User Ultra-Dense Networks™ for 5G

In Urban Areas

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Contents

Chapter 1
User-Centric Ultra-Dense Networks for 5G

1.1 Introduction

In recent years, with the growing popularity of smart devices and wide spreading of mobile Internet, the mobile data traffic is increasing dramatically. By 2020, the global mobile traffic volume will have about 1000 times growth compared to that of 2010 [1, 2]. According to the mobile cellular history from the first Generation Mobile Communication System (1G) to fourth Generation Mobile Communication System (4G), each generation has about ten times data rate enhancement related to the previous generation. The next generation of International Mobile Telecommunication towards 2020 (IMT-2020), i.e. the fifth Generation Mobile Communication System (5G), would thus reach 10 Gbps, which is ten times peak data rate to 4G. In 2015, International Telecommunications Union-Radio Communications Sector (ITU-R) published the recommendation on the framework and key capabilities on IMT-2020 [3]. Base on the recommendation, the area traffic capacity is one of the most important Key Performance Indicators (KPIs) for 5G and requirement value reaches 20 Tbps/km^2 in dense urban or hotspot area. In addition, other requirements such as lower latency, higher spectral efficiency and energy efficiency are also included.

There are usually three paths to improve the area throughput in wireless system: (1) Improving spectral efficiency through new coding and modulation technologies; (2) Increasing available spectrum bandwidth, using more spectrum resources; (3) Cell splitting to improve spectrum space reuse density. In Ref. [4], it is observed that, by 2008, the wireless capacity has increased 1 million times from 1957. Among these gains, 25 times improvements came from wider spectrum, 25 times improvements were contributed by advanced air interface designs, and 1600 times improvements were due to the reduction in cell sizes and transmit distances. Firstly, from technique evolving viewpoint, in 4G, the potential gain derived from the advance of wireless modulation and multi-antenna technologies, is approaching the upper bound based on the Shannon limitation. In Long Term Evolution Advanced (LTE-A),

S. Chen et al., *User-Centric Ultra-Dense Networks for 5G*, SpringerBriefs in Electrical and Computer Engineering, DOI 10.1007/978-3-319-61201-0_1

the theoretical peak spectral efficiency has reached 30 bps/Hz through eight-layer spatial multiplexing. This peak value nearly reaches the limit of typical wireless transmitting technology. Secondly, the spectrum resource is limited. The continuous deployment of radio services, such as satellite, broadcasting, scientific uses, fixed and mobile terrestrial, etc., result that spectrum become limited and rare resources. For year 2020 and beyond, ITU-R Working Party 5D (WP5D) forecasts that the global spectrum requirement of IMT will reach a total amount of 1900 MHz [5]. It is obviously a big challenge to identify and allocate enough spectrum resource to IMT system based on current situation.

Based upon the above analysis, it is hard to meet 5G traffic capacity requirements through increasing spectral efficiency and allocating more spectrum bands only. Therefore, we can conclude that the increasing of the wireless Access Point (AP) density with smaller coverage is the most efficient way to improve the system traffic capacity, especially in hotspot scenarios [4]. China promoted LTE-Hi [6] to increase the system throughput for hotspot areas. LTE-Hi is a LTE based hotspot solution, which aims to provide higher performance in hotspot and indoor environments by exploiting wider bandwidth in higher frequency. On the other hand, since Bell Lab proposed the concept of “cellular” in 1970s, radio network architecture has been adopted in the successive generations of mobile networks. For architecture evolution perspective, authors in [7] point out that the macro cellular and local small cell coexistence architecture in 5G will replace the macro cell-dominated architecture from 1G to 4G.

In ITU-R Report M.2320 [8], Ultra-Dense Network (UDN) is promoted as one of the technology trends to meet the high throughput requirements of 5G. And METIS [9] also take the Ultra Density Network as one of the most important topics towards the mobile system for 2020 and beyond.

Typical deployment scenarios of UDN include: office, apartment, open-air gathering, stadium, subways and railway station [3]. The common requirements in these scenarios are huge numbers of users and connections, high density network traffic and high data rate. To meet these requirements, the AP(s) need to be deployed densely, with minimum Inter-Site Distances (ISD) of tens meters or below, e.g. one or more APs per room for indoor scenarios, and one AP on each lamp post for outdoor street scenarios. Authors in [10] propose user-centric UDN for 5G, which introduces the philosophy of the network serving user and the “de-cellular” method.

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Chapter 2
5G Requirement and UDN

2.1 5G Scenarios and Requirements

International Telecommunications Union (ITU) has defined the framework and overall objectives of the future development of IMT-2020 in light of the roles that IMT could play to better serve the needs of the networked society in the future [1]. There are three usage scenarios for 5G as shown in the following Fig. 2.1.

1. Enhanced Mobile Broadband (eMBB) addresses the human-centric use cases for access to multi-media content, services and data. This scenario will come with new application areas and requirements in addition to existing Mobile Broadband applications for improved performance and an increasingly seamless user experience.
2. Ultra-Reliable and Low Latency Communications (URLLC) use cases have stringent requirements for capabilities such as ultra-low latency and higher availability. Some examples include wireless control of industrial manufacturing or production processes, remote medical surgery, distribution automation in a smart grid, transportation safety, etc.
3. Massive Machine Type Communications (mMTC) use cases are characterized by a very large number of connected devices typically transmitting a relatively low volume of non-delay-sensitive data. Devices are required to be low cost, and have a very long battery life.

For the eMBB scenario, it covers a range of cases, including wide-area coverage and hotspot, which have different requirements. For the hotspot case, i.e. for an area with high user density, very high traffic capacity is needed, while the requirement for mobility is low and user data rate is higher than that of wide area coverage. For the wide area coverage case, seamless coverage and medium to high mobility are desired, with much improved user data rate compared to existing data rates. However the data rate requirement may be relaxed compared to hotspot. Based on above three scenarios, eight key performance capabilities are defined by ITU-R as shown in the Fig. 2.2.

S. Chen et al., *User-Centric Ultra-Dense Networks for 5G*, SpringerBriefs in Electrical and Computer Engineering, DOI 10.1007/978-3-319-61201-0_2

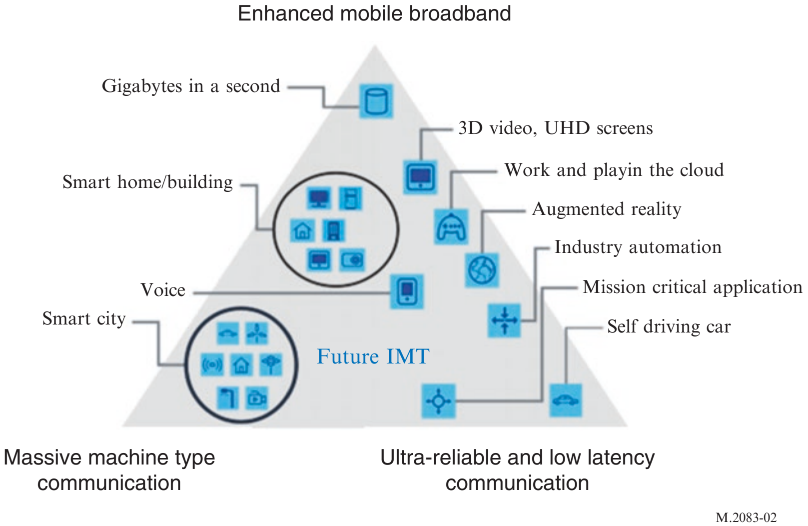

Fig. 2.1 Usage scenarios for 5G. Reprinted from ITU-R M.2083-02 [1]

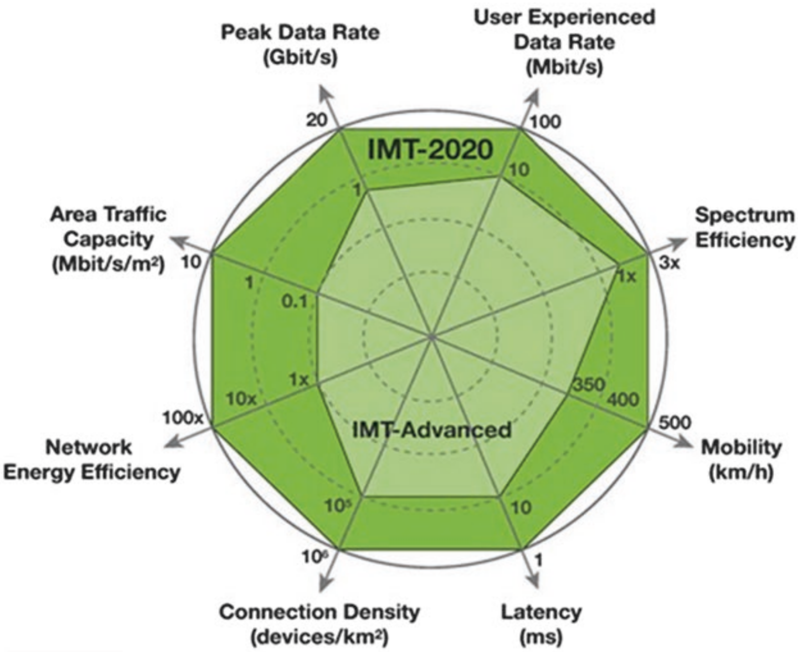

Fig. 2.2 Key performance requirement for 5G. Reprinted from ITU-R M.2083-03 [1]

The peak data rate of IMT-2020 for eMBB is expected to reach 10–20 Gbit/s. IMT-2020 would support different user experienced data rates covering a variety of environments for eMBB from 100 Mbit/s to 1 Gbit/s. The spectrum efficiency of 5G is expected to be three times higher compared to IMT-Advanced for eMBB. And IMT-2020 is expected to support 10 Mbit/s/m^2 area traffic capacity, for example in hot spots area. The network energy efficiency should therefore be improved by a factor at least as high as the envisaged traffic capacity increase of IMT-2020 relative to IMT-Advanced for eMBB. IMT-2020 would be able to provide 1 ms over-the-air latency, capable of supporting services with very low latency requirements. IMT-2020 is also expected to enable high mobility up to 500 km/h with acceptable Quality of Service (QoS). This is envisioned in particular for high speed trains. Finally, IMT-2020 is expected to support a connection density of up to 1 million connections/km^2, for example in mMTC scenarios.

Among all those requirements, data throughput capacity like area traffic capacity and user experienced data rate is most important for 5G eMBB. We can see that 5G is expected to support up to 10 Mbit/s/m^2 area traffic capacity and 1 Gbit/s user experienced data rate. In order to meet above stringent requirement, based on the analysis in Chap. 1, it is critical to rethink the 5G cellular network structure and introduce UDN technologies [2–5].

2.2 UDN in 5G

2.2.1 UDN Deployment Scenarios

The characters of typical UDN scenarios, such as office, apartment, open-air gathering, stadium, subways and railway station, include:

1. Very high user density: Given the office as an example, assuming the grid for each employee is 2 m × 2 m, the corresponding user density is 0.25 person per m^2;
2. Very high traffic density requirement: Open Air gathering as an example, nearly all the people would like to share the video clips with their friends through mobile phone APPs at the moment of exciting show. This will lead very high traffic density requirement, which will reach almost 10 Mbps/m^2;
3. Very high AP density: All those scenarios are capacity limited, so the AP coverage will be very small to ensure enough throughput. For example, the ISD between APs in office can be as low as 10 m.

Based on above analysis, in UDN, the AP coverage range is about 10 m and there are thousands of APs in 1 km^2. But in traditional cellular network, cell range is more than 500 m and usually less than around 3–5 Base Stations (BSs) in 1 km^2. Correspondingly, only one or several terminals are connected to one UDN AP, whereas hundreds or even thousands of active users are resident in one macro cell. Table 2.1 gives the differences between the UDN and traditional cellular network.

Another key point is that the type of APs in UDN is diversified. Small cell station, relay station, distributed Remote Radio Head (RRH) and User Equipment (UE) itself can act as an AP in UDN. However the macro BS in traditional cellular network is the dominate unit for user connection.

Table 2.1 Comparison between UDN and the traditional cellular network

Item	UDN	Traditional cellular network
Deployment scenarios	Indoor, Hotspot	Wide coverage
Site/AP density	More than 1000/km^2	3–5/km^2
User density	High	Low/medium
Site/AP coverage	Around 10 m	Several hundred meters and more
Deployment	Heterogeneous, Irregular coverage	Single layer, Regular cell
Site engineering	User deployment	Operator deployment
AP style	Small-cell, Pico, Femto, UE relay, Relay	Macro/micro BS
AP Backhaul	Ideal/non-ideal, Wired/wireless	Ideal, Wired
User mobility	Low mobility	High mobility
Traffic density	High	Low/medium
Typical bandwidth	Hundreds of MHz	Tens of MHz
Spectrum bands	>3 GHz (up to mm Wave)	<3 GHz

Besides the above features, higher spectrum frequency and wider bandwidth, heterogeneous and irregular deployment, flexible backhaul, lower user mobility are also the obvious differences between UDN and traditional cellular networks.

2.2.2 UDN Technologies in 5G

In ITU-R Report M.2320 [6], UDN is promoted as one of the technology trends to meet the high throughput requirements of 5G. In this report, key issues of UDN include following aspects:

1. Network architecture and protocol procedure enhancements: to optimize data and control paths, mobility management and signalling procedure. These enhancements will reduce the end-to-end latency and overhead;
2. Interference avoidance and inter-cell coordination: interference management and other coordination mechanism among the cells will increase the whole system throughput and guarantee the users' experience;
3. Energy efficiency: including network energy saving and UE power saving;
4. Super Self-organized Network (SON): release the operators' burden for network optimization and increase the flexibility of deployments.

In Ref. [4], METIS defines UDN as a stand-alone system that will be optimized for hotspot areas where the highest traffic increase will be observed. The core concept of UDN includes Radio Access Technologies (RATs), small cell integration/interaction and wireless backhauling. Beside considerations on a new spectrum flexible air interface, it foresees a potentially tight collaboration of nodes w.r.t. resource allocation coordination, a fast (de-)activation of cells and inbuilt self-backhauling support. An extended UDN concept offers additional performance improvement by: (1) context awareness for mobility, resource and network management, (2) inter-RAT/inter-operator collaboration, (3) tight interaction of a UDN layer with a macro layer holding superior role in control and management functions over common area, and (4) macro-layer based wireless backhaul for flexible and low-cost UDN deployments.

In Ref. [7], UDN is one of the most important technology directions to meet 5G traffic density requirement. To meet the requirements of typical scenarios and cope with the technical challenges, cell visualization technology, interference management and suppression technology, joint access and feedback technology, are important research areas in UDN. Cell visualization technology includes user-centric virtual cell technology, virtual layer technology, and soft sector technology.

