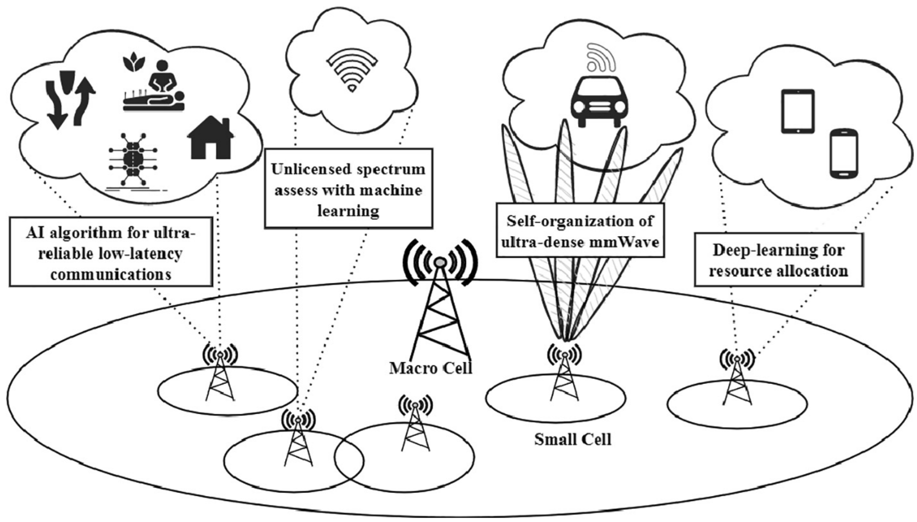


Fig. 25. AI-based B5G Networks.

Table 4
5G Network models and resource allocation based on relay.

Network model	Advantages	Disadvantages	User scenario/Transmission mode	
Relay model based on CR	Spectrum efficiency is improved	Complex power distribution and complex interference management	Single-relay (Sharma et al., 2018; Li et al., 2010; Lan et al., 2013; Li et al., 2016; Mallick et al., 2014; Li and Zhao, 2018)	Multi-relay (Liu et al., 2014; Al-Eryani et al., 2016; Li et al., 2013; Tan et al., 2018; Radi et al., 2018)
Relay model based on Massive MIMO	Improve the system throughput and suppress the interference	Pilot pollution limits system performance and channel modeling	Uplink (Kang et al., 2013)	Downlink (Chen et al., 2015; Kang et al., 2013)
Relay model based on NOMA	Improve spectrual efficiency, independent of CSI	Require additional time slots assignment	Single-relay (Zhang et al., 2017; Sun et al., 2017; Duan et al., 2018; Xu et al., 2018	Multi-relay Wu et al., 2018; Zhao et al., 2018)
Relay model based on UDN	Improve system throughput	Channel conditions become ectremely comlex and need interference coordination	Single-relay (Yang et al., 2016; Ateya et al., 2018)	Multi-relay (Chang et al., 2017; Nguyen et al., 2017)
Relay model based on D2D/V2V	Reduce the network burden and power consumption	Communication distance is limited and interference with other channels	D2D (Gao et al., 2016; Ansari et al., 2016; Chen et al., 2018	V2V Li et al., 2018; Ge et al., 2016; Luo et al., 2014)

6. Cooperative communication network resource allocation model

In a cooperative communication network, different resource allocation schemes lead to different system performances. In order to better optimize the system performance, relay selection, resource allocation, and cooperative diversity signal design in the relay cooperative network have always been the hot research topics (Xu et al., 2018; Teng et al., 2018; Van Nguyen et al., 2018). This section mainly discusses the power distribution and relay selection of co operation networks in 5G communication.

Nowadays, mobile application terminals are widely popular, and due to the concept of green communication (Gandotra et al., 2017), it is very necessary to improve energy efficiency. Optimizing the power distribution of mobile terminals is an important means to improving energy efficiency. In practical studies, there may be multiple alternative relay nodes simultaneously in cooperative communication. The purpose of relay selection is to select the most appropriate of these relay nodes to participate in cooperation (Su et al., 2019). Reasonable selection of relay nodes can not only expand the network coverage, but also effectively improve the system capacity, improve the service quality of users, and achieve the purpose of power-saving (Yan, 2019). We summarize the resource allocation problems based on relay networks under different scenarios and models for different optimization objectives as Table 4 and Table 5 show.

7. 5G Cooperative communication network resource allocation algorithm

As shown in Fig. 19, this paper summarizes the resource allocation algorithm from certain and uncertain channel states based on different system models.

7.1. The resource allocation algorithm based on certain channel state

7.1.1. The resource allocation algorithm based on cognitive relay network

Cooperative communication technology is introduced into cognitive wireless networks, and cognitive users (CR user or sub-user) share frequency bands with the primary users, so as to improve spectrum utilization (Tragos et al., 2013). At the same time, however, the interference between the primary users and CR users makes the power distribution problem of cooperative cognitive relay networks more complex than the traditional relay networks. Li et al. (2010) proposed a resource allocation scheme that jointly considers relay selection and power allocation under the primary

Table 5
5G Network models and resource allocation based on relay (continue).

	Optimization objectives			
	Energy Efficiency	**Power & Rate**	**throughput**	**Probability of interruption**
Relay model based on CR	(Sharma et al., 2018; Chen et al., 2015; Tan et al., 2018)	(Ubaidulla et al., 2013; Al-Eryani et al., 2016; Li et al., 2013; Lan et al., 2013)	(Li et al., 2010; Liu et al., 2014; Ubaidulla et al., 2013; Mallick et al., 2014; Radi et al., 2018; Li et al., 2016)	(Li et al., 2016; Radi et al., 2018)
Relay model based on Massive MIMO	(Sharma et al., 2018; Liu et al., 2017)	(Kang et al., 2013; Tan et al., 2018)	(Zhang et al., 2016)	-
Relay model based on NOMA	(Nomikos et al., 2017)	(Zhang et al., 2017; Mohammadi et al., 2017; Duan et al., 2018)	(Sun et al., 2017; Wu et al., 2018)	(Xu et al., 2018; Zhao et al., 2018)
Relay model based on UDN	(Yang et al., 2016)	(Hung et al., 2017; Ateya et al., 2018; Chang et al., 2017)	(Chang et al., 2017; Nguyen et al., 2017)	(Chang et al., 2017)
Relay model based on D2D/ V2V	(Li et al., 2018)	(Luo et al., 2014; Sakran et al., 2012; Radi et al., 2018; Ubaidulla et al., 2013)	(Gao et al., 2016; Han et al., 2017; Hasan et al., 2014)	(Gao et al., 2016)

user interference power. The proposed scheme has a low complexity while maximizing the throughput. Liu et al. (2014) A proposed convex optimization theory and Karush-Kuhn-Tucher (KKT) condition are used to obtain the optimal power allocation and maximize system throughput under the primary user interference and sub-user total power limits for cognitive multi-relay network systems. Al-Eryani et al. (2016) proposed power distribution scheme for the lower cushion two–hop MIMO cognitive relay network uses the DF forward strategy and takes the interference threshold of a primary user network as a constraint. The scheme maximizes the total rate in each time division.

For the relay selection problem, Ubaidulla and Aissa (2012) proposed a joint relay selection and power allocation scheme that can maximize throughput under the transmission power and primary user interference constraints based on the maximum transmission rate. Simulation results show that the proposed scheme yields more than random relay selection schemes under equal power distribution. For the network model of multi-transceiver relay nodes, Li et al. (2013) jointly consider the relay selection problem and the channel distribution problem, aiming to maximize the transmission rate between the source node and destination node, and proposed a relay selection algorithm that can obtain high spectral efficiency. This calculation also applies to the decoding and forwarding protocol network. For the network model of single transceiver multi-relay nodes, jointly considering the interference of the sub-transmitter to the primary user, Lan et al. (2013) proposed a relay selection scheme that can improve the transmission rate of the primary user while meeting the two–hop DF network.

