DOI: 10.3969/j. issn. 1673-5188. 2016. S1. 009
http://www.cnki.net/kcms/detail/34.1294.TN.20170106.1827.002.html, published online January 6, 2017

Research on Interference Cancellation for Switched-on Small Cells in Ultra Dense Network

SUN Yang[1], CHANG Yongyu[1], WANG Chao[1], ZHANG Lu[1], ZHANG Yu[2], and WANG Xinhui[2]
(1. Beijing University of Posts and Telecommunications, Beijing 100876, China;
2. ZTE Corporation, Shanghai 201203, China)

Abstract

In ultra-dense heterogeneous networks, the co-channel interference between small cells turns to be the major challenge to cell throughput improvement, especially for cell edge users. In this paper, we propose a distributed frequency resource allocation approach for interference cancellation, which allocates appropriate frequency resources when a small cell is switched on to reduce the co-channel interference to its neighboring small cells. This frequency resource pre-allocation aims at avoiding co-channel interference between small cells and improving users' throughput. The simulation results show that our proposed scheme can effectively reduce the co-channel interference and achieve considerable gains in users' throughput.

Keywords

ultra-dense network; interference cancellation; frequency resource allocation; cell switch

1 Introduction

With the exploding increase of portable devices in wireless communications, the wireless industry has stepped in the 5th generation (5G). As estimated in [1], the future wireless network will face 1000x rate challenge beyond 2020. Ultra-dense heterogeneous networks (UDN) are proved to be one of key 5G technologies.

Heterogeneous network (HetNet) is a network that contains macro cells, small cells and users. In HetNet, users can select their serving cell adaptively based on their location and received signal power. Macro cells and small cells can all be served as users' serving cell. In addition, macro cells with high transmission power are deployed to provide wide coverage, whereas some small cells are deployed for coverage extension or offloading. There exist a lot of mature research studies in 3GPP HetNet [2]–[4].

UDN is an enhancement of HetNet. In UDN, there are often dozens of small cells even hundreds of small cells in a macro cell. UDN can provide much more network capacity. In addition, because of low power cost of small cells, it offers a great improvement for energy efficiency. UDN can also ensure full coverage of the service area [5].

However, a large number of small cells deployed in one macro cell lead to a more serious co-channel interference issue between small cells. In sparse HetNet, there are often a few small cells deployed in a macro cell. Because of the large distance between neighboring cells and the low transmission power, co-channel interference is tolerable. On the other hand, due to the dense deployment of small cells, the distance between neighboring cells in UDN is greatly reduced. As a result, the co-channel interference turns to be more severe than before. If the frequency resource cannot be allocated reasonably to every cell, the strong co-channel uplink-downlink interference between neighboring small cells would lead to the whole network performance decline [6].

In order to reduce co-channel interference between neighboring cells, collaboration of a variety of interference cancellation technologies to improve the quality of network service is required. Frequency reuse technology can guarantee the neighboring cells using orthogonal frequency resources, so quality of service (QoS) can be ensured and co-channel interference be alleviated [7]. The cell switching method can bring a more efficient resource management and obviously eliminate the interference [8], [9].

However, existing frequency reuse schemes are generally focused on on-service small cells. When a new cell is informed to be switched on in UDN, unplanned frequency allocation will introduce serious interference to its neighbor cells and impact the system throughput performance. In order to tackle this problem, in this paper, we combine the cell switching operation with the frequency reuse strategy, and propose an advanced interference cancellation method based on frequency resource allocation for candidate switched-on small cells.

In the following parts of this paper, we give an overview of some related resource allocation technologies in section 2, and propose an advanced interference cancellation method based on frequency resource allocation in section 3. In section 4, we demonstrate the effectiveness of our advanced frequency allocation method through system simulation. Finally, we give the

This work was partly supported by ZTE Industry-Academia-Research Cooperation Funds.

conclusion in section 5.