The authors in Ref. [8] suggested that UDN is a major technology to meet the requirements of ultra-high traffic volume density.

In general, UDN is a new wireless network solution for hotspot scenarios, to provide sufficient area capacity and better user experience in 5G. In UDN, the AP density is comparable to or even higher than the user density. So, authors in [9] propose user-centric UDN, different types of APs will be tightly cooperated as a very flexible network to serve each user and achieve higher spectrum efficiency, lower power consumption and seamless mobility.

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Chapter 3
Concept and Challenge of UUDN

3.1 Concept of UUDN

In this book, we define User-Centric Ultra-Dense Networks (UUDN) [1] by introducing the philosophy of network serving user and the "de-cellular" method. UUDN is a wireless network in which the AP density is comparable to the user density; this network will organize an AP Group (APG) as a following coverage to serve each user seamlessly without user's involvement. UUDN lets user feel like a network always following him. So, the network shall intelligently be aware of the user's wireless communication environments, and then flexibly organize the required APG and resource to serve the user to let the user feel like always in the center of a "cell". Figure 3.1 shows the concept from cell centric to user-centric.

3.2 Characteristics of UUDN

In order to make the users feel like always in the center of the cell, there are four main features of UUDN as follows.

1. **Intelligent Network Knows User**
   The network will be more intelligent and can automatically detect the terminal's capability, user's requirements, and its radio environment, as well as construct knowledge information for each user. All those information and knowledge will be used for network management and resource allocation for user-centric experiences.
2. **Moving Network Follows User**
   While a user is moving, its APG will be dynamically adjusted to support its movement, which is quite different from traditional mobility management and handover process. The user will feel like a "moving coverage" is following himself all the time.

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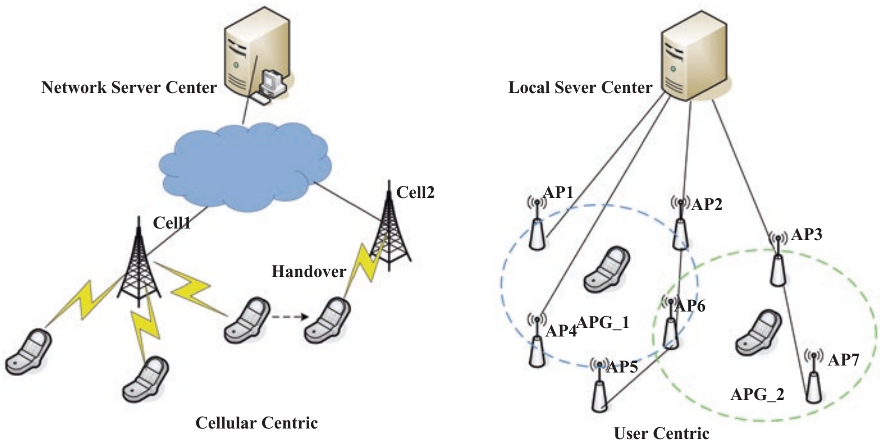

Fig. 3.1 Concept of user-centric

3. **Dynamic Network Serves User**
   APG's members will be adjusted adaptively to match user's service requirement. They can transmit data stream jointly and cooperatively, to enhance the spectrum efficiency and user experience.
4. **Secured Network Protects User**
   The network will provide security guarantees through the special group authentication when an AP joins into the APG. The result of the authentication can thus be smoothly perceived or inherited between the members within the APG.

3.3 Challenge of UUDN

3.3.1 Challenges of Network Architecture

The traditional cellular network architecture is designed for wide area coverage. Due to the differences of UDN and traditional cellular network discussed in Table 2.1, in order to reach the user-centric experience, there are number of issues if applying the traditional cellular network architecture (e.g. 4G) to UUDN.

1. **High Signaling Overhead and Lengthy Data Path**
   In 4G and beyond system architecture, too many functions such as service control and mobility control are centralized in Core Network, which include Mobility Management Entity (MME) and Packet Data Network Gateway (PGW)/Serving Gateway (SGW). It is not efficient for UDN with high traffic throughput and ultra-dense APs deployment, because it will lead to signaling overhead and redundant and lengthy data transmission path between APs and Core Network. Localized and flatter structure is a trend to dealing with the very high area capacity.

2. **Frequently Handover**
   The tight coupling of user plane and control plane in one air connection will result in frequent handover when the AP coverage is very small. It is not efficient and flexible in heterogeneous networking within both macro and UDN AP coverage. Virtualized cells structure with decoupling the user plane and control plane access is critical in UUDN.
3. **Independent Cells**
   In order to better support advanced interference management and resource management for UDN, the higher layer functions of each distributed AP needs to be reduced. Higher layer process, Radio Resource Management (RRM), and mobility management functions are not suitable to be distributed on each AP independently. Centralized management and coordination of UDN APs are very important in UUDN.
4. **Better User Experience**
   UDN aims to provide very smooth handover and very high data rate for each user with ultra-dense AP. The simple data gathering and transmission function of Local Gateway (LGW) cannot support better user experience. More functions are needed in LGW.

   Therefore, a new architecture of UUDN is needed to support high density AP deployment and flexible network management. In this new architecture, a local centralized user service center is necessary for knowing and measuring user's radio environment. Besides, the RRM and user service control center much closer to the user are required to provide better joint processing and QoS control, and a lower mobility anchor is also needed. Meanwhile, the Core Network functions should be simplified to provide only high level service to user.

3.3.2 Challenges of Mobility Management

In the future wireless communication networks, mobility management is a key wireless resource management technology. For the second Generation Mobile Communication System (2G)/the third Generation Mobile Communication System (3G) and even 4G, mobility management is mainly refers to the management of the mobility of UE, including handover and location management. Specifically, the function of the handover control is to use what is measured to keep session when the user moves or AP changes, and location management consists of location tracking [2]. In order to deal with mobility problem, more flat and flexible mobility management approaches and handover methods are proposed, such as local anchor methods and cell clustering Scheme [3]. However, mobility management methods in traditional cellular system cannot be applied to UUDN due to following challenges:

1. Location areas are statically configured in traditional network. These areas are irrelevant to any user. The boundary of a location area in the cellular network becomes unclear in de-cellular UUDN. In traditional cellular network, users

handover from one cell to another, while in UUDN, the network will follow user's movement.

2. The handover control becomes difficult because of the irregular coverage and complex AP neighborhood relationships. Moreover, the different types of APs will result in complicated handover signaling processes. Therefore, the handover control of UUDN needs to be redesigned.
3. The UUDN will follow user's behavior, e.g. movement and on-demand service, to offer user-centric services in a more complicated wireless environment. So that the mobility management should be joint-optimized with the resource management and interference coordination.

Therefore, mobility management is emerging as a topic of research interest in UUDN. The mobility management in UUDN may provide an amorphous, dynamic and virtual location area, from "static AP planning" to "dynamic AP cooperation", and new handover methods should be designed.

3.3.3 Challenges of Network Engineering

UDN scenarios are extremely complex, in which the massive access site may have the ideal or non-ideal, wired or wireless backhaul. There will be homogeneous and heterogeneous network and multi-RATs accesses.

User-centric experience achievements within complex scenarios have brought a lot of challenges to the deployment and operation of the network, network planning and optimization, and network energy consumption control. In order to achieve the target of low cost, easy networking and high efficiency, it needs to combine with the UUDN architecture, cell virtualization technology, scenario adaptive interference management technology, and access, as well as backhaul joint design technology. The user-centric ultra-dense intelligent networking is for perception of wireless environment and business needs, for adjustment and the optimal allocation of system parameters and methods in order to improve the spectrum efficiency and user experience and reduce the energy consumption of the system as well the network operation manual maintenance costs.

Traditional cellular network design focuses on access design and separates access and management, which introduces the Operations & Maintenance (O&M) both to interact with network elements by southbound interface and to interact with network and service by northbound interface so as to achieve network static or semi-static control. In UUDN, the network will be more intelligent and can automatically detect the terminal's capability, user's requirements, and its radio environment, as well as construct knowledge information for each user. So UUDN needs to build a network management plane, to establish a global view of the network, to achieve the organic integration of management control and user plane and to realize intelligent networking.

3.3.4 Challenges of Interference Management

In traditional cellular networks, wireless interference could be controlled by carefully allocating frequencies among different cells and effective power control technologies. The users in the cell edge may endure the possible interference from neighbor BSs. But there is little interference in the cell center area [4]. However, in UDN, the distance between APs may be as close as a dozen of meters. This results in high-complex wireless transmission environments. When the user begins to move, the network should provide user-centric services, then interference becomes an essential problem in UUDN. Several challenges should be considered for effective interference management.

1. Due to the short transmission distance, the traditional resource allocation and power control method of interference management will not work well in the UUDN scenarios. Although the centralized control method may reduce the interference due to carefully schedule the resources in the local area and is suitable in the existing cellular systems, it may result in expensive managing expense and degrading performance in UUDN. The organization of APG following the user makes the interference environment change all the time along with the user's movement. More flexible frequency assignment scheme should be designed. The power control needs to be more accurate. Other interference managing technologies should also be considered.
2. The potential interference sources are much more than in the traditional cellular networks, not only due to the large amount of the APs and terminals, but also from more reflecting and scattering paths of the signals. The refresh of APG also brings new possible interference sources. The transmission models in different typical scenes should be set up, such as indoor office building, indoor spacious hall, crowd subway carriages, outdoor square and so on. These are complex models and would impact the interference control results.
3. The traditional existing parameters to evaluate interference impact such as interference threshold may not reflect the overall performance of the networks. With the enhancement of green communication, energy consumption and spectrum efficiency are both emphasized in UUDN. Relative parameters should be reflected in the resource management and interference control schemes. Then more suitable parameters should be used to give a better indication by trading-off interference managing results and throughput, energy efficiency and other system level parameters.

Therefore, the typical wireless transmission scenarios in UUDN should be analyzed based on the proper interference models, with accurate wireless channel models and suitable evaluation parameters. Then effective interference management schemes could be dedicated designed accordingly.

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Chapter 4
Architecture of UUDN

4.1 Trends on Architecture

The topology of UDN toward 5G can be summarized with following key characteristics: (1) high density of mobile APs distributed randomly without network planning [1]; (2) various kinds of APs with different backhaul or fronthaul capabilities [2]; (3) heterogeneous networks with different overage ranges, different spectrum band and multiple RATs [3–5].

Based on above characteristics, in order to provide high throughput and better user experience, some new principles and methods for network architecture design are introduced:

1. **Localization and Flatten**

It is a promising cost effective method to offloading the 1000 times of traffic throughput requirements to local UDN area. A flatter architecture is needed to support localization and decrease the cost of transmission. Localization of data path and controlling function are introduced by METIS [6] and NGMN [7] toward 5G UDN.

2. **Dual-Connection and User Plane/Control Plane (U/C) separation**

New principle in [8] is the dual/multi-node connections with the separation of control plane and user plane. It's an effective way to provide user high data rate through dense small cells, without mobility and connectivity experience degradation. This feature is supported since 3GPP Release 12 through the inter-evolved Node B (eNB) carrier aggregation.

3. **User-Centric**

Toward 5G, UDN is quite different from traditional cellular network. It is very important to introduce user-centric principle, the network will organize the dense APs dynamically to serve the user to make it feel like always in the center of a cell

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or a cell following the user. UUDN [9], including user-centric mobility management, user-centric clustering for data plane and user-specific network controlling, can provide better user experience and higher spectrum efficiency.

4. **Centralized Radio Access Network (RAN), Distributed RAN and Flexible RAN**

Centralized RAN and Distributed RAN architectures for UDN are discussed in [10]. For centralized architecture, it can provide better joint processing and get higher spectrum efficiency, yet it needs very high backhaul/fronthaul capability. Distributed architecture, it is more flexible for network deployment, but its interference management is difficult and has lower spectrum efficiency. A more flexible architecture is therefore preferred to adaptively connect APs with different backhaul/fronthaul capability [5].

5. **SDN&NFV**

The new trends of Software Defined Network (SDN) and Network Function Virtualization (NFV) also impacts on the design of the network architecture for 5G [11–13]. With the decoupling of controlling and transmission, software and hardware, the network architecture can be redesigned to define the logical functions and their interfaces, yet not the entities and their interfaces. This will also enable even more flexible architecture towards 5G UDN.

In summary, the trends of UDN architecture are becoming more flat, localized, U/C separation, user-centric, flexible and intelligent. Some examples toward small coverage density network are given in following subsections.

4.2 Architecture and Function Entities

The philosophy of the UUDN [9] will be changed from network controlling user to network serving user. It introduces three kinds of decoupling: U/C decoupling from radio access aspects, control and transmission decoupling from network aspects, local service and network service decoupling aspects.

Based on the philosophy, the UUDN architecture adopts de-cellular structure as depicted in Fig. 4.1.

In this architecture, there are no more "cells" logically and physically from user's perspective. Dense APs in one area will be organized intelligently to follow user's movement and provide data transmission on-demand.

Four functional entities are introduced to provide user-centric services. At the radio side, Local Service Center (LSC) and Local Data Center (LDC) are introduced to provide the logical U/C decoupling. All kinds of APs are connected to the LSC and LDC by various backhaul (idea/no-ideal, wire/wireless). At the Core Network side, Network Service Center (NSC) and Network Data Center (NDC) are introduced to provide the control and transmit functions. The LSC and LDC can

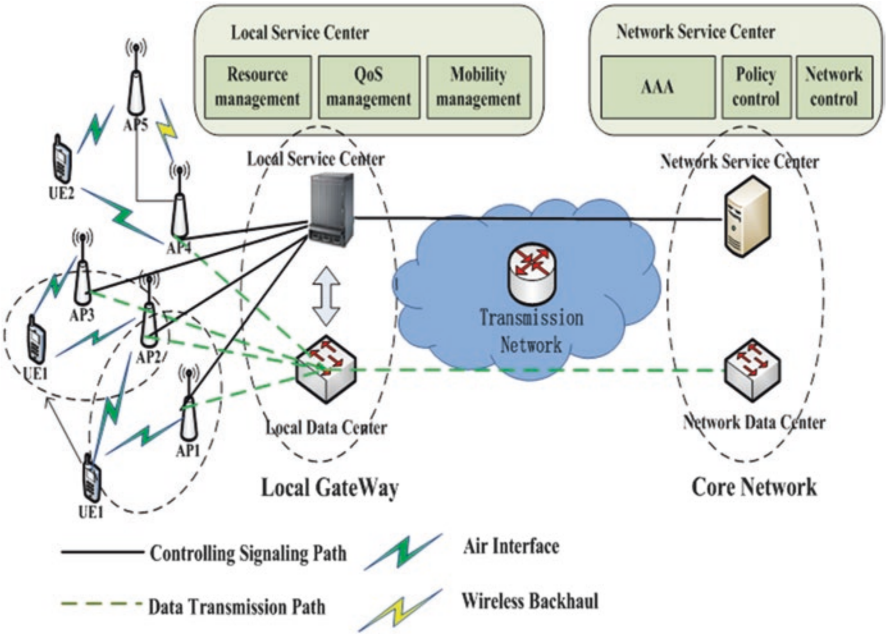

Fig. 4.1 User-centric UDN architecture

be integrated into one Local GateWay as a physical entity, and NSC and NDC may also be integrated into one Core Network entity.

