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Disruptive Technologies and Potential Cellular Architecture for 5G

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Abstract: The 5G wireless communication system is a new generation mobile communication system beyond 2020. 5GNow is still in the exploration stage. There are some shortcomings in LTE and LTE-A, such as strict synchronism, latency in crowded areas, energy consumption, and challenging in IoT, etc. The 5G wireless networks is a will consider satisfying better user experience, manifoldness of services, M2M of IoT. In this paper, we discuss some promising key technologies and conclude 5G potential cellular architecture .

Keywords: 5G, network architecture, disruptive technologies.

1. INTRODUCTION

With the development of mobile communications and electronic element technologies, better user experience and lower price of devices will accelerate the growth rate of penetration of smart phone and tablet beyond 2020. It is estimated that the number of global subscriptions of smart phone could be 10 billion in 2025 and 12 billion in 2030. And the number of global subscriptions of tablet and other smart devices could be 3 billion in 2025 and 5 billion in 2030. However, the number of feature phone subscriptions will decrease rapidly beyond year 2020 [1]. Now, 4G system has been deployed and is reaching maturity. There are only incremental improvements and a little new spectrum can be expected. So, what's the wireless networks in the future [2]. Cisco reports that the wireless data explosion is real and will continue in the annual visual network index (VNI) report (Feb. 2014). Largely driven by video streaming, tablets, and smart phones, the VNI forecasts that incremental changing in wireless networks will not meet the demands beyond 2020 [3].

Accordingly, wireless communications have to properly address key challenges and requirements driven by multiple perspectives of society, environment, economy, users, and operators so as to successfully achieve the vision of an inclusive, cohesive, and sustainable society. Academies are engaging in collaborative projects to meet the intense demands *via* innovative new technologies, such as METIS [4].

The key technologies in 5G networks are not physical layer transmission technology and channel encoding technology, but also considering more extensive breakthroughs such as multi-points, multi-users, massive MIMO, multi-cells cooperation, and higher-level spectral efficiency. The 5G enhancement architecture will greatly improve the system performances.

Compared to the 4G network, it is estimated that the future wireless network services should achieve more than 10 times the spectral efficiency by introducing new wireless transmitssion technology, 25 times the average cell throughput by introducing new architecture, and achieve 1000 times the system capacity [5].This means that the 5G network can support some special circumstances which 4G network cannot support such as supporting users in high-speed trains. The highest supporting speed in 4G is only 250 km/h, but the High-speed trains speed can reach 350 km/h up to 500 km/h.

In this article, we discuss various key technologies and future challenges in 5G communication systems, such as heterogeneity and super dense deployment of wireless devices, D2D telecommunication, massive MIMO, and green communications. Meanwhile we conclude a potential 5G architecture, which has large capacity, high-speed, low-latency characteristics.

2. POTENTIAL CELLULAR ARCHITECTURE

The reform of the 5G system structure will be the main development direction of the next generation wireless mobile communication system. The existing flattening SAE/LTE system structure promotes the high fusion of mobile communication system and Internet. The further development trend of the mobile communication evolution is high density, intelligent, programmable. Meanwhile, content delivery network (CDN) deployment to the core network edge, can effectively reduce the network access routing load, and significantly improve the user's mobile Internet service experience [6].

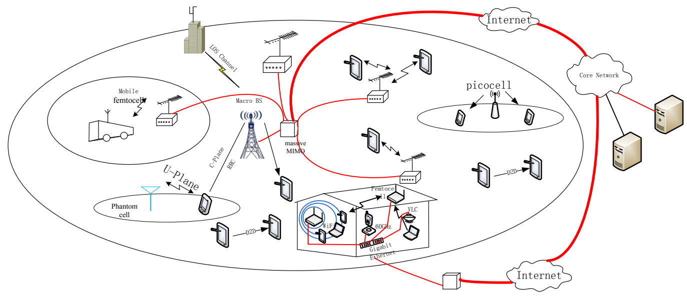

Fig. (1). The proposed architecture of 5G wireless cellular network.