For the two–hop AF model, Jing et al. (2014) proposed an instantaneous and expected gain-based optimal stopping strategy is based on improving the overall system performance to assist in relay selection. The simulation results indicate that in the article, the proposed strategy could meet different system requirements by adjusting the corresponding system parameters. To improve energy efficiency so that relay selection and power distribution are simultaneously optimized under the requirement of quality of service, a relay selection strategy based on a greedy algorithm is presented in Chen et al. (2015).

7.1.2. The resource allocation algorithm based on Massive MIMO

Kang et al. (2013) considered the cooperative transmission between downlink base stations in a large-scale MIMO network and adopted a simple ZF (zero-forcing) beam transmitter, which proposes two power distribution schemes to minimize the total transmission power under the limitation of the total power of the single base station and the minimum transmission SINR (signal to interference plus noise ratio) threshold. Yang et al. (2018) considered that both relay and base stations have large MIMO, considering both uplink and downlink transmission links. The paper found that the emission power of nodes can be reduced by antenna number factor without weakening the system performance. With lower bounds of the ergodic spectral efficiency of links in the closed form of uplink and downlinks obtained, a power distribution scheme is presented for maximizing the spectral efficiency of the system. Compared with the above literature, Tan et al. (2018) considering the AF multi-hop relay large-scale MIMO system, proposes the resource allocation optimization algorithm aiming at maximizing the system energy efficiency, and adopts the dual overlapping method to solve the non-convex optimization problem. Considering the same network model, Sharma et al. (2018) employs co-frequency co-time full-duplex techniques at relay nodes to maximize energy efficiency by approximating the optimization problem as a pseudo-concave problem, and then solved using the classical Dinkelbach method.The full-duplex system performance improved significantly compared to the half-duplex system.

In view of the relay selection problem, Silva et al. (2017) considers the cognitive large-scale MIMO relay network, in which both the primary and sub-users have a large-scale antenna matrix, and ZF for reception and transmission, and the optimal power distribution strategy is proposed under the constraint of the primary user's interference threshold. Since, when using large-scale MIMO, the SINR and rate will be only dependent on the channel path loss coefficients and the average noise level. Therefore, relay selection can select the relay nodes with the largest rate during the deployment stage, and in most cases, the optimal relay is the relay node with the largest number of antennas.

7.1.3. The resource allocation algorithm based on NOMA relay network

For the single cellular NOMA network, Zhang et al. (2017) considered the single relay, source–destination nodes pairing model with AF, proposed the optimal carrier distribution and power distribution scheme, uses the exhaustive search to transform it into a non-deterministic polynomial problem, and uses the water injection algorithm to maximize the power utilization efficiency for the power distribution. Considering the full-duplex NOMA cognitive relay network, Mohammadi et al. (2017) proposed a resource allocation scheme for joint relay beamforming and relay power allocation to maximize the near-and-far user rate to expand the user rate region. Unlike the above model, Sun et al. (2017) sub-user base station acts as relay nodes to assist the primary user in transmission. A power and sub-carrier distribution scheme of joint master and sub-user networks is proposed to maximize the system throughput. Duan et al. (2018) considered NOMA-based cooperative communication systems and proposed a two-stage overlying transmission scheme whose transport rates and total traversal rates have significant advantages over time division and multiple access and traditional NOMA schemes. Considering the multi-relay NOMA cooperative communication system, Wu et al. (2018) proposed the optimal power distribution algorithm, adopts the vertical decomposition and proposed the hierarchical algorithm to effectively solve the optimal power distribution problem.The proposed algorithm can effectively increase the throughput of the system relative to the traditional cooperative communication system.

For the relay selection problem, Xu et al. (2018) considered the NOMA relay network and proposed two relay selection algorithms, maximum-minimizing two-level weighted and maximum weighted harmonic means, respectively, to minimize the outage probability of the system. Considering the same model, Zhao et al. (2018) proposed two single relay options, one considering fixed power and another dynamic power distribution, giving the system with lower outage probability and complete diversity gain without sacrificing spectral efficiency. For multi-relay NOMA networks, Nomikos et al. (2017) indicated a buffer relay to improve system stability and provide additional degrees of freedom for relay selection.

7.1.4. The resource allocation algorithm based on Ud-HetNet

Renewable green energy is widely used in 5G relay cooperative systems. Hung et al. (2017) considered heterogeneous relay system adopts the relay of renewable energy puts forward the relay selection power distribution algorithm, uses the relay of renewable energy, proposes the relay selection power distribution algorithm, and uses mixed-integer linear planning to choose the solar relay and the grid power supply relay, effectively cutting down the energy consumption of the system. In heterogeneous cellular networks, one of the biggest challenges is computational uninstalled task scheduling. Hatamnia et al. (2016) considered heterogeneous cooperative communication network would use microcell user equipment to provide relay services and transform the computational uninstallation task into a two-stage auction problem called TARCO, helping to maximize the utilization of sellers and buyers in the network.

For the relay selection problem, Yang et al. (2016) considered the network model of SeNBs and MeNBs. In order to balance spectral efficiency and energy efficiency, the relay selection and energy load scheme of the system are considered for spectrum hire and collaborative capacity load of the collaboration in both dedicated and same frequency scenarios. Considering ultra-dense small cellular networks, Chang et al. (2017) proposed ultra-dense small cellular collaboration, where users obtain the maximum net profit by choosing the optimal cooperative communication mode based on cost-return, and select the cooperative communities through the reliability of the cooperative candidate cells.

7.1.5. Robust resource allocation algorithm based on D2D/V2V

Gao et al. (2016) jointly considers the relay selection and resource allocation problems, proposing a two-level decentralized algorithm called NC-D2D as well as obtaining the throughput of the system under complex interference. Ansari et al. (2016) compared between SNR-based and random relay selection schemes in D2D networks shows that SNR-based relay selection schemes can better improve end-to-end performance. Currently, most of the work is based on relay selection at the physical layer, and Li et al. (2018) proposed a novel energy-saving relay option scheme, while considering the physical layer and social awareness make more mobile users willing to participate in relay cooperation to further improve the overall system performance. The high-speed mobility of the vehicle makes the 5G cellular network switch very frequently, thus reducing the reliability of the Internet of Vehicles. Ge et al. (2016) is based on the micro cell cooperative Internet of vehicles. In order to balance the on-board communication capacity and the vehicle switching ratio, it can achieve the optimal vehicle switching ratio by adjusting the cooperation gate of the 5G cooperative small cellular network. For the safe Internet of Vehicles with DF forwarding relay, Han et al. (2017) proposed a resource allocation algorithm for joint station relay selection and carrier allocation when considering the presence of eavesdroppers. This algorithm converts the problem into a stochastic dichotomic graph model, which minimizes the security outage probability of the system while ensuring user fairness. Considering D2D-based cooperative communication systems, Chen et al. (2018) proposed a novel multi-attribution D2D relay cooperative network. Among them, the belonging mobile device serves as a relay of the ordinary mobile device. This algorithm is able to reduce the average service delay by more than 25% compared to stochastic schemes that are often used in most existing work.

7.2. The resource allocation algorithm based on uncertain channel state

The above problem assumes that the channel state can be obtained in time, but in the real environment, the CSI is dynamically changed, and it is really difficult to achieve the perfect CSI. Due to this, the study of resource allocation problems in imperfect channel states is indispensable. Also the robustness is a very important feature in this state. Below, we will summarize the robust resource allocation algorithm.