The functions and interfaces of each entity in UUDN are as following:

1. AP is the radio access channel for UE including the data plane and the control plane. APs can be built with Radio Frequency (RF), Physical Layer (PHY), Media Access Control (MAC) and IP layer functions or combinations of them based on the backhaul capacity. If the AP has only RF, the PHY to IP layers will be centralized into LDC. With this architecture, LDC can provide joint processing in PHY layer. The advanced signal process can thus be used to avoid the inter-AP interference.
2. LSC is the control service center to organize a dynamic APG to serve one user. It will have the new functions including user-centric RRM, multi-RATs coordination, effective QoS control, user-centric mobility management, and local radio link control.
3. LDC is the local data center to dealing with user data transmission. It will provide the user plane functions including higher layer processes and dynamic AP channel processing. It also has the functions of Multi-AP coordination and multi radio bear convergence for users.
4. NSC is the network data center to provide the functions of user policy control, AAA, and high level mobility (roaming, inter NSC handover) etc.
5. NDC is worked as packet data gateway at the network side.

With this architecture, LSC and LDC are very close to the location of APs, so that it is easy to provide user-centric service functions, advanced resource management, and interference management. It is more flexible for UUDN deployment with the decoupling of user plane and control plane, and decentralizing the Core Network functions to LSC and LDC. And signaling overhead and backhaul overhead can be greatly reduced in UDN scenarios.

4.3 Technologies Direction

The characteristics of UUDN architecture includes flatter, localized, U/C separation, user-centric, flexible and intelligent. The characteristics comprising of some typical architectures toward UDN are summarized in the Table 4.1.

Based on the new architecture and challenges analysis, many key technologies can be introduced to provide high Quality of Experience (QoE), high area spectrum efficiency, low cost and green communication. The promising technology directions are summarized below:

1. **Dynamic APs Grouping (DAPGing)**

In order to provide user-centric experience, more large “following coverage” for control plane is essential. It can decrease the broadcasting overhead, decrease the frequency handover and simplify the user radio link control. On the other hand, in order to provide very high area capacity, smaller coverage AP for user plane is required. DAPGing with introduction of U/C splitting is a key technology for UUDN.

2. **Intelligent networking**

In order to automatically construct the knowledge information for each user and utilize that information for radio resource management, UUDN should support new protocol to converge management plane, user plane and control plane. From network management point of view, in order to decrease the capital expenditure and operating expense, UUDN should support self-networking and self-optimization. To increase the network flexibility, self-backhauling is also very important for UDN.

Table 4.1 Characteristics of the network architectures toward UDN

	3GPP HeNB architecture	3GPP SCE architecture	UUDN architecture [7]
Localization and flatter	LIPA & SIPTO	LIPA & SIPTO	Localized (user plane and most of the control plane)
U/C separation	No	Yes	Yes
SDN&NFV based	No	No	Yes
Flexible Backhauling	No	No	Yes
User-centric	No	No	Yes

More intelligent networking is required for UUDN at the system protocol and network function design level.

3. **Advanced interference management**

The interference between the close APs is a bottleneck to increase area spectrum efficiency. Advanced interference management is essential to provide very high user experienced data rate in UUDN.

4. **Security**

Complicated network structure, localized data path, diversity access types, all those new features made the security become a new challenge for UUDN. New security mechanisms are required to meet the requirement of 5G in UDN scenarios.

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Chapter 5
Key Technologies of UUDN

5.1 APG

In UUDN architecture, there are no more "cells" logically and physically from user's perspective [1]. In addition, the different types of APs will result in complicated handover signaling processes. Therefore, many APs in one area will be organized intelligently to follow user's movement and provide data transmission on-demand.

The DAPGing changes the traditional cell design concept, in control plane organizes the multiple APs as APG to serve each user seamlessly without the user's involvement, as shown in Fig. 5.1. The APG is managed in a central control plane, while in user plane used as the resource provider to schedule separately, thus avoiding a large number of control signaling overhead and the frequent handover of the terminal. In APG, each user moves in the combined APs as if stays in a single large AP, which can improve the user mobility experience and system efficiency.

5.1.1 DAPGing Method

In UUDN, we introduce the DAPGing based on one idea proposed by Mobility Driven Network [2], i.e. user mobility is one key driven factor for future networking. With this method, every registered user in UUDN has a unique APG with an APG-identity (APG-ID). APG context will be stored in a LSC, and most of the DAPGing processes will be executed by LSC. Some high level processes such as authentication, handover are managed by NSC.

S. Chen et al., *User-Centric Ultra-Dense Networks for 5G*, SpringerBriefs in Electrical and Computer Engineering, DOI 10.1007/978-3-319-61201-0_5

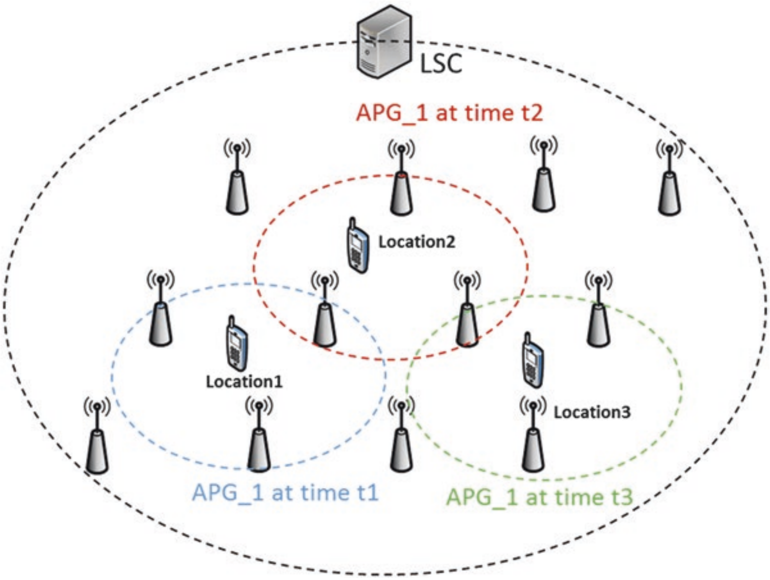

Fig. 5.1 Dynamical group of APs

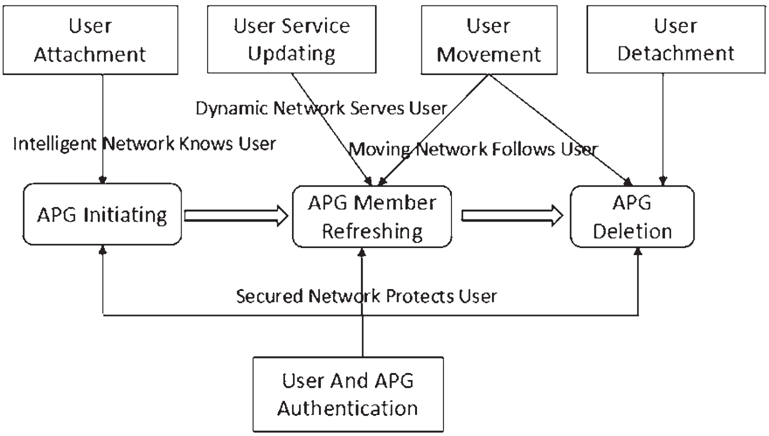

Fig. 5.2 The main processes of DAPGing

5.1.1.1 Processes of DAPGing

The main processes of DAPGing include APG initiating, APG member refreshing and APG deletion as shown in Fig. 5.2.

1. APG Initiating

A unique APG is created by the NSC and maintained by the LSC based on the intelligent sensing of the user's radio environment when a user is attached to the network. The APG is always following the user to provide user-centric services till the user is detached from the network.

2. APG Member Refreshing

After the APG is established, the APG member will be updated dynamically according to the user's movement and radio environment. When the user moves, members of the APG may change accordingly without the user's involvement. When the user is stationary, members of the APG may also be adjusted to meet the changes of the radio environment. The AP on/off will also lead to APG member refreshing.

3. APG Deletion

APG will be deleted when a user detaches from the UUDN.

DAPGing is related to mobility management, resource management, and interference management. Meanwhile, the security impact of DAPGing needs to be considered.

5.1.1.2 Mobility Management for UUDN

In traditional cellular network, users move from one cell to another, which leads to frequent handover. While in our de-cellular UUDN structure, the network will follow UE's movement. The DAPGing makes mobility management functionality different as shown in Table 5.1.

1. Intra LSC or Inter LSC Mobility.

For Intra LSC or Inter LSC mobility, to reach the user in APG, the member of the APG is changed with new APs, but the APG-ID is not changed. In order to apply DAPGing approach to this network, the LSC needs to support following functions:

Table 5.1 Mobility scenarios and related approaches of UUDN

Mobility scenario	Approaches	Control entities	Description
Intra LSC	APG refresh	LSC, NSC	By changing APG member, the radio links between terminal and APs may be moved from one AP to another
Inter LSC			
Inter NSC	APG handover	LSC, NSC	The APG-ID in intra-NSC is unique, thus terminal will get a new APG-ID when moves to a new NSC. AP members will be also re-organized
Between UUDN cellular network	Handover	LSC, NSC, MME	Traditional handover mechanism or improved method

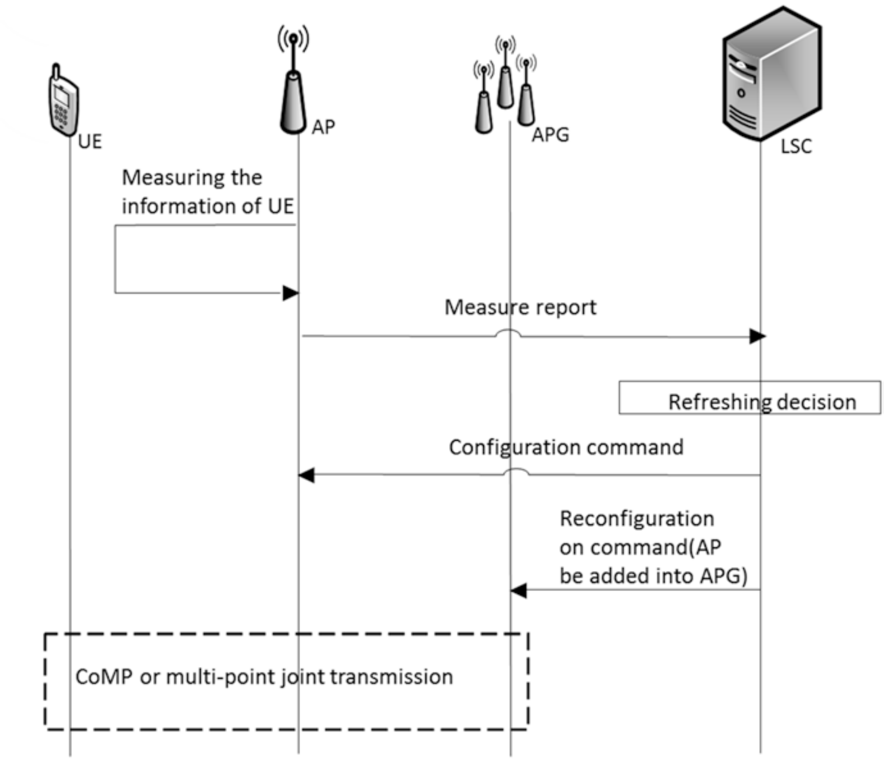

Fig. 5.3 The APG's member refreshing within intra LSC

- APG member refreshing decision: before performing APG member refreshing, the LSC needs to collect information about UE and target AP, including the location of the UE, and signal strength, backhaul conditions and load status of the target AP.
- Configuring link path: once the target AP is determined, the LSC needs to establish link path between target AP and the APG by sending configuration information.

The APG member refreshing procedure of intra LSC is shown in Fig. 5.3. Before the refreshing, the LSC established a control plane connection with a UE. When the UE moves across neighboring APs, all candidate APs, which do not belong to the APG, measure the information of UE, and sends the measure report to the LSC. The LSC makes refreshing decision, e.g. by checking the signal strength of each candidate AP and the location of UE contained in the measure report, if the refreshment is needed, the LSC sends the signaling strengths of all candidate APs to the APG for selecting target AP. Once the target AP is determined, the LSC needs to establish link path between target AP and the APG by sending configuration information.

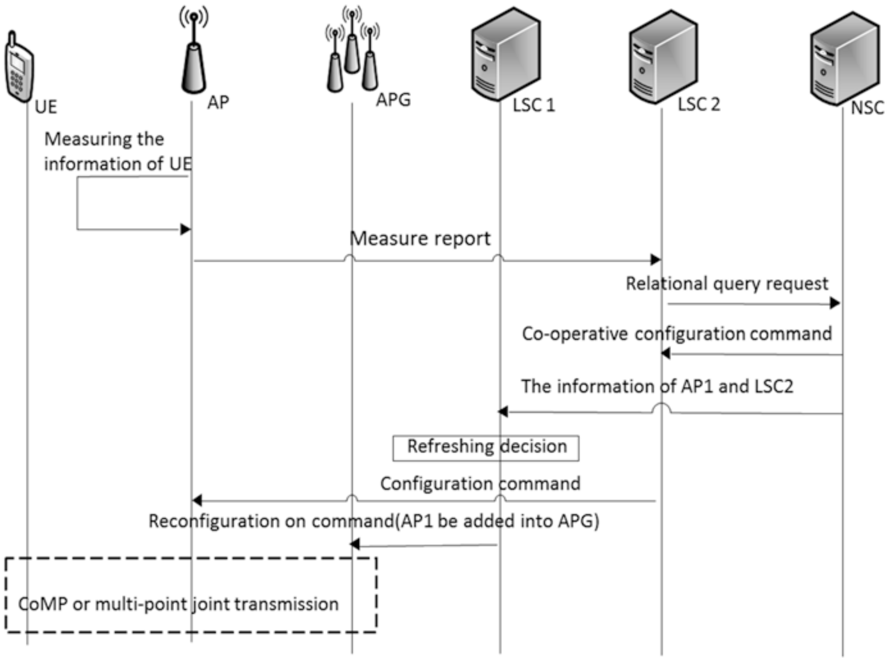

Fig. 5.4 The APG's member refreshing between inter LSC

The APG member refreshing procedure for inter LSC is shown in Fig. 5.4. Originally, the refreshing target AP of a UE sends a path switch request message to its control LSC2 to indicate the preparatory of refreshing and to enable the LSC2 to switch the link path for the UE towards the target AP. But when the APG is not controlled by LSC2, the APG's control LSC1 will be queried by LSC2 with sending the "relational query command" to NSC. Then, the NSC needs to send "co-operative configuration command" to LSC2, and "relational information" to LSC1. After making a refreshment decision based on the response of the LSC1, the LSC2 sends "reconfiguration command" to target AP, while the LSC1 establishes a link path between target AP and the APG by sending configuration information.