2 Overview of Resource Allocation Techniques

2.1 Frequency Reuse in HetNet

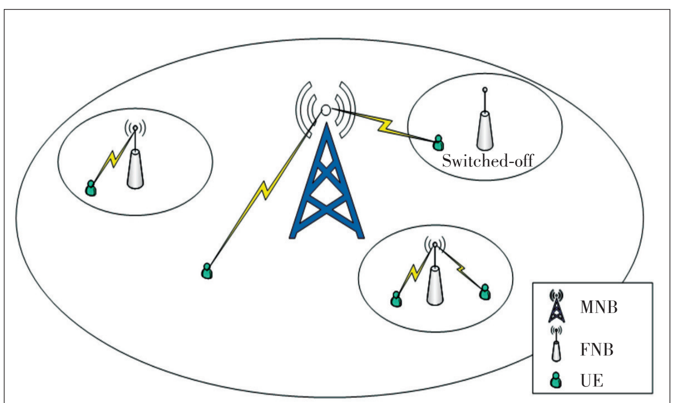
In HetNet, the introduction of small cells brings an obvious improvement for hotspots, and gives a supplement for the macro cell's coverage. In order to achieve a further gain on network capacity, there are much more small cells deployed in a macro cell.

Due to the inter-frequency deployment of Macro eNodeB (MNB) and Femto eNodeB (FNB), the interference between them is negligible. Therefore, we should pay attention to co-channel interference among small cells. In addition, fractional frequency reuse (FFR) and soft frequency reuse (SFR) are useful for macro cells in LTE standards. However, because of random deployment of small cells, FFR and SFR will be complex and difficult to plan in UDN. Therefore, we take traditional frequency reuse technology into account for the UDN scenario [10].

In UDN, if we take other cells' frequency resource and interference information into account to make a more reasonable frequency allocation, co-channel interference will be further decreased and resource utilization will be more increased [11].

2.2 Cell Switching

In HetNet, cell switching is a new radio resource management method which is proposed recently. As **Fig. 1** shows, there are some small cells switched off by using this method, where UE means User Equipment. There are several factors that influence the switch decision of small cells, like interference from neighboring cells, cell load, and packet arrival rate [12]. The cell switching technology can save energy and signaling overhead, and also improve resource utilization of system. As a consequence, it plays a significant role in co-channel interference avoidance [8].



FNB: femto eNodeB MNB: macro NodeB UE: user equipment

▲**Figure 1. Cell switching scenario.**

Due to the dense deployment of small cells in UDN, the propagation environment of network is more complex. In addition, dense deployment of small cells does not equal to dense deployment of users. When users are distributed sparsely, there will be a large proportion of small cells at low load [13]. To save energy and signaling overhead, it is better to switch off a part of small cells; moreover, as mall cell produces strong interference to its adjacent cells for a while, it should be switched off to improve quality of network service. So the cell switch scheme will take a great boost for UDN which has more complex network deployment and propagation environment [7].

However, if frequency resource cannot be allocated reasonably when small cells are turned on, it will introduce serious co-channel interference to the system, and QoS will be negatively influenced. Taking above situations into consideration, we propose a frequency allocation method for switched-on small cells to reduce the interference.

3 Proposed Frequency Pre-Allocation Scheme

3.1 System Model

A downlink resource allocation scheme is proposed in an orthogonal frequency division multiple access (OFDMA) time division duplex system. The system is composed of multiple cells which share the same frequency band with the bandwidth of 10 MHz. In the macro cell's coverage area, there are M small cells. Let K denote the set of user equipment (UEs), S denote the set of small cells and U denote the set of physical resource blocks (PRBs). The system time is divided into fixed-length frames. Since the resource allocation is performed on a per cell basis, we will focus on the small cell that is switched on recently (the target cell) in describing our scheme. Meanwhile, the interference from other cells is considered in designing the scheme.