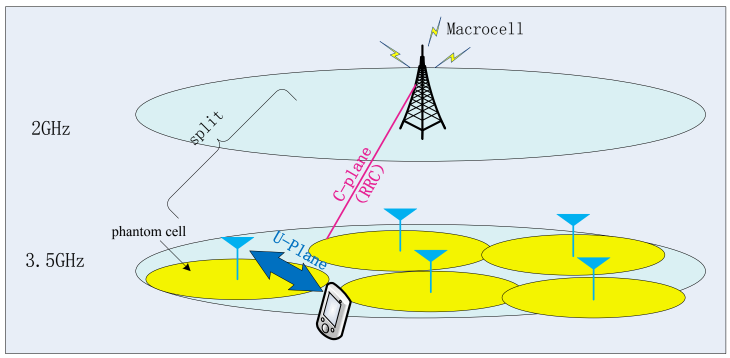

Fig. (2). Phantom cell: macro-assisted small cell [7].

The current conventional cellular architecture doesn't distinguish users stay indoors or outdoors, and communicates with mobile users by an outdoor BS in the middle of a cell. If the user is in the door, the signals will penetrate the door and experience high loss. This will damage the spectral efficiency, data rate, and energy efficiency significantly. So, we consider separating outdoor and indoor scenarios. In the outdoor scenaios, the deployment of the high speed movement condition should be particularly considered. The proposed potential 5G network architecture is consisted by scenarios deployment, access network and core network, which is shown as Fig. (**1**).

2.1. Scenarios Deployment

As the effective method of improving the system spectrum efficiency and transmission reliability, MIMO technology has been applied to a variety of wireless communication systems, such as in LTE, LTE-A, WLAN. The current MIMO systems are mostly used 2-4 antennas. In massive MIMO systems, the capacity of MIMO channel will be approximately linear with the minimum number of transmit or receive antennas.

We equip outdoor base stations with distributed antenna system and massive MIMO technology. The antenna elements were scattered in the cell and connected to the BS by fiber optics technology. Deploy femtocell in mobile terminals and you can dynamically change its connectivity to the operator's core network. At the same time, deploy virtual cellular as a macro cellular complement, and enhance the outdoor coverage.

Indoor users only need to communicate with indoor AP, which was install in the outside the building with large antenna arrays. So we can use variety short distant communication technologies for high data rate transmission, such as WiFi, femtocell, mm-wave (3–300 GHz), and visible light communications (400–490 THz). High-frequency waves are scattered or absorbed by foliage and rain very easy, and penetrate the solid material very poor. But these waves can improve data rate greatly in door. Therefore, this scenario can use more spectrum resources.

For the next generation of intelligent transportation system, mobile femtocells can be deployed in vehicles. The link between Mobile femtocells and core network can be dynamically changed. The Mobile femtocell and users in the coverage as a unit is connected to the BS. It benefits to reduce the network signaling overhead and the cross region handover. So, the deployment of femtocell Mobile on the vehicle can improve the quality of service. Moreover, the shorter distance communication with mobile femtocell, It can prolong user's battery life.

The phantom cell solution can offer good mobility [7]. As shown in Fig. (**2**), the solution splits cell to control plane and user data plane. The control plane's UEs in smallcells use lower frequency band. Meanwhile, user data plane's UEs in smallcells use higher frequency band.

2.2. Access Network

As the distribution of dense even super dense small cellular and mixed different type access points, such as GSM,

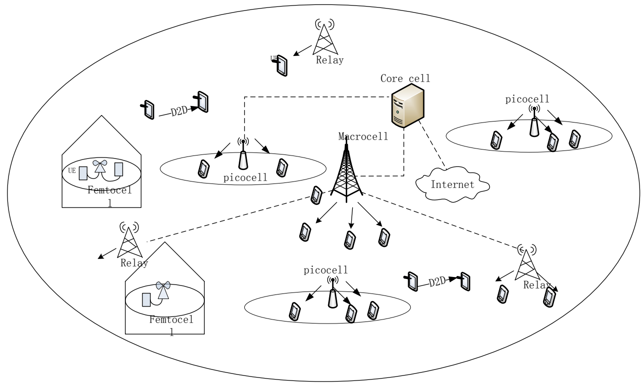

Fig. (3). A multi-tier network composed of distinct type of cell.

LTE, Wifi, using the single radio controller (SRC) can enhance the existing interface, and achieve backward compatibility. Using C-RAN enhanced structure, which evolution to virtual base station based on real-time cloud architecture, can schedule frequency resources dynamic.

2.3. Core Network

With the development of network function virtualization (NFV) and software defined network (SDN), mobile communication network will become more flexible and extensible. Although virtualization is only used in the core network, but it will be extend to the edge of the network gradually.