7.2.1. Robust resource allocation algorithm based on cognitive relay networks

For the cognitive relay network, Mallick et al. (2014) proposed a total power distribution algorithm by considering the constraints of multiple sub-user and a single primary user interference threshold. The algorithm transforms the original probability optimization problem into a convex determination form and is solved by closed form analysis of power localization. Ubaidulla et al. (2013) proposed two power distribution schemes with different optimization objectives. The optimization goal of the first scheme is to minimize the total transmit power of the sub-user relay nodes required to provide the minimum quality of service. The optimization goal of the second scheme is to minimize the total mean variance of the sending nodes. Li et al. (2016) considered cognitive relay networks based on multiple primary and sub users to give out a robust power allocation scheme algorithm constrained by the primary user interference threshold, maximum transmission power and SINR. The proposed algorithm can minimize the total symbol error rate of the system.

For the relay selection problems, Luo et al. (2014) jointly considered the relay selection, channel access, and power distribution issues, and also proposed an energy-aware relay selection scheme. However, the purpose of the scheme is to balance system capacity and energy consumption and maximize system gain. Mallick et al. (2014) targeted cognitive relay networks with multiple sub-users, considered channel uncertainty, approximates and transforms the original probability optimization problem into convex deterministic forms, and is used for closed-form analysis solutions for power distribution. Based on the work, an effective relay selection strategy which based on the Hungarian algorithm is presented. The strategy could maximize the system capacity within the interference threshold of the primary user. The strategy in Sakran et al. (2012) is proposed based on the secrecy rate and Secrecy outage probability, and the authors propose different selection strategies for different scenarios of eavesdroppers, multiple eavesdroppers, and multiple primary users. The aim is all to maximize the achievable secrecy rate while satisfying the interference constraints of the primary user. For the multi-relay cognitive cooperative system, the relay selection process of Radi et al. (2018) is based on the maximum end-to-end effective capacity acquired by the sub-user, obtains the maximum transmission power of the sub-user under the interference constraint of the primary user, and the system performance is judged by the outage probability and the maximum effective capacity. As the concept of green communication pays more attention, energy harvesting technology has become a new hot topic technology. Li and Zhao (2018) targets a cooperative relay system with a DF forwarding strategy. The relay nodes use the energy harvesting technology to propose a power distribution algorithm to maximize the system's capacity while considering the perceptual uncertainty.

7.2.2. Robust resource allocation algorithm based on Massive MIMO

Considering the channel minimum mean variance, Liu et al. (2017) set a MIMO relay network, where multi-to–half-duplex users jointly forward information through the half-duplex massive MIMO relay to optimize power distribution by obtaining maximum ratio combining (MRC)-maximum ratio transmission (MRT) precoding. Considering the same coefficient model limited by power, Zhang et al. (2016) proposed a power allocation scheme to maximizes Secrecy outage probability where a listener exists and instantaneous channel state information cannot be obtained. Relative to semi-duplex, full-duplex enhances inter-pair interference, and massive MIMO can be eliminated by simple antenna transmission processing such as ZFT (zero forcing transmission) and MRT (maximum ratio transmission). Considering the channel estimation error, Sharma et al. (2018) targeted the full-duplex massive MIMO relay network, transforming the non-convex energy efficiency maximum problem into a concave problem and is solved by the Dinkelbach algorithm. This system can effectively alleviate the self-interference and inter-user interference relative to the semi-duplex system.

7.2.3. Robust resource allocation algorithm based on Ud-HetNet

Regarding the problem of relay selection, Nguyen et al. (2017) considered cognitive heterogeneous networks and studies the effect of unreliable back-haul links on relay selection. The performance of the system including outage probability, traversal capacity and symbol error rate are analyzed under the master user interference threshold. Ateya et al. (2018) considered the relay heterogeneous network, jointly considers the cell optimization problem and the power distribution problem, and proposed a power distribution algorithm using the gradient scheduling and KKT conditions.

7.2.4. Robust resource allocation algorithm based on D2D/V2V

Hasan et al. (2014) considered D2D heterogeneous relay wireless networks and proposed a distributed robust power distribution algorithm for multi-user and multi-relay network scenarios. The proposed algorithm is able to maximize the system throughput and improve the spectral utilization. For the relay selection problem, Mishra et al. (2016) considered a best device-centered relay selection strategy based on channel capacity, SINR, residual battery power, buffer interval and reliability in D2D networks under urban power constraints.This strategy can not only minimize the transmission delay and reduce the network overhead, but also make the communication between users more efficient and reliable. Considering the relay node selection problem and the power distribution problems, Uyoata et al. (2017) considered the channel uncertainty due to the mobility of the relay nodes, focusing on the Hungarian matching and stable matching algorithm to solve the relay selection and power distribution problems. The proposed algorithm can effectively reduce the system consumption.

Due to the reason that the CSI feedback is only utilized in power distribution, the requirement for channel feedback will be relaxed in the power domain NOMA. That is, the study of the NOMA system does not require accurate instantaneous CSI information. So, whether it supports fixed users or mobile users, because the channel can not change rapidly, the expired channel feedback with a certain accuracy and a certain maximum uncertainty and delay will not seriously affect the system performance.

8. Future problems and challenges

Based on existing 5G research and the development trend of communication technology, we can summarize that deep connectivity, holographic connectivity, ubiquitous connectivity and intelligent connectivity (Lu and Zheng, 2020; Ejaz et al., 2020) should be the four important features in future 5G beyond (B5G) networks as shown in fig. 20.

So we can consider that B5G should be an ubiquitous information fusion network as shown in fig. 21. Compared with the realized communication system, the data rate of B5G reaches the magnitude of T-bit per second, and the applicable scenario covers land, sea, air, and sky, while.

We can also expect that the same that the enhanced mobile broadband (eMBB), ultra-reliable low-latency communication (uRLCC), and massive machine-type communications (mMTC) (Popovski et al., 2018) which are still three major application scenarios in 5G beyond networks. However, with the continuous enrichment of various vertical applications, the three major 5G scenarios can be expanded to six or even more to form the polygonal application scenarios. For instance:

1. Unitization of eMBB with uRLLC. This unitization could meet the needs of high-speed, high-reliability environments. Consider the XR services..
2. Unitization of eMBB and mMTC. This unitization could satisfy high-speed data needs in diverse scenes. For example, the video sensors in intelligent factories and smart cities.
3. Unitization of mMTC and uRLLC. This unitization could fulfil the the requirement of information transferring under the processing of industrial control.

For the above scenarios, we will realize them through technologies such as millimeter-wave, deployment of micro base stations in ultra-dense networks, and heterogeneous networks (Kazi and Wainer, 2019). The heterogeneity and ultra-dense characteristics improve the network coverage, and also shorten the transmission distance of the signal.

Cooperative transmission, as an ultra-important technology that can effectively improve the signal transmission range and increase network reliability, has been widely used in the 5G mobile communication network (Ji et al., 2021). Therefore, from the angle of great theoretical significance and huge practical value, the research on resource allocation based on relay cooperation in 5G time makes super sense. Although so many researchers have made significant contributions to this issue, there are still the following problems that need to be further studied. As shown in Table 6.

1. From the perspective of system modeling, most of the current studies are based on the single-relay, 2-hop system model, and the characteristics of the small network coverage in future 5G mobile communication determine the widespread existence of multi-relay and multi-hop scenarios in practical applications. Therefore, the practicality of the relay cooperative system needs to be improved, considering complex multi-relay multi-hop models. In addition, the convergence of future networks means

Table 6
Current Scenarios and Future Trends of resource allocation for 5G beyond cooperative communication system.

	Current Scenarios
System Model	Single model
Network architecture	Network heterogeneity & Complex interference
Algorithm application	Convex optimization & Game Theory & Metaheuristics…(Hossain and Muhammad, 2020)
Energy efficiency rightarrow improve performance	Sacrifice power and user fairness(or Qos)
	Future Trends
System Model	Terahertz (THz) communication Deep space communication Satellite communication etc. multi-scene fusion
Network architecture	Multi-layer fusion & Cross-layer interference AI-based communication Self-Aggregating communication fabric
Algorithm application	Machine learning & Deep learning
Energy efficiency	Realize the green communication. Ensure that QoS and try to meet the user fairness while improving the system performance.

that the future network will be combined with multiple technologies to improve the system performance, which is bound to increase the complexity of the system and thus affect the system performance. A challenging problem in the current study is how to balance the relationship between system complexity and performance.