We assume that the transmission modes of all UEs are selected before resource allocation. That is, it is assumed that each UE has determined its best transmitter among macro cells and small cells as the serving transmitter by using an appropriate mode selection method [14]. UEs select their serving cells by Reference Signal Received Power (RSRP), which can be achieved as follows:

$$RSRP = P_u^i \cdot H_{k,u}^i, i \in S, u \in U, k \in K, \tag{1}$$

where $H_{k,u}^i$ denotes the desired channel gain that UE k experiences from eNB i at PRB u including all long-term and short-term channel-fading characteristics. P_u^i is the transmit power allocated to PRB u by eNB i.

In addition, the formulation of the instantaneous Signal-to-

Interference and Noise Ratio (SINR) $\gamma_{k,u}^{i}$ is given as follows:

$$\gamma_{k,u}^{i}=\frac{P_u^i \cdot H_{k,u}^i}{\sum_{j\neq i} P_u^j \cdot H_{k,u}^j + N_w},$$
$$i,j \in S,\ u \in U,\ k \in K, \tag{2}$$

where $H_{k,u}^{j}$ denotes the interfering link *and* P_u^j is the transmit power allocated to PRB u by eNB j. To convert the achievable SINR $\gamma_{k,u}^{i}$ into an effective data rate $r_{k,u}^{i}$, we assume a log-linear function as follows:

$$r_{k,u}^{i}=B \cdot \log_2\left(1+\gamma_{k,u}^{i}\right), \tag{3}$$

where B is the band width allocated for UE k.

3.2 Problem Formulation

The optimization problem is formulated in the context of OFDMA as in the LTE standard. There are U effective sub-channels—PRBs in LTE—available in the system each with a bandwidth of 10 MHz. In our scheme, frequency resources are divided into three parts: available resources, shared resources, and low-prior resources. As **Fig. 2** shows, available resources are the bandwidth which has been not used by small cells. Shared resources are the bandwidth which has been reused by small cells with reuse factor N=1. In addition, the bandwidth with reuse factor N=3 is called low-prior resources, which meets the small cells' minimum resource requirements.

We let $B=\{B_1, B_2, \ldots, B_n\}$ denote the set of bandwidth. After a femtocell is switched on, it is called the target cell i. Our goal is to minimize the interference of the femtocell to its neighboring cells. Then, the interference I is formulated as follows:

$$I(B_i)=\begin{cases}0, & B_i \neq B_j \\ P_u^i \cdot H_{k,u}^i, & B_i = B_j\end{cases},$$
$$i,j \in S,\ u \in U,\ k \in K, \tag{4}$$

where B_i and B_j are the frequency resource of the target cell and neighboring cell, respectively.

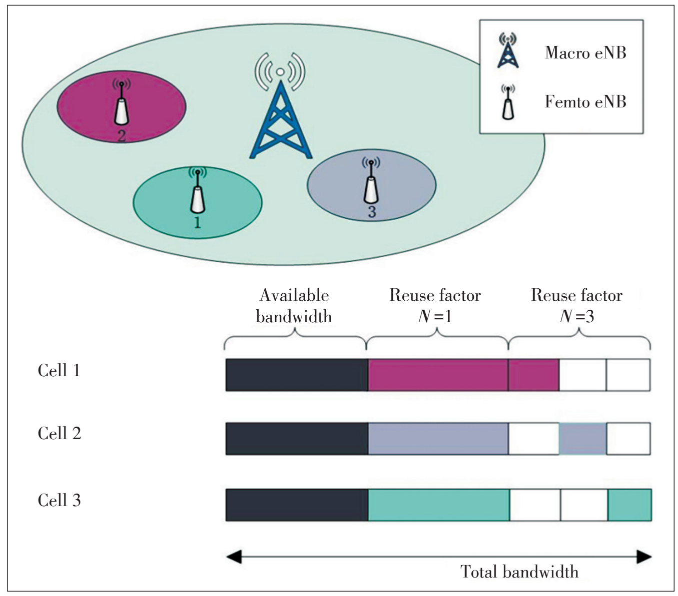
Next, the frequency resource allocation problem is formulated for the target cell as follows:

$$\arg\left(\min \sum I(B_i)\right). \tag{5}$$

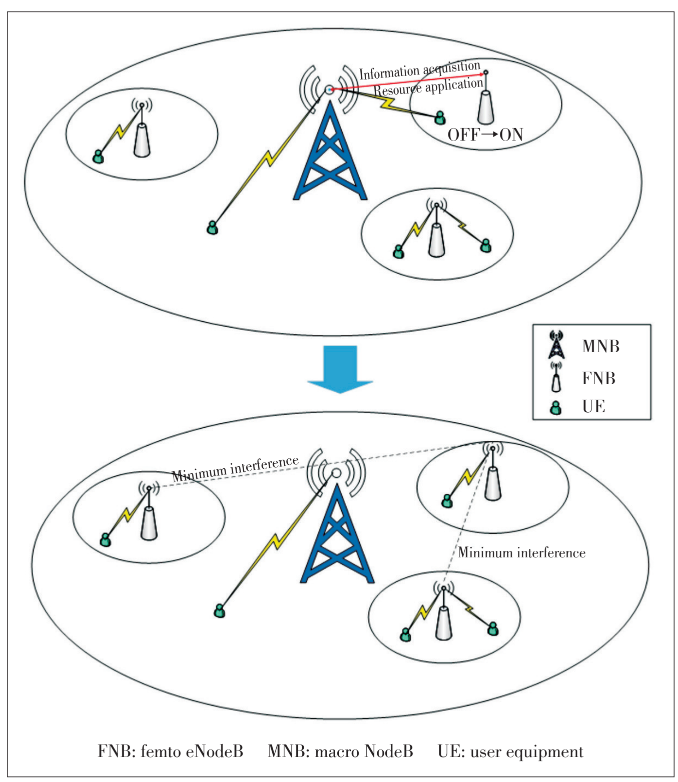
As (4) and **Fig. 3** show, the frequency resource that is orthogonal with other cells' is the best solution to minimize the interference of the target cell. If there are available resources, the target cell will use them. $I(B_i)$ can be zero by this method. If there are no available resources but shared resources, the target cell can occupy for them, and $I(B_i)$ can also be zero. Otherwise, if there are only low-prior resources, the target cell will apply for B_i, which will lead $I(B_i)$ is minimum.

3.3 Process of the Method

When a small cell becomes ON state from OFF state, an initial frequency resource application process is beginning. To minimize the co-channel interference from neighboring cells after frequency resources are allocated, it's better to apply for



▲**Figure 2. Frequency resources in our scheme.**



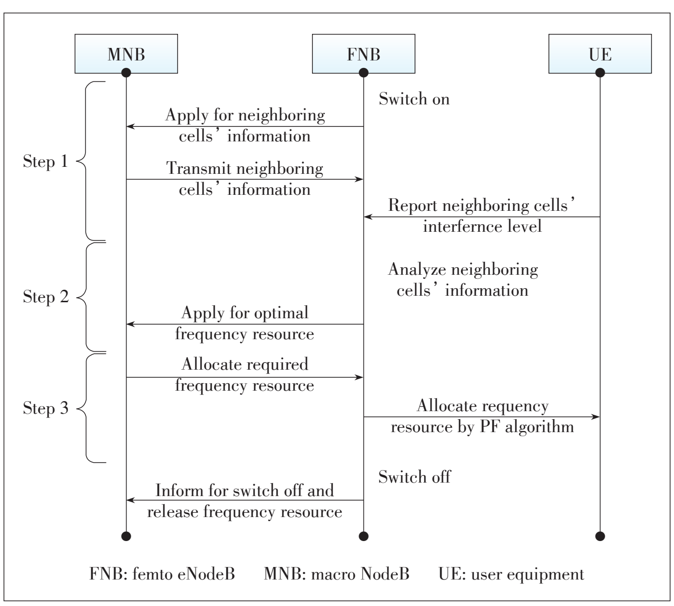
▲**Figure 3. Frequency pre-allocation in our scheme.**

the frequency resource for the cell according to RSRP and neighboring cells' information of frequency resource usage.