Software defined network (SDN) technology is a kind of virtual network structure, which separates the core network control from data planes. The main benefits of this architecture is intelligent network logical decouple, which separate software based on controllers, expose the network capabilities through an application program interface. Therefore, the SDN technology can be summarized as control and forwarding, equipment resources virtualization, general hardware and software programmable.

Network virtual function is relying on hardware network function, which can run on cloud computing infrastructure in the data center. Then it can realize the separation between physical hardware and logic. By using IT virtualization technology, we can migrate core network device to high performace server, and transplant the core network element function from dedicated hardware to the general virtual machine platform. It simplifies the design of hardware platform and reduces the cost of network. Separation network function function from the hardware infrastructure will be the cornerstone of future mobile network architecture. It can be more flexible to create a virtual network and a new type of network service [8].

3. POTENTIAL DISRUPTIVE TECHNOLOGIES

In this section, based on the disruptive change in architectural design, we discuss some potential disruptive technologies in 5G. We can express the total system capacity C_{sum} as follows:

$$C_{sum} \approx \sum_{HetNets} \sum_{Channels} B_i \log_2\left(1+\frac{P_i}{N_p}\right) \quad (1)$$

Table 1. The description of parameters.

Parameters	Description
B_i	i^{th} channel's bandwidth,
P_i	i^{th} channel's signal power
N_p	noise power

The parameters of equation (1) are given in Table **1**. From Eq. 1, we can increase the network coverage, number of sub-channels, bandwidth and power to increase C_{sum}。

3.1. Super Dense Heterogeneous Network Deployment

Making cells smaller is a straightforward effective way to increase the network capacity. This approach has been demonstrated over several cellular generations. With the evolution of femto, Pico and Micro and other small cellular technology, a trend of the future network development is the cellular coverage shrinking. However, as random characteristics of small cellular, small cellular's super dense distribution will inevitably appear, in order to improve the transmission rate and the capacity of the network access [9]. 5G will integrate between different RATs, and 5G-enabled device having radios can not only support 5G-enabled device, but also 3G,4G LTE [10]. In order to solve the future data explosive growth, deploying super dense heterogeneous network will be a effective way.

3.2. Multi-tier Network Interference Management

5G mobile and wireless communication systems will is a mix new system, which can improve the spectral and energy efficiency. There will be larger number of heterogeneity and dense deployment of wireless devices than today's networks. It will be a multitier network composed of macrocell, picocells, femtocells, relays, and D2D, as illustrated in Fig. (**3**). The multiple tiers network architecture will lead to better performance (eg.capacity, coverage, spectral efficiency, and total power consumption). Meanwhile, this network architecture will arise more complicated interference. It is challenging to manage radio resource and interference in multitier and heterogeneous 5G cellular networks. The reasons are as follows:

1) Heterogeneity and dense deployment of wireless devices.

2) Different BS transmit powers lead to imbalance in traffic load

3) Different tiers have different access restrictions (public or private) that lead to interference levels different.

Some previous work investigated interference management schemes in multi-cell scenario. [11] proposed the joint resource allocation scheme. The optimal solution considered a two stage resource allocation. First, considering to select each cell's users sequentially and don't consider the interference. Then, optimized power control by geometric programming solution. [12] proposed a distributed subcarrier and power joint allocation scheme. Through measuring neighboring cell's interference, each cell decides own resource allocation scheme individually. So, the adjacent BSs will relay the cooperative data. [13] conducted a multi-cell joint resource allocation scenario. However, assuming each cell's per tune power was constrained.

The traditional radio resource and interference management (e.g. power control, load balancing, or channel allocation) in single-tier or even in two-tier networks may not be efficient in 5G multi-tier network. So, new interference management methods should be considered in 5G multi-tier network.

3.3. D2D Communication

Another important direction, which is expected to characterize beyond 4G and 5G networks, is the creation of dynamic networking constructs consisting of interconnected end-user equipment, such as D2D communication.

D2D communication is a kind of short distance communication, which allows data transmission between terminals directly. It is clear that D2D will be more efficient, when handle local communication. The advantages are high-data-rate exchanges, low-latency, low transmission cost, saving resources, and reducing interference D2D communication has been approved in the R12 version of LTE-A as an addition-nal 4G technology. Public safety of the D2D communication is the main focus of current studies [14].