2. For Inter NSC mobility, the APG should be possibly moved from one LSC to another LSC which is connected to different NSC, assuming that the APG-ID is unique within one NSC.
3. For Inter NSC mobility the APG handover procedure is applied, e.g. from on one NSC to another NSC. However, APG handover method is not suit for the mobility between UUDN and the traditional cellular network.

The Fig. 5.5a, b show typical DAPGing scenarios. In DAPGing, each APG-ID represents an APG. Every terminal acquires a unique APG-ID when it attaches to an UUDN network. For example, User A has an APG named as GA, and it always follows the User A's movement for different time points t1 and t2 respectively,

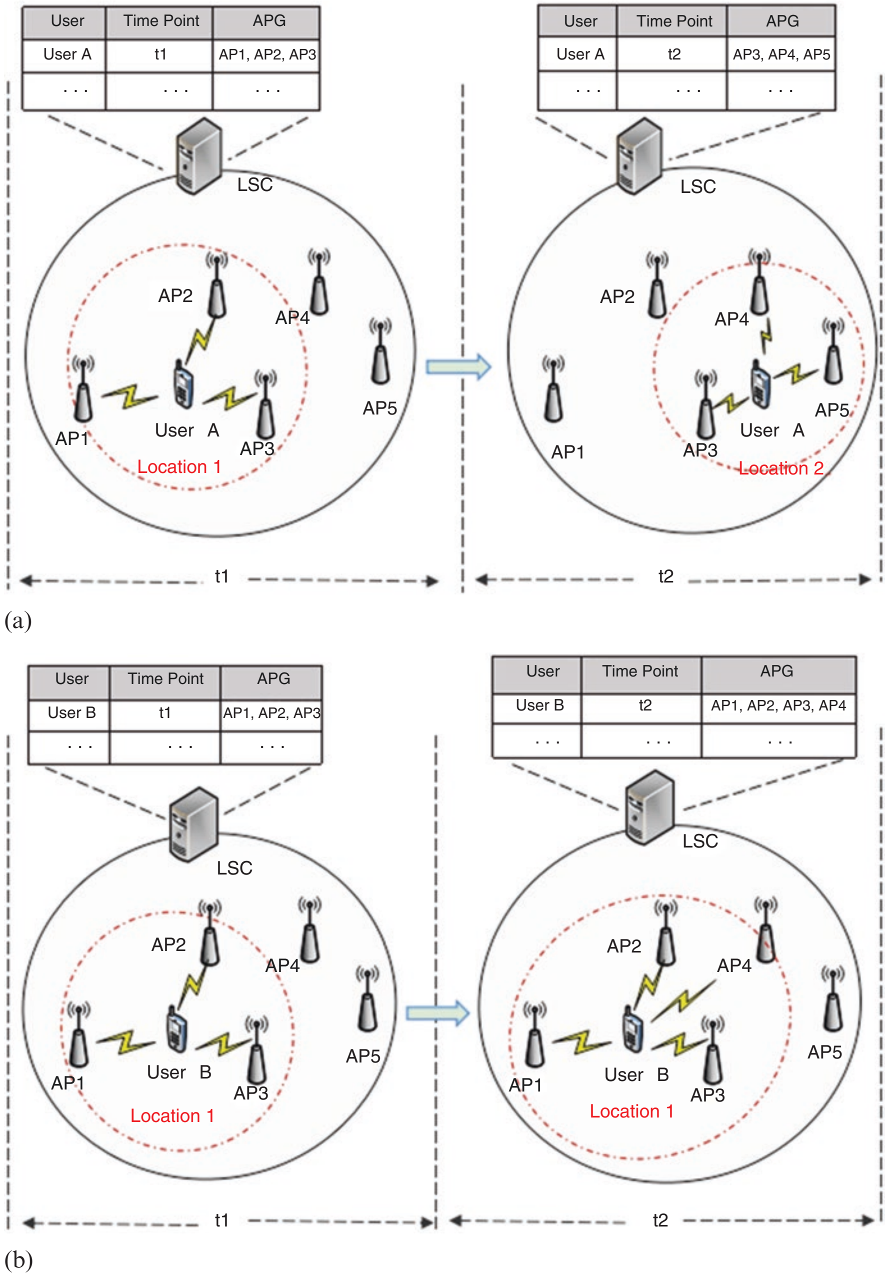

Fig. 5.5 Typical DAPGing Scenarios. (**a**) APG refresh by terminal mobility, (**b**) APG refresh by resource management and others reasons

supported by different combination of APs at each time point. The related radio bearers are also shown for each time point. However, the refreshment of GA is transparent to user A. For User B, which is stationary in this example, User B's APG is also refreshed at different time point t1 and t2, due to the adjustment of resource allocation.

In UUDN, terminals enter the idle mode to save battery power when there is no user data for transmission. For terminal in the idle mode, there are two methods to reach the terminal when mobile terminated service arrives. Within the first method, a terminal periodically monitors whether it has moved out of the coverage of one or more APs in its APG. If the answer is yes, the terminal updates this location to the network and triggers the APG refreshing. In this case, the current APG-ID of this terminal, and its APs members information are stored within the network, e.g. in NSC. The paging is triggered when mobile terminated service arrives, and paging messages are sent to those APs of the current APG-ID, to let the APs pages the terminal at air. This method basically inherits of the idea from cellular system, which has been proven to have reasonable signaling efficiency.

In the second method, the terminal periodically sends out pilot signals to the network, to let the network update its location. Such a updating may result in APG refreshment. When the mobile terminated traffic is arriving, the network could communicate with the terminal directly, without using traditional paging process. This method may result in more terminal power consumption, yet providing quicker response than that of first method.

5.1.1.3 APG vs. Cluster

The main idea of user-centric DAPGing approach is to let UEs be served by a particular group of APs. Conceivably, the way to form an APG can significantly affect the performance of boundary users which is one of the main performance metrics that the DAPGing approach aims at improving. When overlapped clusters are not allowed as shown in Fig. 5.6a, the non-overlapped clusters can manage inter-AP interference within the cluster, but cluster edge users still experience the severe inter-cluster interference. On the other hand, in DAPGing where overlapped APGs are allowed as shown in Fig. 5.6b, the notion of cell or cluster boundaries is essentially eliminated.

The inter-AP resource sharing is also an issue for multiple APs cooperation techniques, and this creates inter-AP allocation constraints. In fixed non-overlapping clusters, this may not be a very difficult task since the constraints are bounded inside the clusters. However, using user-centric DAPGing, these constraints become unbounded.

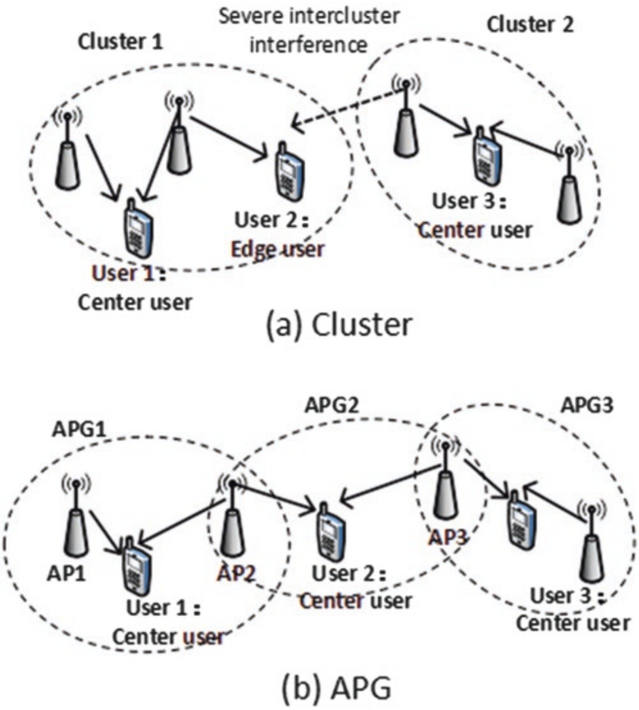

Fig. 5.6 APG vs. cluster

5.1.2 Virtual Cell

The concept of "cell" had been used in the cellular network since 1G standard. It has been proven to be an efficient method of frequency reuse and a very good mechanism for network management and user management, including access, paging, radio resource management, etc. 5G UUDN introduce the concept of no more "cell", which means that the "cell" is decoupling with the physical access cell. But from the industry standard point of view, the "cell" based management mechanism can be inherited. So, the concept of "virtual cell" is now widely used by the industry.

Virtual cell, which changes the traditional cell design concept, in control plane combines multiple APs to form a large virtual cell. The multiple APs are managed in a central control plane and in user plane used as the resources of the virtual cell to be scheduled separately, to avoid a large number of control signaling overhead and the frequent handover of UE, all listed can improve the user experience and system efficiency.

Based on the coverage scenarios and backhaul characteristics, there are three types of virtual cells:

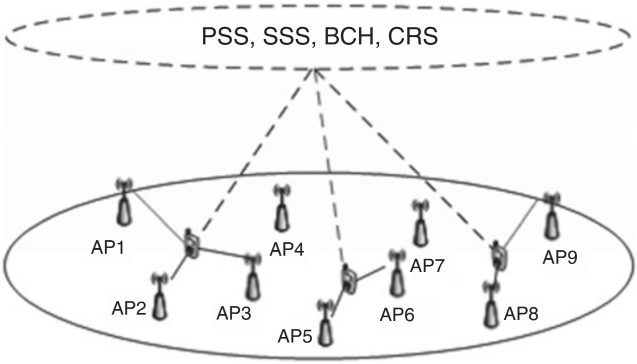

Fig. 5.7 Deployment based static virtual cell

The first one is deployment based static virtual cell as shown in Fig. 5.7. Network will arrange multiple dense nodes as a virtual cell based on the deployment e.g. geographical position, and provide a unified identification and collaboration services for UEs. The users in the same region may have different service node sets, yet see the consistent virtual cell identification and as well other common parameters.

From the perspective of idle mode UE, a virtual cell means a single cell. System information and paging message need to be fully synchronized at the same time to be sent in the same resource location from different APs. Camping with a virtual cell is similar to camp in a legacy macro cell. Cell identification and measurement may be unified.

For connected mode UE, it is necessary to select the most suitable AP for data transmission. Hence the connected mode UE needs to measure each AP separately. The system can configure UE-specific measurements separately for different APs. When UE moves within a single virtual cell, no radio resource control (RRC) handover procedure is needed instead of a L1/L2 reconfiguration procedure. When UE moves across virtual cells, legacy handover procedure occurs.

The second one is heterogeneous virtual cell as shown in Fig. 5.8. This type of virtual cell is composed of macro station and small coverage stations. Macro station can take on most of the control and management functions and small coverage stations can be as access and transmission resources of virtual cell.

For heterogeneous scenarios, dual connectivity is an effective solution to reduce control plane complexity and improve UE's experience and network efficiency. In 5G stage, terminal not only has dual connectivity between a macro cell and a small cell in the 5G system but also supports inter-RAT dual connectivity even multiple connectivity. UE can establish connections simultaneously with 4G/5G macro cell and small coverage nodes including Wireless Local Area Network (WLAN) APs. Multiple connections can be coordinated through the network and the optimization of traffic transmission can be achieved for the improvements of traffic throughput, latency reduction and increasing the resource utilization ratio.

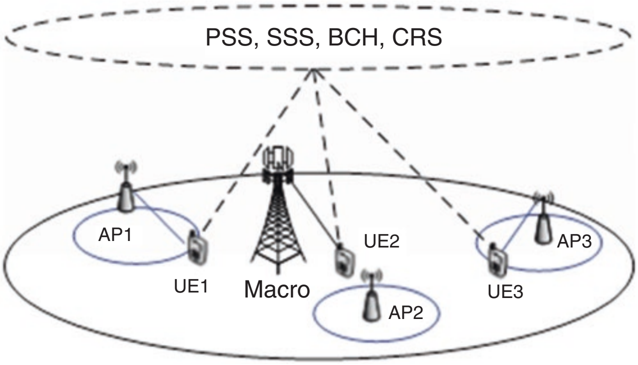

Fig. 5.8 Heterogeneous virtual cell

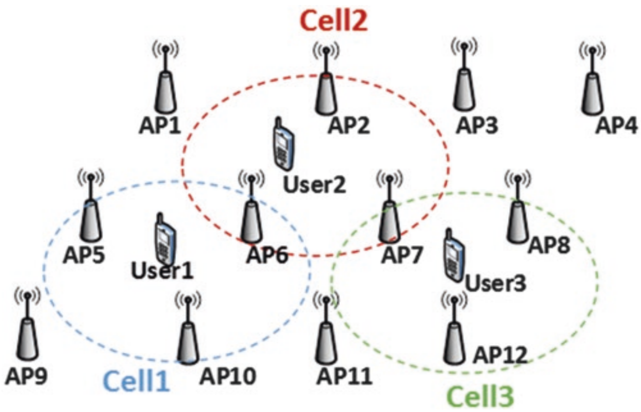

Fig. 5.9 User-centric virtual cell

The third one is user-centric virtual cell as shown in Fig. 5.9, which means that the virtual cell is defined from the user's point of view. The network dynamically organizes service nodes to constitute virtual cell serving for the users. The users at different positions belong to different virtual cells. User-centric virtual cell is a promising cell and user management solution for DAPGing based on the industry standard.

5.2 Intelligent Networking

UUDN will provide the user-centric user experience based on the DAPGing method within extremely complex and diversified scenarios. The massive APs may have the ideal and non-ideal backhaul, wired and wireless backhaul with in either homogeneous or heterogeneous networks under multiple RATs accesses. Complex scenarios have brought many challenges for the deployment and operations of the network, network planning and optimization, and network energy consumption control. In order to realize low cost, easy networking and efficient target, it needs to combine with the UUDN architecture, cell virtualization technology, scenario adaptive interference management technology, and access and backhaul jointed design technology.