This method can be divided into three steps. As **Fig. 4** shows, the first step is the information acquisition. After a small cell is switched on, it becomes the target cell in our scheme and it should obtain its neighboring cells' on/off status and information of frequency resource usage through backhaul links between macro cells and small cells. Then the small cell commands its UEs to measure downlink RSRP of all neighboring cells which are on-state. After that, UEs report the measuring result to the target cell, and the target cell will calculate every neighboring cell's average RSRP. In this way, it can estimate the interference strength of each cell according to its RSRP. The higher RSRP is, the stronger interference between the target cell and neighboring cell is.

The second step is frequency resource allocation. First, the target cell should find if there are any available bands. It will apply for the spare frequency resources if they are available. Otherwise, it will apply for some frequency resource reusing with other cells according to frequency resource usage of these cells. In our system models, there are shared frequency resources and low-prior frequency resources. If there are the shared resources used by some neighboring cells, the target cell can apply for the shared resources directly. Otherwise, if all the adjacent cells only use low-prior resources, the target cell should apply for reusing the frequency resources with the neighboring cell which has the lowest RSRP. In this way, we can guarantee that the introduction of the target cell produces the minimal interference to other cells.

In the third step, the target cell obtains the frequency resources from network. If the resources are the available resources or shared resources, the system allocates them to the target cell directly. If the resources are low-prior resources, the



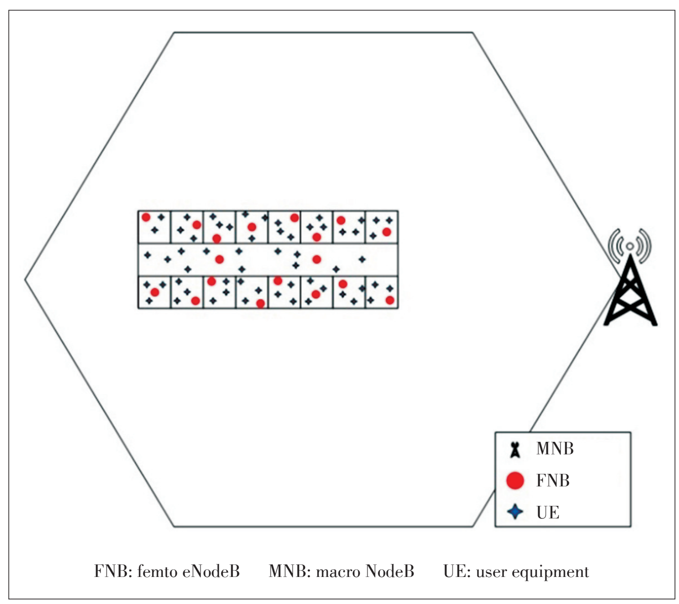
▲Figure 4. Process of the proposed scheme.

system allocates them to the target cell and informs the original cell for frequency reusing.

After the small cell is switched off, its frequency resources will go back to the resource pool waiting for scheduling next time.

4 Simulation Scenario and Results

We evaluated the performance of the proposed scheme. The simulation is based on the LTE standard [4]. The downlink transmission scheme for an LTE system is based on OFDMA. As **Fig. 5** shows, an inter-frequency indoor office scenario is used in our simulation. We consider FNBs as small cells. Resources are allocated to users according to proportional fair scheduling. **Tables 1** and **2** list the simulation parameters and the scenario parameters we used. Because of the inter-frequency deployment of macro cells and femtocells, their cross-tier in-



▲Figure 5. Simulation scenario.