The challenges of D2D communication in 5G is as follows:

1) Radio resource allocation for D2D: When is suitable to enable D2D communication mode. How does D2D communi-cation share resource with cellular communication?

2) The interference manages in D2D mode.

3) The reliability and the real-time problem.

3.4. Massive MIMO

MIMO research is blossom in late 1990s [15, 16], and it was introduced into 3G cellular and WiFi systems. The MIMO transmission technology was used in the IMT-Advanced standard thereafter. In 2010, Marzetta studied the MIMO technology, which equips BSs with infinite number of antennas. Meanwhile, he put forward the concept of "large-scale MIMO" or "Massive MIMO" [17]. In massive MIMO, the number of antennas which are equipped with BSs is very large(usually dozens to hundreds).On the antenna configuration mode, the antenna can not only be centrally configured on a BS and form the centralized mass MIMO, but also be distributed to configuration on multiple nodes and form a distributed mass MIMO. The benefits of mass MIMO are as follows:

1) The spatial resolution of massive MIMO has been significantly enhanced compared with the existing MIMO. By mining spatial dimension resources deeply, the multiple users in the network can use the same time-frequency resources communicating with BS at the same time. So, without increasing the BS densification, the spectrum efficiency can be greatly improved.

2) Massive MIMO beam can be concentrated in a very narrow range, so as to reduce the interference.

3) The transmission power will be reduced significantly, and the power efficiency will be improved.

Therefore, 5G using MIMO for the current large-scale system design is a big leap, which needs to be further studied in channel model to conform to the actual application scenario, and analyze its influence on channel capacity. Meanwhile, we should analyze the spectral efficiency, power efficiency, and study the wireless transmission of the optimal methods, channel information acquisition method, and multiuser wireless resources sharing space joint resource allocation methods in the actual channel model with a moderate amount of pilot overhead.

From the discussion above, massive MIMO for 5G is a major leap for current communication system. We need to further study channel model, and analyze its influence on channel capacity. Meanwhile, we need analyze spectral efficiency, power efficiency, and study the optimal wireless transmission methods in the actual channel model.

3.5. New Waveforms

LTE-A has been designed to meet strict orthogonal and synchronous. This is the major obstacle to design the service architecture. Orthogonality requires no crosstalk, when it detects waveform in the receivers. Synchronism requires that all senders operate with the same clock. But in 5G systems, the characteristics of Internet of Things (IoT) are bursting to transport very small packets, requiring low latency and fast response times. So, how to avoid wastage should be considered when designing the air interface. Meanwhile, very short frames are the key factor to guarantee the fast response.

Table 2. The description of UFMC parameters.

Parameters	Description
X	transmitting multi-carrier symbol
B	the number of subband
F_i	Toeplitz matrix of subband i , including filter impulse response
v_i	inverse Fourier matrix of subband i
s_i	per-subcarrier of transmitting in subband i

FBMC and UFMC are potential candidate for 5G wireless. FBMC was considered filtering on a subcarrier level, instead of the whole frequency band. Except for sinc-pulses, the sub-carriers can be used more suitable shape to reduce side lobe levels, when design the filter. CP will not be considered, and it will improve time-frequency efficiency. The offset-QAM is used in FBMC. Because of burst data transmission, filters require long lengths, so the areas in ramp up and down are long.

The UFMC solution is filtering on per subband. The transmitting multi-carrier symbol in time-domain is [18, 19]:

$$X = \sum_{i=1}^{B} F_i * V_i * s_i \tag{2}$$

The parameters of equation (2) can be found in Table **2**.

The temptation of UFMC functions is shown in Table **2**.

The UFMC is considered the advantages of filtered OFDM and FBMC, and trade off the disadvantages of the two schemes. Designing the filter which is performed per sub-band, suppress the spectral side-lobe levels and offer better ICI robustness. Hence, the UFMC waveform is better suitability for short bursts. Additionally, UFMC may efficiently use QAM modulation, comparing to offset QAM in FBMC.

CONCLUSION

According to the development of mobile communication, 5G systems will be deployed beyond 2020. The basic development goal is to meet the rapid growth of mobile internet business, and better user experience. In this paper, we discuss some promising key technologies and conclude 5G potential cellular architecture. With more and more study on key technology, 5G will enter the standardization stage in the coming years.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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