The researches include ultra-dense intelligent networking which achieves adjustment and the optimal allocation of system parameters and methods through the network intelligent perception of wireless environment and business needs. The aim is to improve the spectrum efficiency and user experience, to achieve low energy or low power consumption of the system, to reduce the network operation, and to reduce the manual maintenance costs. Traditional cellular network design focuses on access design, separating access and management. On the basis of access, it introduces the O&M, by southbound interface for network interaction, through the northbound interface for the network and service interaction to achieve network static or semi static control. In UUDN architecture, a network management plane is built to establish a global view of the network, to achieve the organic integration between management control and user plane, and to realize intelligent networking. Based on a high degree of Management/Control/User plane (MCU) integrations of the network architecture, further study will include SON (Self Organize Network), super network resource configuration optimization, and intelligent networking technology. At the same time, combined with the traffic distribution under the ultra-dense scenario, the tidal effect and other characteristics will carry out the research of energy saving technology in UDN to reduce the network energy consumption.

5.2.1 Management-Control-User Plane (MCU) Structure

In the traditional cellular network, the management of the network through the O&M usually can only realize the relatively static artificial management and optimization. In LTE, in order to reduce networking complexity, improve the intelligent networking, the SON function is introduced based on the O&M architecture. Through the terminal Minimization of Drive Tests (MDT) function and test report, combined with the southbound interface and northbound interface extensions, there are the deployment of new features on the O&M to achieve the network self-configuration and self-optimization function, such as automatic neighbor management and establishment, mobility robust optimization and load optimization etc. In 4G network, network management functions are independent of access network design, some network configuration and management functions require terminal auxiliary, such as automatic neighbor establishment, MDT etc., but its implementation is based on the RRC signaling bearer and the transparent forwarding way, that is to patch on the user control plane for implementation of network self-configuration and self-optimization, and the efficiency and intelligent degree are difficult to meet the UUDN requirements.

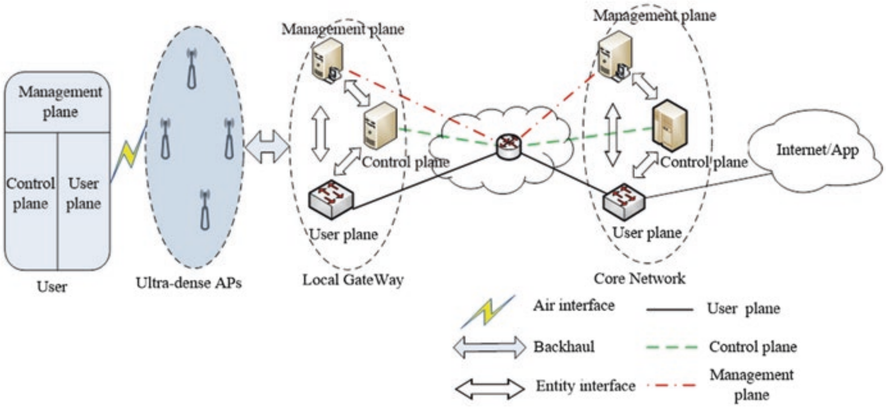

Fig. 5.10 MCU convergence architecture of intelligent networking

In UUDN, the concept of "cell" are changed, the user management and network management mechanism are also change to be more flexible. In order to facilitate the realization of DAPGing, a tighter relationship of user plane, control plane and network management functions are required. At the same time, in order to further realize the intelligent networking such as SON, it is necessary to introduce the architecture with integration design of management plane, control plane and user plane.

A kind of MCU architecture of intelligent networking is shown in Fig. 5.10, in which management plane, control plane and user plane are introduced into both the user side and network side. On the bearers, it allows separation of management plane, control plane and the user plan. But for the protocol design mechanism, it realizes the organic combination and the dynamic interaction of the three. The intelligent management functions are in the Local GateWay and the Core Network center. The intelligent management functions carry out user level, cell level or regional level dynamic intelligent management to achieve real-time dynamic business and network environment perception. Based on the perception of more efficient and feature-rich functions of the network, self-configuration and self-optimization can be carried out to achieve user-centered sophisticated network management, to enhance the management level of the network and to further reduce the labor costs of network maintenance and optimization.

We can see that there are three planes as follows.

1. User plane: is responsible for the user service data transmission.
2. Control plane: is responsible for the system information broadcasting, user service signaling, user radio connection control and the fast scheduling control.
3. Management plane: is responsible for the dynamic arrangement and management of the system and network, as well as the management information of users in the network to facility realize the DAPGing method.

Based on MCU structure of intelligent networking solutions, UDN can achieve the following capabilities.

1. Network Intelligence: through distributed and centralized cloud computing, based on machine learning, data mining and enhanced network self-configuration and self-optimization, to realize network energy saving and intelligent control.
2. DAPGing management: using software defined network to realize cloud of resources and further to realize DAPGing management and optimization in UUDN, including APG management, user scheduling, power control, load balance and etc.
3. Advanced interference management: using virtual cell joint transmission in management plane, control plane, and user plane, it can provide scenario adaptive interference management technology based on user requirements and backhaul capabilities.
4. Access and backhaul joint design: the separation of management plane and control plane simplifies the control plane design, which helps to achieve the separation of user plane and control plane, the novel carrier access transmission and efficient access and backhaul joint design.

The network management plane is mainly responsible for the management and coordination of network nodes. This plane corresponds to the access network management entity at the access network side. At the Core Network side there is a corresponding Core Network management entity, whose function is to make unified decision of access network management strategy, and make coordination and optimization of different access network management entities. The Core Network management entity is not a necessary option, and its researches shall focus on the architecture, functions and processes related to the access network management entity.

The main functions of the access network management entity are to manage and configure the access nodes including: (1) Physical layer related configuration, such as working frequency point and bandwidth, transmit power, Time Division Duplex (TDD) time slot configuration of APs, etc.; (2) backhaul related configurations, such as the backhaul path, and the resources used for the backhaul transmission, etc.; (3) ownership and identification information, such as the cell identity, the virtual cell information APs belonged to, virtual cell control node information, etc.; (4) neighbor AP information, such as neighbor AP ID, neighbor AP configuration, interface or backhaul, whether they belong to a same virtual cell, etc.; (5) the flexible configuration of the access network node function, such as an AP can be configured to the type of the whole protocol stack, and the other AP is configured to only have the function of RF transmission, etc.

Access network management entity also receives reporting information from the APs and UEs. This reporting information is from the measurements of APs and UEs, or from the reports of their own states, and even from requests triggered by some unusual situations or new demands. The reporting information helps access network management entity to better evaluate the network state and to optimize the DAPGing management and organization. The access network management entity is mostly the concept of a logical function, and the access network management entity function can be deployed in a single entity.

In the above framework, at the highest location there is the management plane nodes of the Core Network center, the Core Network management node will be responsible for all the functions associated with the Core Network management including: (1) to send down the overall control decision; to send down the control information of a particular management node in a access network service center; (2) to send down the control information for a particular AP; the coordination between the different management nodes of access network service center; (3) to collect information from the underlying nodes (such as access network management nodes, APs, UEs, etc.) for subsequent optimization and decision-making.

There are interfaces between the Core Network management node and the access network management node as well as the users for managing the transmission of the signaling and the collection of the information.

The access network management node will be responsible of the management function at the access network side including: (1) to configure APs in detail; (2) to receive the management signaling of the Core Network management node; (3) to report information to the Core Network management node; (4) to collect information from the APs for subsequent optimization and configuration; (5) to collect information from users for subsequent optimization and configuration.

There are interfaces between the access network management node and the Core Network management node as well as the APs and the users for managing the transmission of the signaling and the collection of the information.

The main contents of the APs in the management plane include: (1) To be configured by the access network management node, and work in accordance with the configuration; (2) to report the status and measurement, and even demand to the access network management node; (3) to receive the reconfiguration and various coordination signaling from the access network management node; transparent transmission of signaling of UE's management plane.

In general, the APs establish direct interfaces with the access network management node, which are used to manage the receiving of the signaling and information reporting.

Users participated in management plane is mainly for information reporting, including measurement information, abnormal event trigger information, or other related information reporting based on other configuration information of the network side management nodes. Users usually establish direct interfaces with the access network management node for information reporting.

According to the technology of self-configuration and self-optimization in the UDN, based on the MCU integration architecture it will continue to improve the traditional self-configuration, to make the optimization based on the characteristics of the UDN and the new architecture. Here it focuses on the introduction of the self-establishment and self-optimization of the virtual cell clusters, the self-establishment and self-optimization of the wireless backhaul for the 5G new features of intelligent networking.

5.2.2 Backhaul Management and Optimization

In UUDN, the backhaul management and optimization is made by the flexible configuration of the wireless backhaul path and distribution of wireless backhaul link resources, to provide the foundation for the plug and play of the APs. The backhaul automatic establishment and optimization can be carried out by the Local GateWay so as to realize intelligent networking, and its illustration is shown as shown in Fig. 5.11.

From the perspective of backhaul management and optimization, Local GateWay includes the following functions:

5.2.2.1 Backhaul Node Management

Backhaul nodes include the destination nodes and the intermediate nodes, where the destination nodes are the interfaces between the backhaul data and Local GateWay and intermediate nodes are for relay transmission of backhaul data in the backhaul paths. Local GateWay determines the parameters of the position, quantity and backhaul specifications of destination nodes and the intermediate nodes according to the network structure and traffic distribution. The following Table 5.2 is the information table of backhaul nodes maintained in Local GateWay.

5.2.2.2 Management and Optimization of Backhaul Network Topology

Management and optimization of backhaul network topology determines the destination node for each wireless AP, and the intermediate nodes in the path to its destination node, considering a variety of network performance criteria (such as the

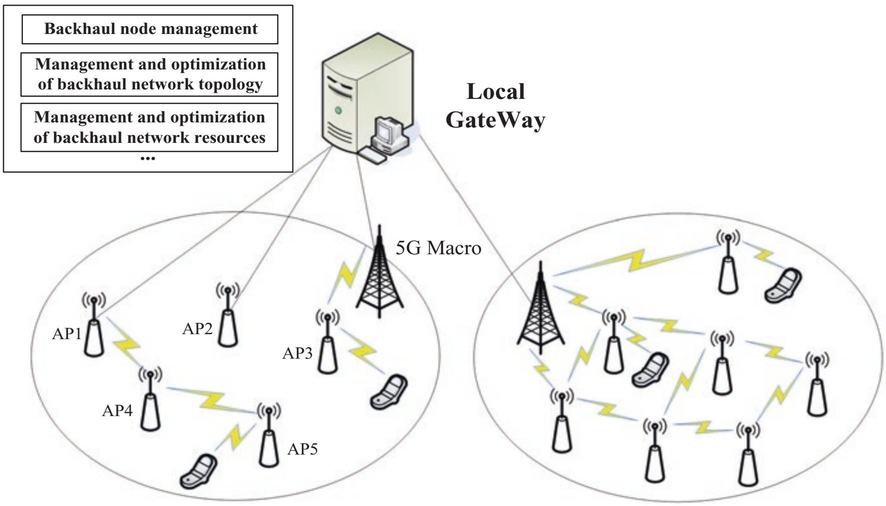

Fig. 5.11 Illustration of backhaul automatic establishment and optimization

Table 5.2 Information table of backhaul nodes (an example)

Nodes	on/off	Backhaul throughput	Backhaul delay	Supported frequency points
5G Macro	on	1 Gbps	<1 ms	f1
AP1	on	1 Gbps	<1 ms	f1, f4
AP2	off	1 Gbps	<1 ms	f1, f3
AP3	on	100 Mbps	<5 ms	f1, f2
AP4	on	500 Mbps	<5 ms	f2, f4

total throughput, level of QoS guarantee, etc.) at the same time, to make the network topology and path to adjust the traffic distribution.

For example, AP5 is a new plug and play AP, when it turns on to access network, Local GateWay automatically establishes the backhaul path <AP1 (1 Gbps, <1 ms)—AP4 (500 Mbps, <5 ms)—AP5 (200 Mbps, <50 ms) > according to the information table of backhaul nodes in Table 5.2 and its traffic requirements (for example 200 Mbps throughput and delay <50 ms). When the network topology changes (such as AP2 turns on), or traffic requirements changes (for example the throughput increases to 600 mbps), Local GateWay chooses a new backhaul path <AP2 (1 Gbps, <1 ms)—AP5 (600 Mbps, <50 ms) >, in which the backhaul path hop is decreased, throughput is increased, and the backhaul path is optimized.

5.2.2.3 Management and Optimization of Backhaul Network Resources

Based on current wireless backhaul network topology and backhaul paths management and optimization of backhaul network resource management is to adopt wireless backhaul resource allocation (such as working frequency point and bandwidth allocation), so that the network resources adapts to changes of data transmission, effectively improving the efficiency and the transmission performances of wireless backhaul network resources.

For example, AP5 supports the frequency points of f2 and f3, for its established backhaul path, Local GateWay allocates f2 as its backhaul link working frequency point and f3 as its access link working frequency point according to the supported frequency points of f2 and f4 for the upstream node AP4 in the information table of backhaul nodes in Table 5.2. When the backhaul path is changed, Local GateWay allocates working frequency point f3 for its backhaul link between itself and the upstream node AP2, and working frequency point f2 for its access link.

5.2.3 Other Technologies for SON

As we have pointed out, intelligent SON is very necessary for UUDN. The network self-organization technology and its function, such as self-configuration, self-optimization and self-healing may enhance the network management efficiency and reduce the operating costs. In order to improve the intelligence of the network management, mobile sensing technology could be adopted. The network nodes get real-time environmental information. By the methods of data mining analysis, the data could be processed and utilized, so as to enhance the perception ability of the network entities, and improve the network management ability. In addition, for UUDN, APs are densely deployed and network topology is very complex. We could combine the idea of SDN and NFV to further ensure coverage of regional hotspots and fulfill the regional capacity enhancement. The network management efficiency and resource utilization are effectively improved by the hierarchical self-optimization design of control plane and data plane.

The following are some potential technologies for SON in UUDN.

1. Self-configuration of Physical Cell Identity (PCI): PCI is the only identity for the terminal device to identify the AP, e.g. AP ID. There are two basic requirements for allocation PCI: avoid conflicts and avoid confusion. The PCI of any neighboring cell in a wireless network must be different, and the PCI of any two APs adjacent to the same AP must be different. In the actual wireless network, especially for the UUDN, the number of APs is much more than the total number of PCI. Therefore, it needs to realize the PCI configuration by multiplexing. The reuse distance is a key issue. If it is too close, it will lead to conflict and confusion of adjacent cell PCI. Conversely, too far will lead to the waste of PCI resources. Besides, the signaling interference is any other problem. Interference management technologies should be combined to resolve it. On the base of proper algorithm, UUDN would realize the intelligent self-configuration of PCI.
2. Self-allocation of Neighbor Relation List (NRL): NRL is a list of neighboring AP information generated within the network for internal use of the AP, not in the system information broadcast. When the new AP joins the network, the NRL self-allocation can automatic discover adjacent APs, create and update the NRL, including the management of adjacent APs relationship. In UUDN, APs are not only intensive deployed, but might also be heterogeneous in frequency or RATs. Therefore, the self-allocation of NRL is much necessary. The early static NRL self-allocation is no longer suitable. Adaptive algorithms should be designed. Considering the increasing processing ability of the user terminals, NRL may help APs by reporting its environment sensing results and part of data analysis. Besides, NRL self-allocation in UUDN might be realized by using the multiple criteria decision making, PCI and NRL combined optimization and big data analysis, etc.
3. Load balance self-optimization: it is to provide a higher user experience by allocating the resources of the wireless network to the users in the network, so as to improve the throughput of the whole system. In UUDN, it is very important. The mobile service has the characteristics of time and space imbalance. Different APs may have various loads at the same time, resulting in the shortage of resources caused by overload obstruction in some area, and resource utilization rate is low in other APs. The main goal of load balancing is to balance the spatial imbalance of the business of each AP. By optimizing the network parameters and switching behavior, the traffic flow of overload AP is diverted to the relatively

idle AP, and the difference between the traffic of different APs is balanced, and the capacity of the system is promoted. The possible resolution for UUDN may include coverage extending and cell breath. With the combination with AP grouping, the load among AP members may also be balanced inside group.