▼Table 1. Simulation parameters

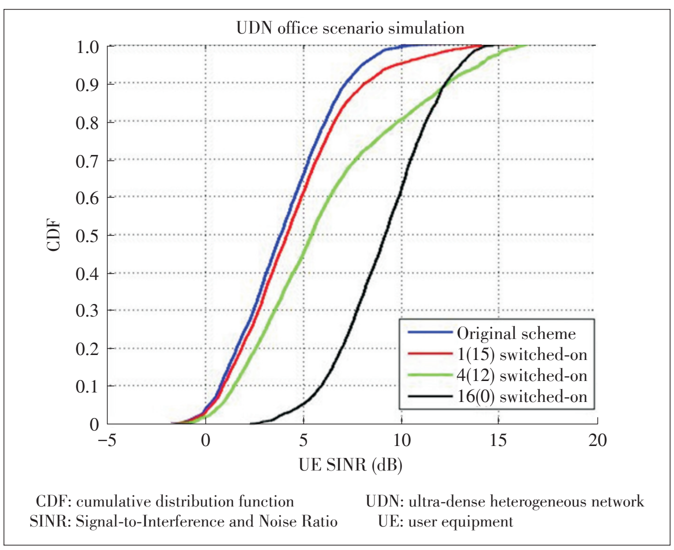
	Macro	Femto
Carrier frequency	1.8 GHz	2.5 GHz
Bandwidth	20 MHz	10 MHz
Antenna gains	17 dBi	5 dBi
Antenna models	3D sectors	Omnidirectional antenna
Transmission power	46 dBm	20 dBm/30 dBm
Inter-site distance	500 m	none
Log-normal shadow	10 dB	3 dB
Minimum access distance	35 m	3 m
Maximum service users	10	3
Traffic model	Full buffer	

▼**Table 2. Scenario parameters**

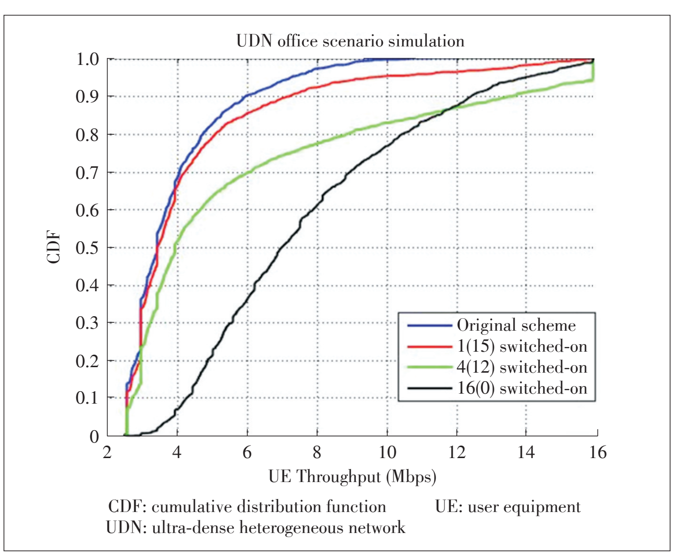
Cell model	7 cells model, 3 sectors per cell
Building model	1 one-layer building per sector (16 rooms, 1 corridor)
Building scale	Room: 15 m×15 m, Corridor: 20 m×120 m
Users per room	3
Corridor users	16
Number of FNB	2 FNBs in corridor, 1 FNB per room
FNB: Femto eNodeB	

terference is negligible and we only focus on the co-channel interference between the femtocells.

According to the simulation in the office scenario, we get SINR and the cumulative distribution function (CDF) of users' throughput (**Figs. 6** and **7**). In the figures, the original scheme uses the unplanned frequency allocation method of 16 small cells without cell switch and 1(15)/4(12)/16(0) switched-on denote switched-on 1/4/16 small cells based on 15/12/0 existing small cells with unplanned frequency allocation in the proposed advanced scheme.