2. From the perspective of network architecture, the future 5G mobile communication network will develop in a heterogeneous and ultra-dense direction, such as D2D, UAV (Unmanned Aerial Vehicle), and other network fusion. And we will move ground communication to deep space communication and satellite communication and so on.The network environment is more complex and changeable, and the interference sources have become richer. The study of interference management problems has become an important direction for the allocation of relay cooperative resources in 5G mobile communication.
3. From the perspective of algorithm application, the relay selection based on the NOMA relay cooperative system and a resource allocation algorithm based on user fairness and security in different network scenarios remains an open problem. In addition, channel information uncertainty, serial interference elimination residuals, feedback channel unreliability, bandwidth limitation, and scarce spectrum resources all pose great challenges to the practical application and design of the relay cooperative wireless network resource distribution algorithm.
4. From the perspective of information transmission, information security is an important issue that must be concerned about in the development process of heterogeneous wireless communication technology. Although the heterogeneous wireless network can realize multi-network fusion and can meet the communication quality and service requirements of different networks, it will also inevitably lead to many new problems such as information leakage, network eavesdropping and seamless link. Therefore, the resource allocation problem of heterogeneous wireless network considering security constraints is an important problem in the future development level of this technology, such as the resource allocation based on security capacity, security interruption performance analysis, etc.
5. From the perspective of energy utilization, the finiteness of resources pays people more attention to the improvement of energy consumption and utilization. The concept of green energy makes the resource allocation of cooperative communication systems based on green communication and energy collection a hot topic. In addition, the spectrum switching back of collaborative communication at high-speed movement causes power waste, because how to solve the power waste caused by switching more effectively is also one of the research hot topics.
6. As Fig.25 shows, the development of artificial intelligence (AI) and big data technology brings opportunities and challenges to the resource allocation of the intelligent cooperative communication system. B5G will have greater complexity than the preceding generations of wireless networks, which will introduce the need for intelligent mechanisms to orchestrate the available resources, services, and users. Thus, AI-enabled techniques or, more precisely, the use of machine-learning algorithms may allow future networks to learn from their environment, adapt the changes in an automated fashion, and achieve optimal performance. Machine-learning algorithms have paved the way for significant agility in network management, yet several challenges are still open for research efforts. The relatively long convergence time of machine learning methods undermines their usefulness in highly dynamic wireless networks. A careful investigation of the convergence problem, as well as the factors that influence the convergence, is needed. Novel machine-learning techniques with faster convergence and online learning capabilities can better benefit wireless networks. Besides convergence, the uncertainty in the wireless network calls for ongoing updates of the parameters of the machine-learning method or even the method itself. The stochastic nature of the wireless channel may require continuous adaptation. Besides convergence, the uncertainty in the wireless network calls for ongoing updates of the parameters of the machine-learning method or even the method itself. In addition, the scalability of machine learning algorithms must be addressed. Machine-learning algorithms can become unfeasible for moderately large data, especially in collaborative-learning approaches. This calls for a scalable learning algorithm to accommodate the dense use cases of future wireless networks. Furthermore, supervised and unsupervised learning techniques have recently been used for massive MIMO. Further research is needed to investigate whether it is possible to enhance the performance of massive MIMO by using reinforcement learning and deep learning.

Actually, cooperative communication is a network problem, but most of the current research is limited to the physical layer, so the expansion to the high level and cross-layer design problems deserve attention. For example, carrier, symbol, and frame synchronization are not only physical layer problems, but also link layer problems; for example, signal processing, coding, and decoding in the physical layer can also be regarded as part of link-layer coding, re-transmission, etc.

9. Conclusions

Cooperative communication has attracted wide attention from academic circles for its unique transmission characteristics and has always been an important research field in wireless communication technology. In the 5G era, cooperative communication still has its unique advantages and is combined with other new 5G technologies to improve network performance. In this paper, we review some of the research results of 5G cooperative communication.

Firstly, this paper introduces the development situation of 5G and the key technologies. Secondly, we classify relay nodes, signal forwarding modes, and antennas of receiver and transmitter, expound their characteristics, and give corresponding models. Next, we introduce several important technologies of cooperative networks and detail relay selection and power allocation. Finally, cooperative communication is classified into different network scenarios. Resource allocation is a very critical problem in mobile communication networks. This paper mainly addresses the problem of relay selection and resource allocation and discusses the resource allocation algorithms for different optimization targets in the case of perfect and imperfect channels. Based on the above, the paper concludes by discussing problems and challenges based on 5G beyond the network.

References

Ahad, A., Tahir, M., Yau, K.L.A., 2019. 5G-based smart healthcare network: architecture, taxonomy, challenges and future research directions[J]. IEEE Access 7, 100747–100762.

Ahmed, Q.Z., Park, K., Alouini, M., Aissa, S., 2014. Linear Transceiver Design for Nonorthogonal Amplify-and-Forward Protocol Using a Bit Error Rate Criterion. IEEE Trans. Wireless Commun. 13 (4), 1844–1853. https://doi.org/10.1109/TWC.2014.022114.130369.

Ajewale Alimi, I., Jesus Muga, N., Abdalla, A.M., et al., 2019. Towards a Converged Optical-Wireless Fronthaul/Backhaul Solution for 5G Networks and Beyond[J]. Opt. Wireless Convergence 5G Networks, 1–29.

Akbar, A., Jangsher, S., Bhatti, F.A., 2021. NOMA and 5G emerging technologies: A survey on issues and solution techniques[J]. Comput. Netw. 190, 107950.

Al-Eryani Y F, Salhab A M, Zummo S A.A low complexity relay selection & power allocation schemes for cognitive MIMO buffer-aided DF relay networks[C] 2016 IEEE Wireless Communications and Networking Conference. IEEE, 2016: 1-6.

Al-Eryani Y F, Salhab A M, Zummo S A.A low complexity relay selection & power allocation schemes for cognitive MIMO buffer-aided DF relay networks[C] 2016 IEEE Wireless Communications and Networking Conference. IEEE, 2016: 1-6.

Ali, K.S., Sampath, P., Poongodi, C., 2019. Symbol Error Rate Performance of Hybrid DF/AF Relaying Protocol Using Particle Swarm Optimization Based Power Allocation[C]. In: 2019 International Conference on Advances in Computing and Communication Engineering (ICACCE). IEEE, pp. 1–5.

Alsharif, M.H., Nordin, R., 2017. Evolution towards fifth generation (5G) wireless networks: Current trends and challenges in the deployment of millimetre wave, massive MIMO, and small cells[J]. Telecommunication Systems 64 (4), 617–637.

Ansari R I, Hassan S A, Chrysostomou C. Energy efficient relay selection in multi-hop D2D networks[C] 2016 International Wireless Communications and Mobile Computing Conference (IWCMC). IEEE, 2016: 620-625.

Ateya A A, Muthanna A, Koucheryavy A. 5G framework based on multi-level edge computing with D2D enabled communication[C] 2018 20th international conference on advanced communication technology (ICACT). IEEE, 2018: 507-512.

Başaran, S.T., Kurt, G.K., Uysal, M., et al., 2016. A tutorial on network coded cooperation[J]. IEEE Commun. Surveys Tutorials 18 (4), 2970–2990.

Basar, E., Di Renzo, M., De Rosny, J., Debbah, M., Alouini, M.-S., Zhang, R., 2019. Wireless Communications Through Reconfigurable Intelligent Surfaces. IEEE Access 7, 116753–116773. https://doi.org/10.1109/ACCESS.2019.2935192.