4. Network self-energy saving: dense deployed APs indicate possible more energy consumption. The green communication has raise the increasing attention in recent years. Energy efficiency becomes the important network performance parameter. In UUDN, AP sleep-waking technologies may be used as a proper method. When the data traffic is decreasing, some unnecessary APs could be autonomously closed on the premise to ensure the user service demand, so as to reduce the overall system energy consumption. There are many research results for AP sleep-waking in traditional cellular networks. But considering the special environment of UUDN, the APs should have a more effective and fast reflection to the changing situation. Cognitive technology may be introduced for real time sensing, and intelligent algorithms should be designed for distributed managing of the many APs in the large area.
5. Failure detection and analysis: network failure detection is an intelligent automatic fault processing function. Through the analysis of the wireless parameters and other information, entities may automatic detect the possible failure in the network. The traditional network failure detection usually takes time and consumes a large amount of costs. In UUDN, network entities and user service requirements continue to increase, and effective failure detection technology needs special design for this complex environment. Big data mining and cloud computing could be introduced to collect and analyze the user behavior and network anomaly information. Then the entities may realize network failure detection and give the corresponding reaction scheme. In addition, due to heterogeneous nature of UUDN, different APs have various kinds and amount of information. Therefore, respective failure detection methods should be adopted accordingly.

5.3 Advanced Interference Management

With much closer ISD, APs in UUDN should have more accurate power control algorithms as well as frequency multiplexing methods to accomplish the effective interference control. Traditional interference management methods need to be re-evaluated in UUDN. These possible candidates include interference randomization, interference cancellation, and Inter-Cell Interference Coordination (ICIC), Interference Alignment (IA) and etc. Meanwhile, new technologies such as millimeter-wave and massive Multiple Input Multiple Output (MIMO) introduced into UUDN should also be investigated about their impacts on interference management [3].

In the following subsection, we will first describe the requirements in the design of the interference control algorithms. We will then give the possible research directions about the interference management technologies in UUDN. The suggested approaches for the interference control are also proposed for the UUDN scenes.

5.3.1 Requirements for the Interference Management Design

As we have mentioned above, the interference control faces new challenges in UUDN. Existing technologies and new methods need to be jointly considered in designing effective schemes. The following are some necessary requirements:

1. Careful consideration on the different UUDN scenarios. The interference control has a close relationship with the wireless transmission environments, especially in the cases of ultra-dense APs. There are several typical scenes, with different APs distribution pattern, wireless transmission channel models and users behavior. When APG follows user's movement, it gets even more complicated. Therefore, there is no single algorithm that could suit all the cases. We need to find proper solutions for each typical scenario.
2. Existing technologies should be adjusted for UUDN. These include interference randomization, interference cancellation, and ICIC, IA and etc. With different performance, they are suitable in different cases. But they are all designed for the traditional networks. While the radio environments have changed greatly in UUDN, as well as the specially designed APG structure, these technologies should be discussed and modified to fit the corresponding scenes.
3. The limited complexity is important in the algorithms design for quick reaction to the requirement changes. With the real time refreshing of APG and challenging radio environment, the data transmission may change fast and drastic. Therefore, the interference level may change. The proposed algorithms should be adapted to it efficiently with acceptable complexity.
4. The interference management needs to work together with the resource management, access control and wireless backhaul transmission schemes. All the possible wireless transmissions may result in interference. Therefore, the related schemes need to be jointly considered for UUDN.

5.3.2 Research Directions

The research on interference management may include, but not limited to, the following directions:

1. Channel model and capacity analysis. The wireless transmission environments in UUDN become very complex with many APs in multi-layer and multi-RATs condition. Therefore, the effective channel models need to be setup for various scenarios. Meanwhile, the channel capacity should be studied. It is worth to note that this research direction relates to not only interference evaluation, but also other key technologies, such as coding method, antenna technique, etc.
2. Interference model based on the effective evaluation methods. The ultra-dense environment results in more interference sources. For example, in crowd subway trains, lots of terminals and APs exist, therefore, signals may have more reflecting

and scattering paths. Proper model should be set up to describe the interference level. Meanwhile, the existing parameters to measure and evaluate the impact of interference, such as interference temperature and interference threshold, may not reflect the overall interference, conditions, and performance control of the networks. More suitable parameters should be discussed to give a better indication between interference managing results and throughput, associated with energy efficiency and other system level parameters.

3. Interference management technologies with proper complexity. Interference management technologies have been studied with many research results [4] in traditional cellular networks. Considering the constraint in UUDN, these techniques should be optimized with proper modification.
4. Interference cancellation. It provides methods to regenerate the interfering signals through various coding methods and then subtract them from the input signal [5]. It requires for other interfering source information. Considering the complexity, it is usually used in the BSs. In UUDN, APs' functions may be simplified. Therefore, interference cancellation should be modified.
5. Inter-cell interference coordination. Fractional frequency reuse (FFR) and soft frequency reuse (SFR) have been proposed to control the neighbor cells interference from spectrum planning [6]. Dynamic ICIC (D-ICIC) has the flexibility advantage within many existing works. These methods need coordination among BSs, therefore the signaling overhead generated in the process of exchanging information may impact the network performance.
6. Coordinated Multipoint Transmission and Reception (CoMP). One classic scheme to achieve CoMP is joint processing (JP) /joint transmission (JT), which is regarded as an advanced downlink solution and mainly focuses on achieving spectral efficiency in LTE-A [7]. It is also possible to use the idea in UUND, under the effective cooperation among APs.
7. Interference Alignment. Each user is capable of reaching higher Degrees of Freedom (DoF) by using IA. DoF known as multiplexing gain [8], is a good characterization of the approximate capacity because it becomes increasingly accurate in the high signal noise ratio (SNR) regime. IA regulates the interference falling into a particular signal subspace and leaves the residual subspace interference free. In UUDN, appropriate pre-encoder could be designed at the transmitter with the purposes of preprocessing signals.
8. Interference problems brought by new technologies. Advanced technologies have been introduced into UUDN, to provide wider usable spectrum, higher throughput and better user experience. Millimeter-wave and non-orthogonal multiple access technology are considered as some of the most promising candidates and will be used in wireless access and backhauling. Then new interference is introduced due to the new spectrum band. High-gain beam forming is adopted to mitigate path loss and ensure low interference [4]. Besides, other traditional interference management methods should also be used to improve the overall performance.

The interference management needs to be jointly considered with resource management, mobility management and network deployment. During the design of relative algorithms, interference control should be taken into consideration. Therefore, the high throughput and high spectrum efficiency requirements can eventually be fulfilled in UUDN.

5.3.3 Proposed Approaches

In order to realize the effective interference management, we propose the following model which contains several basic steps during the interference control processing and combines with the reliable resource allocation in UUDN.

From Fig. 5.12, we could see that the interference control model is a closed loop that may be used periodically for maintaining the overall network interference level, as well as adopted when a new user accesses to the APG and needs to have allocated resources. The main steps and modules are explained in details as following:

1. Environment sensing: considering the complex transmission environment of UUDN, sensing technologies such as cognitive radio, movement prediction and user behavior modeling should be adopted to have a clear picture of the user/AP's neighborhood situation. The accuracy and efficiency of the sensing results will directly impact the next information collection step. On the basis of the current contributions, more advanced models and algorithms designed for UUDN should be investigated, such as the broadband spectrum sensing, user moving model in typical UUDN scenarios and transmission requirement evaluation, etc.
2. Information collection: based on the environment sensing results, several concerned information that could reflect the overall transmission condition could be collected and categorized. Considering the possible huge data amount in UUDN, these information need to be further processed, analyzed and concluded. Then they are transformed into series of parameters for next interference evaluation step. Here in this module, advanced technologies like data analysis and signal procession would be used for effective and fast output. Furthermore, when considering the cooperation among neighbor APs, distributed information transmission should also be designed for UUDN, including the message exchange method, parallel transmission routes and redundant data processing, etc.
3. Interference evaluation: we should define an interference control threshold depending on the exclusive situation for UUDN scenarios. This threshold could be a combination of vectors of many respects in the interference level of the network. In fact, it is the comprehensive output of the interference evaluation model. When the parameters reflecting the environment situation are being derived from the former step, they are sent into the interference evaluation model. This model is set up based on effective mathematical tools, such like fuzzy decision-making, game theory, deep learning, and so on. It is more complex

and suitable than traditional interference temperature level and Signal to Interference plus Noise Ratio (SINR) for UUDN. Besides, the computation complexity should also be considered. In one loop, if the outcome of the model is less than the threshold, it means the overall interference is endurable currently and no more measures need to be carried out. On the contrary, next step would be triggered and interference control should be conducted immediately.

4. Interference control methods: when the interference exceeds certain threshold, or there is new user for resource allocation, effective measurements should be adopted to limit the interference. As we have mentioned before, there are many possible methods. But in UUDN, these technologies should be modified to suit to the typical scenario and special requirements. Furthermore, several technologies may be combined to deploy. Meanwhile, other respects like resource allocation, intelligent networking and AP grouping have direct impact on the interference level and control performance. We should have a comprehensive consideration for these Schemes.
5. Parameter adjustment: the outcome of these interference control methods is expressed as the necessary adjustment of related network parameters. These may include user/AP transmission power, allocated frequency, wireless channels, APG member, and etc. Then the communication environment may be changed again due to both these adjustment and user behavior which the system could not control, a new loop of interference control may begin.

This model could have many concrete expressions within different UUDN sceneries and have various designed algorithms. But the basic steps could be concluded as the steps in Fig. 5.12. Many interesting branches inside the model call for further investigation and fruitful contributions would push related advanced technologies to develop.

If we consider the interference control from the management respect, it could be designed from different responsible entity. Accordingly, here we propose the possible approaches for interference management from respective network and user sides with two different methods.

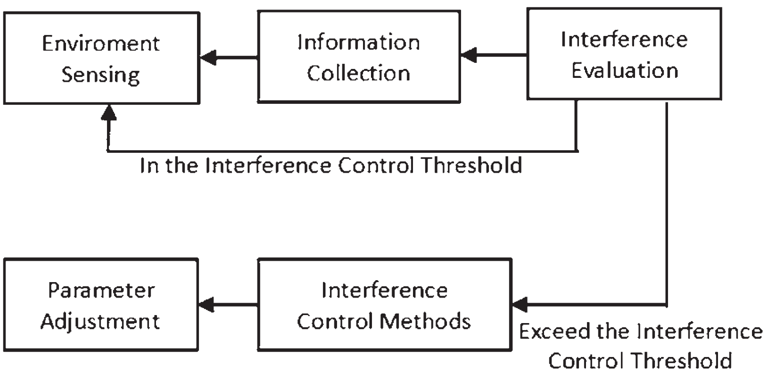

Fig. 5.12 Interference control model

When there are sufficient available resources and function supports from the terminal, the resource allocation may be fully distributed. In addition, negotiation models should be introduced, such as cooperative game theory among APs or among users. Under this approach, the network side will not involve in the resource allocation process, which means that the algorithms should be fully distributed and adjustable. Also, the APs should be capable of environment sensing on idle channels, interference levels, and neighbor APs conditions. The advantages of this approach include the high efficiency of local resource managing and real-time fulfilling for the users requirements. Yet its disadvantages are also obvious. The processing complexity will impact on the resource allocation efficiency. Also the requirements will be very high for environment cognitive ability of APs.

Another approach requires the network side to participate and to offer center control at certain degree. A local control unit in LSC maintains the resource list within the neighbor areas, as an available resource pool. The APs may get the information by periodical broadcast or dedicated request. Once there is need for transmission, APG would then select the proper resource from the pool, the resource list kept by LSC may change accordingly. If there is a contention in the resource allocation, LSC has the arbitration right. By this approach, the resource management may achieve optimization by avoiding resource contention and decreasing interferences. The disadvantage is that it is hard to determine the neighbor area of the resource list in real cases.

As we have discussed, these two approaches have respective features. When we jointly handle the interference control problem, situations become more complicated. The traditional interference managements include interference concealment and IA, interacting with synchronizing, cooperation, and signaling overhead. Corresponding to the two resource allocation approaches mentioned earlier, the interference control might be added into the design. In the first approach, interference evaluation models should be added to the negotiation schemes as well as the environment sensing procedure. These models need further investigation in UUDN scenario and may influent directly on the resource allocation results. In the second approach, the available resource list could have the item/entry of interference impact, or even have occupied resources of the neighbors, to provide more details for the APG in choosing proper resource. This requires for effective information collection of the real-time local resource condition. For the joint optimization of resource management and interference control, when considering implementation, other factors should also be included into the design, such as transmission efficiency, algorithm complexity and signaling overhead.

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Chapter 6
Security

6.1 Security Domain

As we know aforementioned, the architecture UDN and UUDN are flatter than that of the traditional cellular network such as 3GPP defined EPC architecture [1]. Additionally, a group APs around UE will be dynamically organized as an APG to serve the user and follow user's movement in UUDN [2]. Therefore, any counterfeited AP in the UUDN not only threatens the organization security of APG, but also may threaten the overall security of UUDN. The security of UE access via UUDN also needs to be reconsidered according to the new architecture. Based on the special feature and the network architecture of UUDN, we define five the security domains, as shown in Fig. 6.1. The six security domains includes: (1), AP access security (2) APG organization security, (3) UE to UUDN access network security, (4) UE to UUDN core network security, (5) Network domain security.

The AP access security refers to the set of security features that the APs act as the trusted entities when they access the network of UUDN. The APG organization security means the security features that the APs are organized into a group which can secure refresh. The UE-to-UUDN access network security is the set of security features that the UEs access network used by mutual authentication. The UE-to-UUDN core network security refers to the set of security features that the UE connects the core network with traffics of control plane and user plane. The network domain security is similar to the existing network system such as LTE 4G etc., and we are not going to make a detailed description of it. Here, we focus on the security of the previous four domains.