▲**Figure 6. Users' SINR.**



▲**Figure 7. Users' Throughput.**

Fig. 6 shows that the SINR of the advanced method is better than the original method. According to SINR cumulative distribution function (CDF) curves showed in Figs. 6 and 7, we can see that after a small cell is switched on, the interference level has been apparently alleviated. What's more, it turns out that with more small cells switched on, the interference level is more improved in Fig. 6. Based on the improvement of system capacity from switched-on cells, our proposed scheme provides higher performance for system.

Fig. 7 gives the femto users' average throughput and shows that the trend of throughput curves are consistent with SINR curves. In our system models, there are different numbers of small cells switched on during a drop. Compared with the original scheme, UEs' average throughput is improved visibly because of interference cooperation of our proposed scheme. In addition, after more small cells are switched on, the system capacity is more enhanced and UEs' average throughput is also improved more evidently.

Frequency pre-allocation can reduce co-channel interference after a small cell is turned on. With this method, users can get a higher data rate because of low interference. In addition, the introduction of this method has no negative effect on the whole system service. The cell switch method can save system energy and signaling overhead. In a word, our proposed scheme for switched-on cells can provide a higher system performance.

5 Conclusions

In this paper, we proposed an advanced frequency allocation method for co-channel interference cancellation via analysis of existing resource management methods. It turns out that the improvement of frequency resource allocation method can guarantee the quality of system service according to our simulation results. The proposed method can also play the role of interference cancellation. However, band utilization of this method is lower than the whole frequency reuse, and cell center users' throughput will be a little reduced. In the future, we will further optimize the method and enhance the service quality of the system.

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Manuscript received: 2015-12-19

Biographies

SUN Yang (sunyangemail@bupt.edu.cn) received the BS degree from the Beijing University of Posts and Telecommunications (BUPT), China in 2011. She is currently working toward the PhD degree with the School of Information and Communication Engineering, BUPT. Her current research interests focus on ultra-dense heterogeneous network, massive MIMO and green telecommunications.

CHANG Yongyu (yychang@bupt.edu.cn) received her PhD from BUPT in July 2005. Since then, she has worked with the Wireless Theory and Technology Laboratory of School of Information and Communication Engineering there. She has been engaged in the research of theories and key technologies in mobile communication for many years. She has made remarkable achievements by leading or participating in many research programs, some of which are supported by the government, such as the China National "973" Program and the China National "863" Program. Her current research is focused on the key technologies and system performance evaluation for 4G/5G wireless networks.

WANG Chao (874699078@qq.com) received his BE degree in communications engineering from BUPT in 2015. Currently, he is a postgraduate with the Wireless Theory and Technology Laboratory in BUPT. His research focuses on M2M communication, radio resource management and massive MIMO.

ZHANG Lu (zhanglu.lucas@outlook.com) received his BE and MS degree in communications engineering from BUPT in 2013 and 2016 respectively. His research interests include mobility management and radio resource management in 5G ultra-dense network.

ZHANG Yu (Zhang.yu38@zte.com.cn) received her master's degree in signal and information processing from Nanjing University of Post and Telecommunication, China in 2006. She is a senior standard engineer with ZTE Corporation, engaged in wireless high-level protocol standard research from 2008 with a focus on 5G related topics such as UDN and Massive MIMO from 2014. She is the co-authors of "White Paper of 5G Future Forum" and "White Paper of IMT-2020(5G) Wireless Technology" of ZTE Corporation.

WANG Xinhui (wangxinhui@zte.com.cn) received his master's degree in database processing and design from Northeastern University, China in 1998. He is the director of standardization of ZTE Corporation, engaged in standard research and industry relationship from 2006. He has led the 5G Standardization team to work on 3GPP RAN/3GPP SA/IEEE/ITU specifications in different radio aspects from 2013. He is the first authors of ZTE 5G white paper "Driving the Convergence of the Physical and Digital Worlds", 5G paper "Focusing on User Experience to Build in Converged, Innovative 5G Networks", and CCSA 5G speech "5G Vision and Challenges".