Bletsas, A., Khisti, A., Reed, D.P., et al., 2006. A simple cooperative diversity method based on network path selection[J]. IEEE J. Selected Areas Commun. 24 (3), 659–672.

Cai, J., Shen, X., Mark, J.W., et al., 2008. Semi-distributed user relaying algorithm for amplify-and-forward wireless relay networks[J]. IEEE Trans. Wireless Commun. 7 (4), 1348–1357.

Chang B J, Liou S H, Liang Y H. Cooperative communication in ultra-dense small cells toward 5G cellular communication[C] 2017 8th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON). IEEE, 2017: 365-371.

Chen, C., Zhao, X., 2017. Performance of handoff rate for two transitions under base stations cooperation in ultra-dense network[J]. Iet Communications 11 (2), 218–224.

Chen, J., Lv, L., Liu, Y., et al., 2015. Energy efficient relay selection and power allocation for cooperative cognitive radio networks[J]. IET Commun. 9 (13), 1661–1668.

Chen, L., Wu, J., Dai, H.N., et al., 2018. BRAINS: Joint bandwidth-relay allocation in multihoming cooperative D2D networks[J]. IEEE Trans. Veh. Technol. 67 (6), 5387–5398.

Chen, S., Sun, S., Xu, G., et al., 2020. Beam-space multiplexing: Practice, theory, and trends, from 4G TD-LTE, 5G, to 6G and beyond[J]. IEEE Wirel. Commun. 27 (2), 162–172.

Chien, W.C., Huang, S.Y., Lai, C.F., et al., 2020. Resource management in 5G mobile networks: survey and challenges[J]. J. Inform. Processing Syst. 16 (4), 896–914.

Chi, Y., Liu, L., Song, G., et al., 2018. Practical MIMO-NOMA: Low complexity and capacity-approaching solution[J]. IEEE Trans. Wireless Commun. 17 (9), 6251–6264.

Correia, L.M., Zeller, D., Blume, O., et al., 2010. Challenges and enabling technologies for energy aware mobile radio networks[J]. IEEE Commun. Mag. 48 (11), 66–72.

Cover, T., Gamal, A.E., 1979. Capacity theorems for the relay channel[J]. IEEE Trans. Inform. Theory 25 (5), 572–584.

Ding, Z., Shen, L., Chen, H., et al., 2020. Energy-efficient relay-selection-based dynamic routing algorithm for IoT-oriented software-defined WSNs[J]. IEEE Internet Things J. 7 (9), 9050–9065.

Duan, W., Jiang, X.Q., Wen, M., et al., 2018. Two-stage superposed transmission for cooperative NOMA systems[J]. IEEE Access 6, 3920–3931.

Du, Y., Zhang, F., Xue, L., 2018. A kind of joint routing and resource allocation scheme based on prioritized memories-deep Q network for cognitive radio ad hoc networks[J]. Sensors 18 (7), 2119.

Ejaz, W., Sharma, S.K., Saadat, S., et al., 2020. A comprehensive survey on resource allocation for CRAN in 5G and beyond networks[J]. J. Network Computer Appl. 160, 102638.

Fan, B., Li, Y., Zhang, R., et al., 2020. Review on the technological development and application of UAV systems[J]. Chinese Journal of Electronics 29 (2), 199–207.

Feng, D., Lai, L., Luo, J., et al., 2021. Ultra-reliable and low-latency communications: applications, opportunities and challenges[J]. Sci. China Inform. Sci. 64 (2), 1–12.

Gandotra, P., Jha, R.K., Jain, S., 2017. Green communication in next generation cellular networks: A survey[J]. IEEE Access 5, 11727–11758.

Gao, C., Li, Y., Zhao, Y., et al., 2016. A two-level game theory approach for joint relay selection and resource allocation in network coding assisted D2D communications[J]. IEEE Trans. Mob. Comput. 16 (10), 2697–2711.

Garg J, Mehta P, Gupta K.A review on cooperative communication protocols in wireless world[J]. International Journal of Wireless & Mobile Networks, 2013, 5 (2): 107.

Gazestani, A.H., Ghorashi, S.A., Mousavinasab, B., et al., 2019. A survey on implementation and applications of full duplex wireless communications[J]. Physical Communication 34, 121–134.

Gazestani, A.H., Ghorashi, S.A., Mousavinasab, B., et al., 2019. A survey on implementation and applications of full duplex wireless communications[J]. Physical Commun. 34, 121–134.

Ge, X., Cheng, H., Mao, G., et al., 2016. Vehicular communications for 5G cooperative small-cell networks[J]. IEEE Trans. Veh. Technol. 65 (10), 7882–7894.

Ge, X., Tu, S., Mao, G., et al., 2016. 5G ultra-dense cellular networks[J]. IEEE Wirel. Commun. 23 (1), 72–79.

Gkonis, P.K., Trakadas, P.T., Kaklamani, D., 2020. I.A comprehensive study on simulation techniques for 5g networks: State of the art results, analysis, and future challenges[J]. Electronics 9 (3), 468.

Gui, G., Liu, M., Tang, F., et al., 2020. 6G: Opening new horizons for integration of comfort, security, and intelligence[J]. IEEE Wirel. Commun. 27 (5), 126–132.

Han, D., Bai, B., Chen, W., 2017. Secure V2V communications via relays: Resource allocation and performance analysis[J]. IEEE Wireless Commun. Letters 6 (3), 342–345.

Hasan, M., Hossain, E., Kim, D.I., 2014. Resource allocation under channel uncertainties for relay-aided device-to-device communication underlaying LTE-A cellular networks[J]. IEEE Trans. Wireless Commun. 13 (4), 2322–2338.

Hatamnia, S., Vahidian, S., Aïssa, S., et al., 2016. Network-coded two-way relaying in spectrum-sharing systems with quality-of-service requirements[J]. IEEE Trans. Veh. Technol. 66 (2), 1299–1312.

He C, Gitlin R D. System performance of cooperative massive MIMO downlink 5G cellular systems[C] 2016 IEEE 17th Annual Wireless and Microwave Technology Conference (WAMICON). IEEE, 2016: 1-5.

He, J., Tervo, V., Zhou, X., et al., 2018. A tutorial on lossy forwarding cooperative relaying[J]. IEEE Commun. Surveys Tutorials 21 (1), 66–87.

Hong, Y.W.P., Huang, W.J., Kuo, C.C.J., 2010. Cooperative communications and networking: technologies and system design[M]. Springer Science & Business Media.

Hossain, M.S., Muhammad, G., 2020. A Deep-Tree-Model-Based Radio Resource Distribution for 5G Networks. IEEE Wirel. Commun. 27 (1), 62–67. https://doi.org/10.1109/MWC.001.1900286.

Hossain, E., Rasti, M., Tabassum, H., et al., 2014. Evolution toward 5G multi-tier cellular wireless networks: An interference management perspective[J]. IEEE Wireless Commun. 21 (3), 118–127.

Hossain, M.A., Noor, R.M., Yau, K.L.A., et al., 2019. A survey on simultaneous wireless information and power transfer with cooperative relay and future challenges[J]. IEEE Access 7, 19166–19198.

Huang, J., Han, Z., Chiang, M., et al., 2008. Auction-based resource allocation for cooperative communications[J]. IEEE J. Sel. Areas Commun. 26 (7), 1226–1237.

Huang, Y., Zhang, C., Wang, J., et al., 2018. Signal processing for MIMO-NOMA: Present and future challenges[J]. IEEE Wirel. Commun. 25 (2), 32–38.

Hu, F., Chen, B., Zhu, K., 2018. Full spectrum sharing in cognitive radio networks toward 5G: A survey[J]. IEEE Access 6, 15754–15776.