1. AP access security: The APs are very close to the user and even may be deployed by the user. The security threats of AP deployment which UUDN facing is similar to that of Home eNB in LTE network. In order to prevent the attacker from using HNB as a springboard to enter into the LTE network, the HeNB supports a device

S. Chen et al., *User-Centric Ultra-Dense Networks for 5G*, SpringerBriefs in Electrical and Computer Engineering, DOI 10.1007/978-3-319-61201-0_6

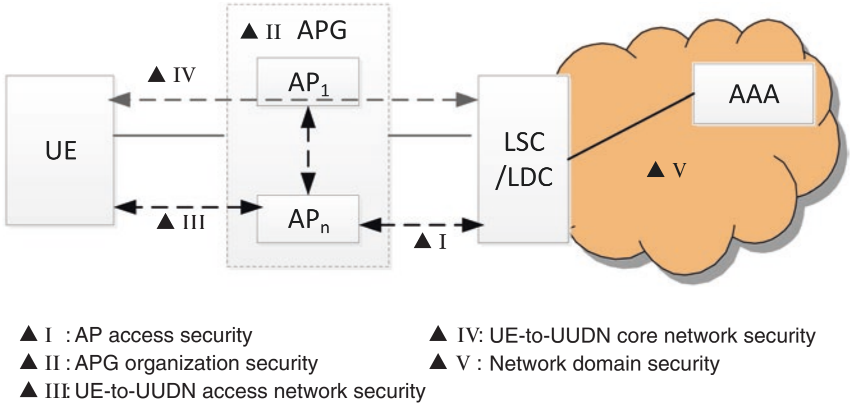

Fig. 6.1 Security Domains of UUDN

validation method with certification-based or USIM-based mutual authentication [3]. Similarly, the APs also need the mutual authentications between the APs and UUDN network when the APs access the UUDN. When the authentication is success, the APs then can enter into the working status.

2. APG organization security: A malicious AP counterfeiting into the APG will threaten the overall security of UUDN. Facing the APG security threats, there are two security aspects that APG organization security should considered. One is the member refreshing security due to some new APs join the APG or registered APs leave the APG. Another is that the secure communication (such as collaborative signaling and data exchange, etc.) associated with the key derived structure among the APG members.
3. UE to UUDN access network security: Because of the refreshing of APG, many threats are emerged. The members of APGs will be change and the AP wireless connections may be intercepted by attackers. For example, when the data transferred between the UE and APs (APG), the signaling and user data can be eavesdropped or manipulated by the attackers. The user's movement between the APs may be also traced or discovered the whereabouts of a specific user. These can pose a huge threat to user's privacy. It is the effective measures to protect the user's privacy data with the keys based on specific encryption algorithms. For example, based on the APG temporary key to derive keys for ciphering of user plane (K_{UPint}) as well as ciphering and integrity protection of the RRC signaling between the UE and AP/APG (K_{RRCenc} and K_{RRCint}) is an effective way.
4. UE to UUDN core network security: In UUDN, an AP may belong to multiple APGs (within deferent APG-ID) at one time in one LSC. Obviously, there are threats that the APG or AP may be counterfeited. Then, the UE may be hijacked to access the other APG or UUDN core networks by the counterfeited AP. To prevent these threats, a mechanism for mutual authentication between the UE and the LSC (APG-ID recognized in it) should be considered to grantee the UE access security.

6.2 Access Security of APs

In UUDN, APs are located closer to a UE and may not be deployed by the operator. The physical environment of the APs deployed may not be trusted and the APs may be attacked. For example, the sensitive data such as key configuration data stored in the APs may be illegally obtained or cloned. Then the counterfeited APs may illegally access to the UUDN network and the threats may be brought into the network. Malicious APs may attack Core Network entities and attack the UE, such as eavesdropping, the operation of packages etc. Therefore the how to do access control of AP is the essential security issue for UDN and UUDN that prevent the the counterfeited APs which bring the threats to the network including eavesdropping, packet manipulation and Dos attacks.

To ensure the access security of APs, the following security mechanisms can be considered.

1. Trusted initialization and secure configuration of APs: On the boot stage, APs must to start the security initialization processes and get the on-demand configuration from the boot server. After the AP started with secure configuration, then it should be trusted by the core network.
2. Mutual authentication mechanism for APs: In the actual deployment, in order to prevent the counterfeited APs access the network, UUDN should use the mutual authentication mechanism between AP and the network entities. When the authentication is succeeded, the UUDN should allow the trusted AP to access the network. The mutual authentication mechanism is known as the Authentication and Key Agreement (AKA) protocol defined by the 3GPP or other AKA improvements [4]. The AKA used by APs will be enhanced to adapt the APG refreshing mechanism and also should considerate the authentication efficiency for large APs in UUDN.

6.3 APG Security

APG is the key feature of UUDN. The system shall intelligently recognize the user's wireless communication environments, and then flexibly organize into APG and resource to serve the user. As the description aforementioned, a dynamic APs group (APG) will be organized as a following coverage to serve each user continually in UUDN. Therefore, the action of an AP join the APG or the registered AP leave the APG will happen at any time within the movement of UE. The APG refresh process is shown as following Fig. 6.2. At one time point, an AP joins into the APG. Then another time the AP maybe leaves the APG. The dynamic change of APG member will bring possible security threats for UUDN. For example, if a malicious AP joins into APG, it may make a man-in-the-middle attack, which threaten user and UUDN network. The illegal AP can intercept the sensitive data within interaction between UE and CN, and send false message. The other APG members even might be subject to malicious attack. Similarly, this scenario will also threaten to the access security of UE. The illegal APs of the APG may cheat APG and UE. An untrusted APG and its members will directly threaten the security of the whole UUDN. Thus, achieving APG security is the most important for ensuring UUDN security.

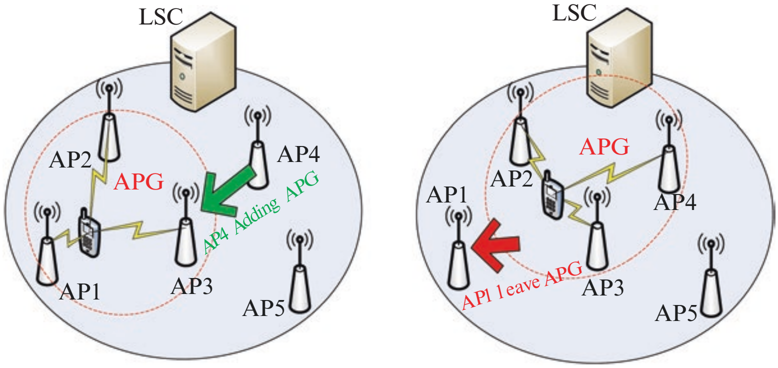

Fig. 6.2 APG refresh following UE's movement

The APG security includes three aspects: (1) New AP joins APG through the authentication and key agreement process. (2) The secure process triggered by the registered AP leaving the APG. We can collectively name the two processes aforementioned as APG AKA process. (3) The secure communications among the member APs of APG. As in [5, 6], the group communication is considered an important security feature. In UUDN, based on the APG features, we propose the three processes naming APG-AKA process. According to the APG-ID, the APG-AKA process can provide a key parameter separation between the different APGs. Additionally, the APG-AKA process includes the dynamic secure refresh of APG members, the security communication between the group members and the key generation for each group member.

When UE moves into the coverage of AP, it is measured by AP. Then the AP will send the request of APG which it can join to LSC. The APG-AKA process as shown in Fig. 6.3 begins:

1. LSC receives the request from AP, and applies to NSC/AuC for the authentication vectors including the derived key K_{LSC} for APG.
2. NSC/AuC generates the authentication vectors and APG-ID, and then sends them back to LSC.
3. LSC receives and stores the vectors. LSC begins to derive the $K_{APG\text{-}G}$ with K_{LSC} and the parameter APG-ID. Then, LSC sends the vectors to APs which belongs to the APG (APG-ID).
4. The AP computes out the local results of AUTN and compare the local results with the received vector AUTN using parameter APG-ID. If the result is consistent, then send the vector RES||APG-ID to the LSC.
5. LSC receives the vector from AP and compares with XRES||APG-ID. If the result is consistent, it means the authentication success and the AP can join into the APG. Here, the AP can communicate with the other APs in APG by the derived key of itself.

According to the security policy, when the APG cannot measure the members AP (or the AP shutdown and reports to APG), the key of the AP derived in LSC will be destroyed. LSC will remove the AP from the APG index list. At the same time, the LSC will send some configuration change commands to the APG and its members. If the AP rejoins APG, the authentication process is needed.

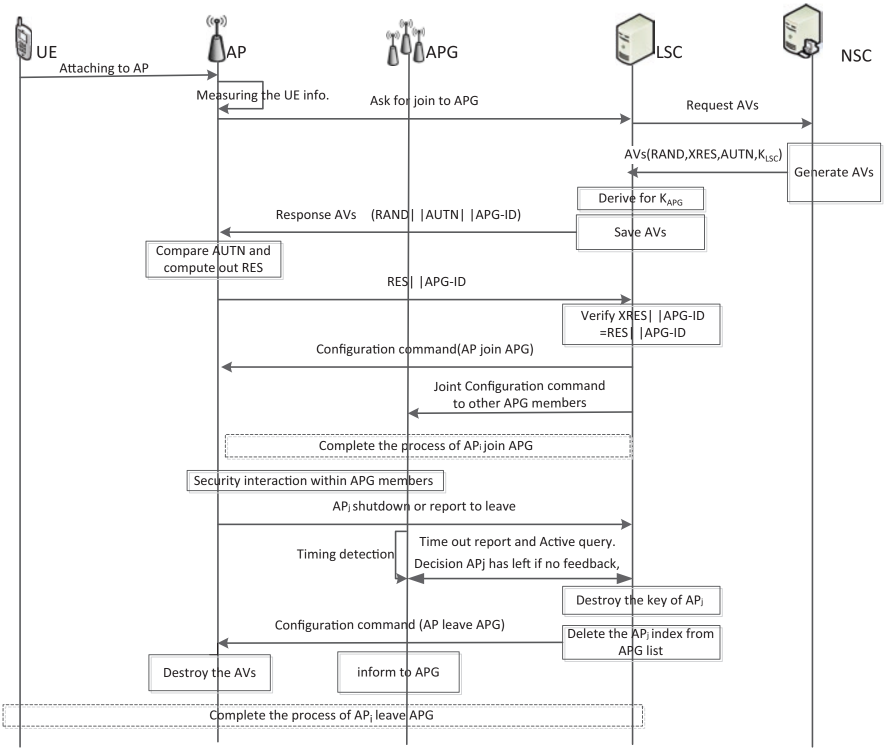

Fig. 6.3 APG-AKA process

The APG-AKA in UUDN has its special functions, which is different from the solution which named the group-based authentication and key agreement for MTC in LTE networks LTE in [7]. To building a secure APG, another solution is that innovative a new algorithm and build a tunnel by joint using of the group digital signature [8, 9] and the blind digital signature [10, 11]. We also consider this method as another worthy research direction.

6.4 Expanded Key Derived Hierarchy

In order to grantee the network security, encryption algorithms are usually used on link or user data. Obviously, the key for ciphering or integrity processes should not transmission over the network directly. Otherwise, there will be a risk that the key can be eavesdropped or even manipulated. A feasible method is that the keys for ciphering or integrity are derived by the temporary key and then the keys never leave the secure entities. The key derive hierarchy should designed to adapt to the network architecture. In [12], it depicts various keys and the other keys in the key hierarchy system in LTE from which they are derived. Similarly, the design of an expanded key derived hierarchy of UUEN has its own characteristics and support the introduction of the APG method in its network architecture. As a result, an APG key hierarchy is added to the "family tree" of the expanded key derived hierarchy structure in UUDN.

In UUDN, there may be multi APGs, even in the same network area, serve for different UE. An AP may serve multiple UEs at the same time accordingly and an AP may belong to different APGs. Then, there are still threats that the APG may be misuse or misappropriation by the malicious APs. For example, if a malicious AP of APG1 counterfeit act as the member of APG2 using APG2-ID, then the communications between the APG2 will face security threats. Thus, these issues even maybe lead the threats to spread to other APGs and its members. In order to prevent the above threats, the system achieves the security isolation between APGs security, using key separation based on different parameters of APG-ID. In the expanded key derived hierarchy, a key level of $\mathbf{K}_{\mathbf{APG}}$ is added to keep the separation between the APGs and to protect the communication security between the UE and APs. The $\mathbf{K}_{\mathbf{APG\text{-}i}}$ and $\mathbf{K}_{\mathbf{APG\text{-}G}}$ are generated from $\mathbf{K}_{\mathbf{APG}}$ with different parameter APG-ID. The $\mathbf{K}_{\mathbf{APG\text{-}i}}$ is used to derive the communication protection keys between the UE and APs (APG members). The $\mathbf{K}_{\mathbf{APG\text{-}G}}$ is used to derive the communication protection keys among the APs (APG members). The expanded key derived hierarchy is illustrated in Fig. 6.4.

The K is the root key, and stored in secured environments, i.e., AuC in the network and in UICC, for each UE. Different keys are used for each set of procedures, and also different ciphering and integrity protection keys are used. The K_{LSC} is stored on LSC and derived from the K in the process of AKA. The key K_{LSC}, which used by UE and LSC, can derived the keys for ciphering and integrity protection of NAS signaling (K_{NASint}, $K_{NASenct}$). The K_{APG} can be derived by the K_{LSC} using the different parameter APG-ID.