Hung, H.J., Ho, T.Y., Lee, S.Y., et al., 2017. Relay selection for heterogeneous cellular networks with renewable green energy sources[J]. IEEE Trans. Mob. Comput. 17 (3), 661–674.

Huo, Q., Liu, T., Sun, S., et al., 2014. Selective combining for hybrid cooperative networks[J]. IET Commun. 8 (4), 471–482.

Hussein, H.H., Elsayed, H.A., El-kader, A., et al., 2020. Intensive Benchmarking of D2D communication over 5G cellular networks: prototype, integrated features, challenges, and main applications[J]. Wireless Netw. 26 (5), 3183–3202.

Hwang K S, Ko Y C. An efficient relay selection algorithm for cooperative networks [C] 2007 IEEE 66th Vehicular Technology Conference. IEEE, 2007: 81-85.

Ibrahim, A.S., Sadek, A.K., Su, W., et al., 2008. Cooperative communications with relay-selection: when to cooperate and whom to cooperate with?[J]. IEEE Trans. Wireless Commun. 7 (7), 2814–2827.

Islam, S.M.R., Avazov, N., Dobre, O.A., et al., 2016. Power-domain non-orthogonal multiple access (NOMA) in 5G systems: Potentials and challenges[J]. IEEE Commun. Surveys Tutorials 19 (2), 721–742.

Jameel, F., Hamid, Z., Jabeen, F., et al., 2018. A survey of device-to-device communications: Research issues and challenges[J]. IEEE Commun. Surveys Tutorials 20 (3), 2133–2168.
Ji, B., Han, Y., Liu, S., et al., 2021. Several key technologies for 6G: challenges and opportunities[J]. IEEE Communications Standards Magazine 5 (2), 44–51.
Jijo, B.T., Zeebaree, S.R.M., Zebari, R.R., et al., 2021. A comprehensive survey of 5G mm-wave technology design challenges[J]. Asian J. Res. Computer Science, 1–20.
Jing, T., Zhu, S., Li, H., et al., 2014. Cooperative relay selection in cognitive radio networks[J]. IEEE Trans. Veh. Technol. 64 (5), 1872–1881.
Kang J, Kang J, Lee N, et al. Minimizing transmit power for cooperative multicell system with massive MIMO[C] 2013 IEEE 10th Consumer Communications and Networking Conference (CCNC). IEEE, 2013: 438-442.
Kazi, B.U., Wainer, G.A., 2019. Next generation wireless cellular networks: ultra-dense multi-tier and multi-cell cooperation perspective[J]. Wireless Netw. 25 (4), 2041–2064.
Khan, A., Rehman, S., Abbas, M., et al., 2018. On the mutual information of relaying protocols[J]. Phys. Commun. 30, 33–42.
Kothari, M., Ragavendran, U., 2021. Massive MIMO Pre-coders for Cognitive Radio Network Performance Improvement: A Technological Survey[J]. Machine Learning, Deep Learning and Computational Intelligence for Wireless Communication, 211–226.
Kwon, T., Lim, S., Choi, S., et al., 2010. Optimal duplex mode for DF relay in terms of the outage probability[J]. IEEE Trans. Veh. Technol. 59 (7), 3628–3634.
Laneman, J.N., Tse, D.N.C., Wornell, G.W., 2004. Cooperative diversity in wireless networks: Efficient protocols and outage behavior[J]. IEEE Trans. Inform. Theory 50 (12), 3062–3080.
Lan, P., Sun, F., Chen, L., et al., 2013. Power allocation and relay selection for cognitive relay networks with primary QoS constraint[J]. IEEE Wireless Commun. Letters 2 (6), 583–586.
Lan, P., Sun, F., Chen, L., et al., 2013. Power allocation and relay selection for cognitive relay networks with primary QoS constraint[J]. IEEE Wireless Commun. Letters 2 (6), 583–586.
Li, Y., Baduge, G.A.A., 2020. Relay-Aided Downlink Massive MIMO NOMA With Estimated CSI[J]. IEEE Trans. Veh. Technol. 70 (3), 2258–2271.
Li, H., Zhao, X., 2018. Power allocation for capacity maximization in sensing-based cognitive DF relay networks with energy harvesting[J]. IEEE Access 6, 48556–48565.
Li, L., Zhou, X., Xu, H., et al., 2010. Simplified relay selection and power allocation in cooperative cognitive radio systems[J]. IEEE Trans. Wireless Commun. 10 (1), 33–36.
Li, P., Guo, S., Zhuang, W., et al., 2013. On efficient resource allocation for cognitive and cooperative communications[J]. IEEE J. Sel. Areas Commun. 32 (2), 264–273.
Li, H., Zhao, X., Xu, Y., 2016. Power control for cognitive relay networks with sensing uncertainties[J]. EURASIP J. Wireless Commun. Networking 2016 (1), 1–15.
Li, J., Zhang, H., Fan, M., 2017. Digital self-interference cancellation based on independent component analysis for co-time co-frequency full-duplex communication systems[J]. IEEE Access 5, 10222–10231.
Li, Y., Zhang, Z., Wang, H., et al., 2018. SERS: Social-aware energy-efficient relay selection in D2D communications[J]. IEEE Trans. Veh. Technol. 67 (6), 5331–5345.
Li A, Zhang C, Li L. An Encryption Algorithm for Long-Distance Data Transmission in the Internet of Things Based on Channel Nonlinear Transformation[C] 2021 Fifth International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud)(I-SMAC). IEEE, 2021: 1567–1570.
Ligwa, M., Balyan, V., 2022. A Comprehensive Survey of NOMA-Based Cooperative Communication Studies for 5G Implementation[J]. Expert Clouds and Applications, 619–629.
Lin, S.L., Liu, K.H., 2015. Relay selection for cooperative relaying networks with small buffers[J]. IEEE Trans. Veh. Technol. 65 (8), 6562–6572.
Lin Z, Erkip E, Stefanov A. Cooperative regions for coded cooperative systems [mobile radio systems][C] IEEE Global Telecommunications Conference, 2004. GLOBECOM'04. IEEE, 2004, 1: 21-25.
Liu, Y., Chen, Q., 2017. On the energy efficient multi-pair two-way massive MIMO AF relaying with imperfect CSI and optimal power allocation[J]. IEEE Access 6, 2589–2603.
Liu, K.J.R., Sadek, A.K., Su, W., et al., 2009. Cooperative communications and networking[M]. Cambridge University Press.
Liu, J., Shroff, N.B., Sherali, H.D., 2012. Optimal power allocation in multi-relay MIMO cooperative networks: Theory and algorithms[J]. IEEE J. Sel. Areas Commun. 30 (2), 331–340.
Liu, Y., Wang, L., Duy, T.T., et al., 2014. Relay selection for security enhancement in cognitive relay networks[J]. IEEE Wireless Commun. Letters 4 (1), 46–49.
Liu, H., Ding, Z., Kim, K.J., et al., 2018. Decode-and-forward relaying for cooperative NOMA systems with direct links[J]. IEEE Trans. Wireless Commun. 17 (12), 8077–8093.
Liu, J., Luo, Z., Xiong, X., 2019. Low-resolution ADCs for wireless communication: A comprehensive survey[J]. IEEE Access 7, 91291–91324.
Lu, Y., Zheng, X., 2020. 6G: A survey on technologies, scenarios, challenges, and the related issues[J]. J. Ind. Inform. Integration 19, 100158.
Lu, Y., Cheng, P., Chen, Z., et al., 2020. Deep autoencoder learning for relay-assisted cooperative communication systems[J]. IEEE Trans. Commun. 68 (9), 5471–5488.
Luo, C., Min, G., Yu, F.R., et al., 2014. Joint relay scheduling, channel access, and power allocation for green cognitive radio communications[J]. IEEE J. Sel. Areas Commun. 33 (5), 922–932.
Lv, Y., He, Z., Rong, Y., 2019. Multiuser multi-hop AF MIMO relay system design based on MMSE-DFE receiver[J]. IEEE Access 7, 42518–42535.
Mahmoud, H.H.H., Amer, A.A., Ismail, T., 2021. 6G: A comprehensive survey on technologies, applications, challenges, and research problems[J]. Trans. Emerging Telecommun. Technol. 32, (4) e4233.
Malik, P.K., Wadhwa, D.S., Khinda, J., 2020. S.A survey of device to device and cooperative communication for the future cellular networks[J]. Int. J. Wireless Inf. Networks 27 (3), 411–432.
Malik, P.K., Wadhwa, D.S., Khinda, J., 2020. S.A survey of device to device and cooperative communication for the future cellular networks[J]. Int. J. Wireless Inf. Networks, 1–22.
Mallick, S., Devarajan, R., Loodaricheh, R.A., et al., 2014. Robust resource optimization for cooperative cognitive radio networks with imperfect CSI[J]. IEEE Trans. Wireless Commun. 14 (2), 907–920.
Mao, Y., You, C., Zhang, J., et al., 2017. A survey on mobile edge computing: The communication perspective[J]. IEEE Commun. Surveys Tutorials 19 (4), 2322–2358.
Maraqa, O., Rajasekaran, A.S., Al-Ahmadi, S., et al., 2020. A survey of rate-optimal power domain NOMA with enabling technologies of future wireless networks [J]. IEEE Commun. Surveys Tutorials 22 (4), 2192–2235.
Mishra, P.K., Pandey, S., Biswash, S., 2016. K.A device-centric scheme for relay selection in a dynamic network scenario for 5G communication[J]. IEEE Access 4, 3757–3768.
Mohammadi, M., Chalise, B.K., Hakimi, A., et al., 2017. Joint beamforming design and power allocation for full-duplex NOMA cognitive relay systems[C] GLOBECOM 2017–2017 IEEE Global Communications Conference. IEEE, 1–6.
Multiple access techniques for 5G wireless networks and beyond[M]. Berlin: Springer, 2019.
Nabar, R.U., Bolcskei, H., Kneubuhler, F.W., 2004. Fading relay channels: performance limits and space-time signal design. IEEE J. Sel. Areas Commun. 22 (6), 1099–1109. https://doi.org/10.1109/JSAC.2004.830922.
Nguyen H T, Duong T Q, Dobre O A, et al. Cognitive heterogeneous networks with best relay selection over unreliable backhaul connections[C] 2017 IEEE 86th Vehicular Technology Conference (VTC-Fall). IEEE, 2017: 1-5.
Nguyen, B.C., Tran, X.N., Tran, D.T., 2019. Full-duplex amplify-and-forward relay system with direct link: Performance analysis and optimization[J]. Phys. Commun. 37, 100888.
Ni, D., Hao, L., Tran, Q.T., et al., 2018. Power allocation for downlink NOMA heterogeneous networks[J]. IEEE Access 6, 26742–26752.
Ni, Y., Liang, J., Shi, X., et al., 2019. Research on key technology in 5G mobile communication network[C]. In: 2019 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS). IEEE, pp. 199–201.
Nomikos N, Charalambous T, Vouyioukas D, et al. Relay selection for buffer-aided non-orthogonal multiple access networks[C] 2017 IEEE Globecom Workshops (GC Wkshps). IEEE, 2017: 1-6.
Nosratinia, A., Hunter, T.E., Hedayat, A., 2004. Cooperative communication in wireless networks[J]. IEEE Commun. Magazine 42 (10), 74–80.
Okogbaa, F.C., Ahmed, Q.Z., Khan, F.A., et al., 2022. Design and Application of Intelligent Reflecting Surface (IRS) for Beyond 5G Wireless Networks: A Review [J]. Sensors 22 (7), 2436.
Peng, M., Liu, Y., Wei, D., et al., 2011. Hierarchical cooperative relay based heterogeneous networks[J]. IEEE Wirel. Commun. 18 (3), 48–56.
Popovski, P., Trillingsgaard, K.F., Simeone, O., et al., 2018. 5G wireless network slicing for eMBB, URLLC, and mMTC: A communication-theoretic view[J]. Ieee Access 6, 55765–55779.
Popovski, P., Trillingsgaard, K.F., Simeone, O., et al., 2018. 5G wireless network slicing for eMBB, URLLC, and mMTC: A communication-theoretic view[J]. Ieee Access 6, 55765–55779.
Qiao, D., Gursoy, M.C., Velipasalar, S., 2012. Effective capacity of two-hop wireless communication systems[J]. IEEE Trans. Inf. Theory 59 (2), 873–885.
Quality, Reliability, 2017. Security and Robustness in Heterogeneous Networks: 12th International Conference, QShine 2016, Seoul, Korea, July 7–8, 2016, Proceedings[M]. Springer.
Radi, W., Abdel-Hadi, R.H., El-Badawy, H.M., et al., 2018. Performance Assessment for Cognitive Cooperative Multiple Relays Network (CCMRN) With Imperfect Channel State Information[J]. IEEE Access 6, 44607–44615.
Rajatheva N, Atzeni I, Bjornson E, et al. White paper on broadband connectivity in 6G[J]. arXiv preprint arXiv:2004.14247, 2020.
Renzo, M.D., Debbah, M., Phan-Huy, D.T., et al., 2019. Smart radio environments empowered by reconfigurable AI meta-surfaces: An idea whose time has come [J]. EURASIP J. Wireless Commun. Networking 2019 (1), 1–20.
Riaz, S., Khan, F.A., Saleem, S., et al., 2020. Reducing the mutual outage probability of cooperative non-orthogonal multiple access[J]. IEEE Trans. Veh. Technol. 69 (12), 16207–16212.
Rost, P., Banchs, A., Berberana, I., et al., 2016. Mobile network architecture evolution toward 5G[J]. IEEE Commun. Mag. 54 (5), 84–91.
Sakran, H., Shokair, M., Nasr, O., et al., 2012. Proposed relay selection scheme for physical layer security in cognitive radio networks[J]. Iet Communications 6 (16), 2676–2687.
Saleh, H.H., Hasoon, S.T., 2018. Capacity enhancement for the vehicular network using spatial multiplexing[J]. Int. J. Eng. Technol. 7, 347–353.

Sanguinetti L, D'Amico A A, Rong Y.A tutorial on the optimization of amplify-and-forward MIMO relay systems[J]. IEEE Journal on Selected Areas in Communications, 2012, 30(8): 1331-1346.
Sayed, A.H., Tarighat, A., Khajehnouri, N., 2005. Network-based wireless location: challenges faced in developing techniques for accurate wireless location information[J]. IEEE Signal Processing Magazine 22 (4), 24–40.
SB L.A Hybrid adaptive relay technique for cooperative communication system[J]. Wireless Personal Communications, 2018, 103(3): 2245-2258.
Sharma, A., Jha, R.K.A., 2021. Comprehensive Survey on Security Issues in 5G Wireless Communication Network using Beamforming Approach[J]. Wireless Pers. Commun., 1–55
Sharma, S.K., Wang, X., 2019. Toward massive machine type communications in ultra-dense cellular IoT networks: Current issues and machine learning-assisted solutions[J]. IEEE Commun. Surveys Tutorials 22 (1), 426–471.
Sharma, E., Budhiraja, R., Vasudevan, K., et al., 2018. Full-duplex massive MIMO multi-pair two-way AF relaying: Energy efficiency optimization[J]. IEEE Trans. Commun. 66 (8), 3322–3340.
Silva S, Ardakani M, Tellambura C. Relay selection for cognitive massive MIMO two-way relay networks[C] 2017 IEEE Wireless Communications and Networking Conference (WCNC). IEEE, 2017: 1-6.
Spencer Q H, Swindlehurst A L. Channel allocation in multi-user MIMO wireless communications systems[C] 2004 IEEE International Conference on Communications (IEEE Cat. No. 04CH37577). IEEE, 2004, 5: 3035–3039.
Su W, Sadek A K, Liu K J R. SER performance analysis and optimum power allocation for decode-and-forward cooperation protocol in wireless networks[C] IEEE Wireless Communications and Networking Conference, 2005. IEEE, 2005, 2: 984-989.
Su, W., Sadek, A.K., Ray Liu, K.J., 2008. Cooperative communication protocols in wireless networks: Performance analysis and optimum power allocation[J]. Wireless Pers. Commun. 44 (2), 181–217.
Su, Y., Lu, X., Zhao, Y., et al., 2019. Cooperative communications with relay selection based on deep reinforcement learning in wireless sensor networks[J]. IEEE Sens. J. 19 (20), 9561–9569.
Sun Y, Ng D W K, Schober R. Resource allocation for MC-NOMA systems with cognitive relaying[C] 2017 IEEE Globecom Workshops (GC Wkshps). IEEE, 2017: 1-7.
Tan, F., Lv, T., Huang, P., 2018. Global energy efficiency optimization for wireless-powered massive MIMO aided multiway AF relay networks[J]. IEEE Trans. Signal Process. 66 (9), 2384–2398.
Tanwar, S., Tyagi, S., Budhiraja, I., et al., 2019. Tactile Internet for autonomous vehicles: Latency and reliability analysis[J]. IEEE Wirel. Commun. 26 (4), 66–72.
Telatar, E., 1999. Capacity of multi-antenna Gaussian channels[J]. Eur. Trans. Telecommun. 10 (6), 585–595.
Teng, Y., Liu, M., Yu, F.R., et al., 2018. Resource allocation for ultra-dense networks: A survey, some research issues and challenges[J]. IEEE Commun. Surveys Tutorials 21 (3), 2134–2168.
Tragos, E.Z., Zeadally, S., Fragkiadakis, A.G., et al., 2013. Spectrum assignment in cognitive radio networks: A comprehensive survey[J]. IEEE Commun. Surveys Tutorials 15 (3), 1108–1135.
Tsai, T.C., Chan, H.H., 2015. NCCU Trace: Social-network-aware mobility trace[J]. IEEE Commun. Mag. 53 (10), 144–149.
Tullberg, H., Popovski, P., Li, Z., et al., 2016. The METIS 5G system concept: Meeting the 5G requirements[J]. IEEE Commun. Magazine 54 (12), 132–139.
Ubaidulla, P., Aissa, S., 2012. Optimal relay selection and power allocation for cognitive two-way relaying networks[J]. IEEE Wireless Commun. Letters 1 (3), 225–228.
Ubaidulla P, Alouini M S, Aissa S. Cognitive relaying and power allocation under channel state uncertainties[C] 2013 IEEE Wireless Communications and Networking Conference (WCNC). IEEE, 2013: 3358-3363.
Ullah, S., Higgins, H., Braem, B., et al., 2012. A comprehensive survey of wireless body area networks[J]. J. Medical Syst. 36 (3), 1065–1094.
Uyoata U, Dlodlo M. Joint power allocation and relay selection for relay assisted D2D communication with channel uncertainties[C] IEEE EUROCON 2017-17th international conference on smart technologies. IEEE, 2017: 486-490.
Vaigandla, K.K., Venu, D.N., 2021. A Survey on Future Generation Wireless Communications-5G: Multiple Access Techniques, Physical Layer Security, Beamforming Approach[J]. Journal of Information and Computational Science 11 (9), 449–474.
Van Nguyen, B., Jung, H., Kim, K., 2018. Physical layer security schemes for full-duplex cooperative systems: State of the art and beyond[J]. IEEE Commun. Mag. 56 (11), 131–137.
Wang, B., Han, Z., Liu, K.J.R., 2007. Distributed relay selection and power control for multiuser cooperative communication networks using buyer/seller game[C]. In: IEEE INFOCOM 2007–26th IEEE International Conference on Computer Communications. IEEE, pp. 544–552.
Wang, T., Cano, A., Giannakis, G.B., et al., 2007. High-performance cooperative demodulation with decode-and-forward relays[J]. IEEE Trans. Commun. 55 (7), 1427–1438.
Wang, B., Han, Z., Liu, K.J.R., 2008. Distributed relay selection and power control for multiuser cooperative communication networks using stackelberg game[J]. IEEE Trans. Mob. Comput. 8 (7), 975–990.
Wang, W., Yang, S., Gao, L., 2008. Comparison of schemes for joint subcarrier matching and power allocation in OFDM decode-and-forward relay system[C]. In: 2008 IEEE International Conference on Communications. IEEE, pp. 4983–4987.
Wang, F., Guo, S., Yang, Y., et al., 2016. Relay selection and power allocation for cooperative communication networks with energy harvesting[J]. IEEE Syst. J. 12 (1), 735–746.
Wang, X., Wang, J., He, L., et al., 2017. Outage analysis for downlink NOMA with statistical channel state information[J]. IEEE Wireless Commun. Letters 7 (2), 142–145.
Wu, Y., Qian, L.P., Mao, H., et al., 2018. Optimal power allocation and scheduling for non-orthogonal multiple access relay-assisted networks[J]. IEEE Trans. Mob. Comput. 17 (11), 2591–2606.
Xu, P., Yang, Z., Ding, Z., et al., 2018. Optimal relay selection schemes for cooperative NOMA[J]. IEEE Trans. Veh. Technol. 67 (8), 7851–7855.
Yan, G., 2019. Simulation analysis of key technology optimization of 5G mobile communication network based on Internet of Things technology[J]. Int. J. Distrib. Sens. Netw. 15 (6). 1550147719851454.
Yang, C., Li, J., Guizani, M., 2016. Cooperation for spectral and energy efficiency in ultra-dense small cell networks[J]. IEEE wireless communications 23 (1), 64–71.
Yang, X., Liang, X., Song, T., et al., 2018. Multiuser massive MIMO AF relaying: Spectral efficiency and power allocation[J]. IEEE Access 6, 18894–18906.
You, X.H., Wang, D.M., Sheng, B., et al., 2010. Cooperative distributed antenna systems for mobile communications [coordinated and distributed MIMO][J]. IEEE Wirel. Commun. 17 (3), 35–43.
Youssef, M.J., Farah, J., Nour, C.A., et al., 2019. Resource allocation in NOMA systems for centralized and distributed antennas with mixed traffic using matching theory[J]. IEEE Trans. Commun. 68 (1), 414–428.
Yu, W., Xu, H., Zhang, H., et al., 2016. Ultra-dense networks: Survey of state of the art and future directions[C]. In: 2016 25th international conference on computer communication and networks (ICCCN). IEEE, pp. 1–10.
Zhang, C., Ge, J., Li, J., et al., 2016. Complexity-aware relay selection for 5G large-scale secure two-way relay systems[J]. IEEE Trans. Veh. Technol. 66 (6), 5461–5465.
Zhang, S., Di, B., Song, L., et al., 2017. Sub-channel and power allocation for non-orthogonal multiple access relay networks with amplify-and-forward protocol [J]. IEEE Trans. Wireless Commun. 16 (4), 2249–2261.
Zhang, Z., Xiao, Y., Ma, Z., et al., 2019. 6G wireless networks: Vision, requirements, architecture, and key technologies[J]. IEEE Veh. Technol. Mag. 14 (3), 28–41.
Zhang, H., Zhang, H., Liu, W., et al., 2020. Energy efficient user clustering, hybrid precoding and power optimization in terahertz MIMO-NOMA systems[J]. IEEE J. Sel. Areas Commun. 38 (9), 2074–2085.
Zhao, J., Ding, Z., Fan, P., et al., 2018. Dual relay selection for cooperative NOMA with distributed space time coding[J]. IEEE Access 6, 20440–20450.