To protect UE-to-APG security and the AP-to-AP of APG member security, the corresponding keys are need. The $K_{APG\text{-}I}$ and $K_{APG\text{-}G}$ will be derived from K_{APG}. The

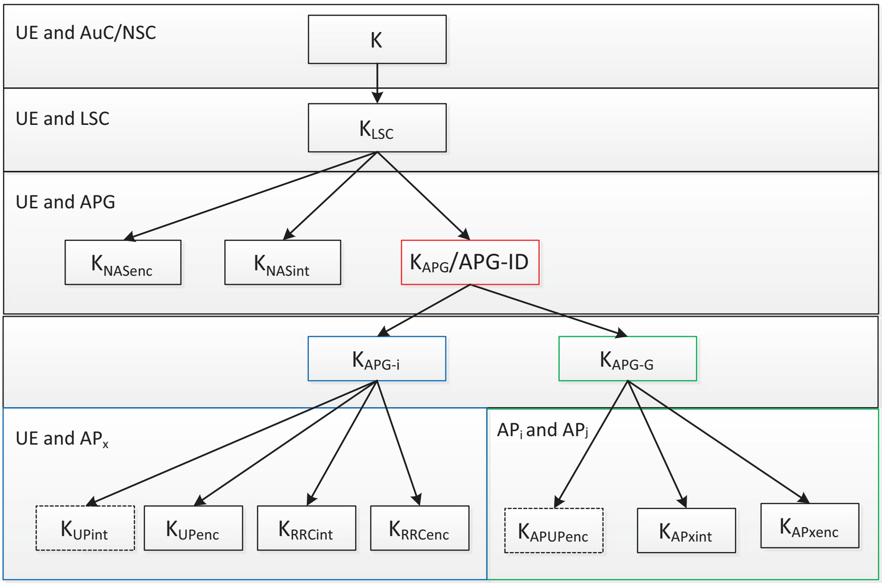

Fig. 6.4 Key hierarchy system of UUDN

Table 6.1 Keys derived structure

Keys	Derived from	Function
K	–	Root key
K_{LSC}	K	The key of LSC
K_{APG}	K_{LSC}	The key of APG
$K_{APG\text{-}i}$	K_{APG}	The key for the member i of APG, using security for UE and AP_i
K_{RRCenc}	$K_{APG\text{-}i}$	The ciphering key for RRC between the UE and AP
K_{RRCint}	$K_{APG\text{-}i}$	The integrity key for RRC between the UE and AP
K_{UPenc}	$K_{APG\text{-}i}$	The ciphering key for UP link between the UE and AP
$K_{APG\text{-}G}$	K_{APG}	The key for the member of APG, using security for AP_i and AP_j
K_{APXenc}	$K_{APG\text{-}G}$	The ciphering key for RRC between the APs of APG
K_{APXint}	$K_{APG\text{-}G}$	The integrity key for RRC between the APs of APG
$K_{APUPenc}$	$K_{APG\text{-}G}$	The ciphering key for UP link between the master AP and the other APs of APG

key of $K_{APG\text{-}i}$ is used by UE and APG in LSC to derive keys for ciphering of user plane (K_{UPint}) as well as ciphering and integrity protection of the RRC signaling between the UE and APG (K_{RRCenc} and K_{RRCint}). The UE derives the same keys as the APG. Similarly, the key of $K_{APG\text{-}G}$ is used by APs (APG member) to derive keys for ciphering of user plane ($K_{APUPint}$) as well as ciphering and integrity protection of the RRC signaling among APs of APG ((K_{APXenc} and K_{APXint}). The relation schema of the derived keys is shown briefly in Table 6.1.

Based on the key hierarchy of UUDN above, the UE with its key not only can do authentication during AKA procedure run, but also can complete security information exchange through the APG.

6.5 Dual Authentication Method

In UUDN, The UE accesses to the APG who is managed by LSC. That means that some mutual authentications will occur when UE go into the coverage of some APG of UUDN. We call these authentications Authentication and Key Agreement in UUDN as UUDN-AKA. Due to the dynamics of APG, any AP may belong to multiple APGs. The UE may access to the illegal APG, if the AP was counterfeited. Then, it is not exclude that an illegal AP counterfeits some one member of other APGs and does some attacks. Therefore, we design a double authentication mechanism. The first mutual authentication occurs between the UE and the LSC, which is named Authentication and Key Agreement on Non-Access Stratum (AKA-NAS). And the second mutual authentication occurs between the UE and the APs of APG, which is named Authentication and Key Agreement on Access Stratum (AKA-AS).

The AKA-NAS process is similar to that of the traditional EPS-AKA in 4G. The difference from EPS-AKS is that the result of authentication can be distinguished for the different APG based on APG-ID on LSC.

The processes of AKA-AS and AKA-NAS are interrelated. In AKA-AS process, the AP’s parameters can be from the results in the vectors of AKA-NAS process. If the AP has no the parameters received from AKA-NAS, the AKA-AS process should not success and the UE cannot access the network.

When AKA-NAS completed, at the same time, the results of AKA-NS and APG-ID as the access stratum parameters will send to UE and APG members. Then the process of AKA-AS begin to run. The AKA-AS process has the following steps:

1. LSC checks the access stratum vectors. If the vectors have not received, then it will ask to the NSC/AuC.
2. LSC sends the access stratum vectors to the APG whose APG-ID has assigned in previously process above.
3. The vectors are stored by APG. The member APs of the APG send the authentication request vectors to UE, including RAND, AUTN||APG-ID.
4. UE computes and gives the comparison with the local results for AUTN||APG-ID. If the result is consistent, then the UE will send the vector RES||APG-ID to the AP.
5. The AP receives the vectors from UE and compares with XRES||APG-ID and that of itself. If the result is consistent, it means the authentication above success and then the AKA-AS is completed.

Here, the UE completed UUDN AKA process. The evolved authentication method of UUDN AKA is shown in Fig. 6.5.

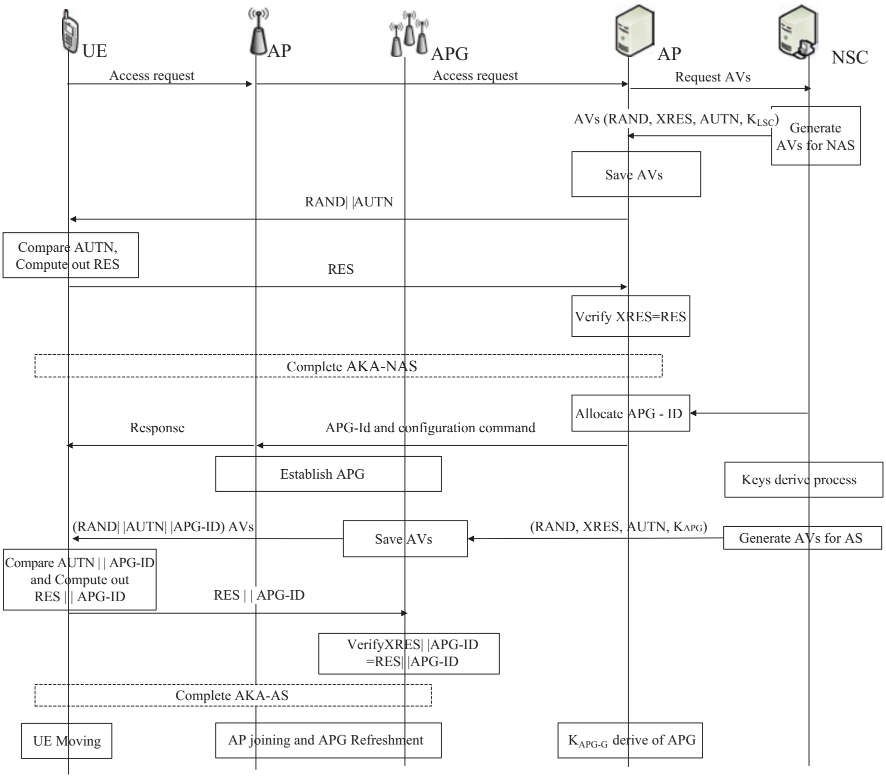

Fig. 6.5 Basic principle of AKA based on APG of UUDN

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Chapter 7
Simulation and System Solution

7.1 APG Simulation

7.1.1 Introduction

Densely deployed APs put forward new challenges to the mobility of UEs. The AP/small cell coverage will lead to a rising in the UE handover frequency and increasing of the handover failure. In addition, the dense deployment of APs needs to optimize the configuration of the handover threshold, which gives the challenges of network planning. Dual connection can reduce the handover failure rate, UE at least can guarantee the connection in the Master evolved Node B (MeNB), but when the UE in the Secondary evolved Node B (SeNB) changing, its throughput is reduced and the user experience is poor. The APG is suitable for all scenarios, especially for the scenario without the macro station, in which the APs can achieve smooth changing and the user experience is better.

Here we compare three solutions which are the legacy handover, dual connection and APG in the ultra-dense deployment scenario. In legacy handover, UE moves among the APs with the legacy handover process. As the APs are densely deployed, it leads to frequent handover and handover failure rate is very high. In dual connection, the macro station is as MeNB and the APs are as SeNBs. UE are in the SeNB changing process, and the MeNB transmits RRC connection reconfiguration message which avoids handover failure while conducting handover command transmission, so handover failure rate is reduced and the throughput increases. In APG, the local centralized control node or the macro station is the control plane service node, and a number of APs are the user plane service node. Through the service node set changing and selecting a dynamic service node, UE can be chosen the best AP for its service, which eliminates the handover failure and the throughput is further improved.

UUDN system simulation platform is developed on the Windows platform, using Visual Studio C++ 2010 tools. The simulation platform is running on Windows

S. Chen et al., *User-Centric Ultra-Dense Networks for 5G*, SpringerBriefs in Electrical and Computer Engineering, DOI 10.1007/978-3-319-61201-0_7

Server 2003/Windows Server2008 R2 platform. The simulation platform supports to read the configuration parameters from the database, and can save some of the simulation results to the database, such as static Reference Signal Received Power (RSRP), SINR, downtilt etc. The simulation platform includes the following function models to realize the evaluation of the system performances of three solutions, such as network topology, interference calculation, UE mobility, access control, scheduler, radio link monitoring, cell reestablishment, RRM measurement, handover/SeNB change execution, APs set selection/serving AP selection, statistic etc.

7.1.2 Simulation Assumptions

In the simulation, the macro station is the center of the grid, in which 256 APs are regularly deployed, and the ISD is 10, 20, 30 and 50 m, corresponding to the grid size of 160×160 m^2, 320×320 m^2, 480×480 m^2 and 800×800 m^2.

The basic configuration of the system simulation parameters are shown in the following Table 7.1.

Handover/changing process related parameters are configured as shown in the following Table 7.2.

Radio link monitoring process related parameters are configured as shown in the following Table 7.3.

According to the UE speed, the different parameters are configured as shown in the following Table 7.4.

7.1.3 Simulation Results and Conclusions

In the simulation, comparison of different ISD is provided. When UE speed are 3, 30, 60 and 120 km/h, the system performance under different ISD (10, 20, 30 and 50 m) is compared including the interrupt ratio and spectrum efficiency. The interrupt ratio refers to the proportion of the user's data transmission interrupt in the statistical time. Data transmission interrupt time of legacy handover includes the handover execution delay, the delay between the time when T310 starts and the occurrence of radio link failure (RLF), and the reestablishment delay. Data transmission interrupt time of dual connection includes the SeNB changing execution delay, the delay between the time when T310 starts and the occurrence of RLF, and the reestablishment delay. Data transmission interrupt time of APG includes the service node changing delay, the delay between the time when T310 starts and the occurrence of RLF, and the reestablishment delay. The spectrum efficiency includes the cell average spectral efficiency and 5% user spectral efficiency, whose units are bps/Hz. T310 will start upon detecting physical layer problem, i.e. receiving consecutive out of sync indications from lower layers. T310 will stop upon receiving

Table 7.1 Basic configuration of the system simulation parameters

	AP
Layout	One macro site, three sectors per site, the macro station is the center of the grid, in which 256 APs are regularly deployed
System bandwidth per carrier	10 MHz
Carrier frequency	Macro station: 2.0 GHz, AP: 3.5 GHz
Carrier number	1
Total BS TX power	Macro station:46 dBm, AP: 24 dBm
Distance-dependent path loss	Referring to Table A.2.1.1.2–3 in [1] *Pico to UE:*
	$PL_{LOS}(R) = 103.8 + 20.9log10(R)$
	$PL_{NLOS}(R) = 145.4 + 37.5log10(R)$
	For 2 GHz, *R* in km
	Case 1: $Prob(R) = 0.5\text{-}min(0.5,5exp(-0.156/R)) + min(0.5, 5exp(-R/0.03))$
	Referring to [3] delta(3.5 GHz) = 20*log10(3.5/2) = 4.8 dB
Penetration	For outdoor UEs: 0 dB
Shadowing	ITU UMi (referring to Table B.1.2.1–1 in [1])
Antenna pattern	2D Omni-directional
Antenna height	10 m
UE antenna height	1.5 m
Antenna gain + connector loss	5 dBi
Fast fading channel	ITU Umi
Antenna configuration	2T × 2Rx in DL, Cross-polarized
UE dropping	570 UEs are randomly and uniformly dropped within the grid
Minimum distance (2D distance)	AP-AP: 10, 20, 30 and 50 m
	AP-UE: 5 m
Traffic model	Full buffer
UE receiver	Minimum Mean Square Error-Interference Rejection Combining (MMSE-IRC)
UE noise figure	9 dB
UE speed	3, 30, 60 and 120 km/h

consecutive in-sync indications from lower layers, upon triggering the handover procedure and upon initiating the connection re-establishment procedure.

The following Fig. 7.1 shows the simulation results of the interrupt ratio of different ISD, in where UE speeds are 3, 30, 60 and 120 km/h. HO refers to the legacy handover, DC refers to the dual connection.

We can see that the larger the ISD is, the smaller the interrupt ratio will be. When the ISD is small, the interrupt ratio of APG and dual connection is far less than that of the legacy handover. And when the ISD is large, the interrupt ratio of APG and dual connection is slightly less than that of the legacy handover.

Table 7.2 Handover/changing process related parameters [2]

Items	Description
Time To Trigger (ms)	40, 80, 160, 240
A3-offset (dB)	2
L1 to L3 period (ms)/L1 sample interval (ms)	200/40
RSRP L3 Filter K	4, 1
Measurement error	To obtain the 90% bound for +/− 2 dB, a normal distribution with deviation = 2 dB/(sqrt(2)*erfinv(0.9)) = 1.216 dB can be used
Handover/SeNB changing preparation (decision) delay (ms)	50
Handover/SeNB changing execution delay (ms)	40
Service node changing delay (ms)	5

Table 7.3 Radio link monitoring process related parameters [2]

Items	Description
Qout	−8 dB
Qin	−6 dB
T310	1 s
N310	1
T311	1 s
N311	1

Remark: T310 is a timer related to radio link failure and recovery

Table 7.4 Parameter configuration of different UE speed [2]

Items	3 km/h	30 km/h	60 km/h	120 km/h
L1 to L3 period (ms)	200	200	200	200
L1 sample interval (ms)	40	40	40	40
Time To Trigger (ms)	240	160	80	40
A3-offset (dB)	2	2	2	2
RSRP L3 Filter K, $\boldsymbol{a} = 1/2^{(k/4)}$	4	4	4	1
	0.5	0.5	0.5	0.84

The following Fig. 7.2 shows the simulation results of the cell average spectrum efficiency of different station spacing, in which UE speeds are 3, 30, 60 and 120 km/h.

We can see that the larger the ISD is, the higher the AP average spectral efficiency will be. The AP average spectral efficiency of APG is higher than those of legacy handover and dual connection, and when ISD is small the gain is much obvious. At the same time, the cell average spectrum efficiency of dual connection is slightly higher than that of legacy handover when ISD is small, and both are basically the same when ISD is large.

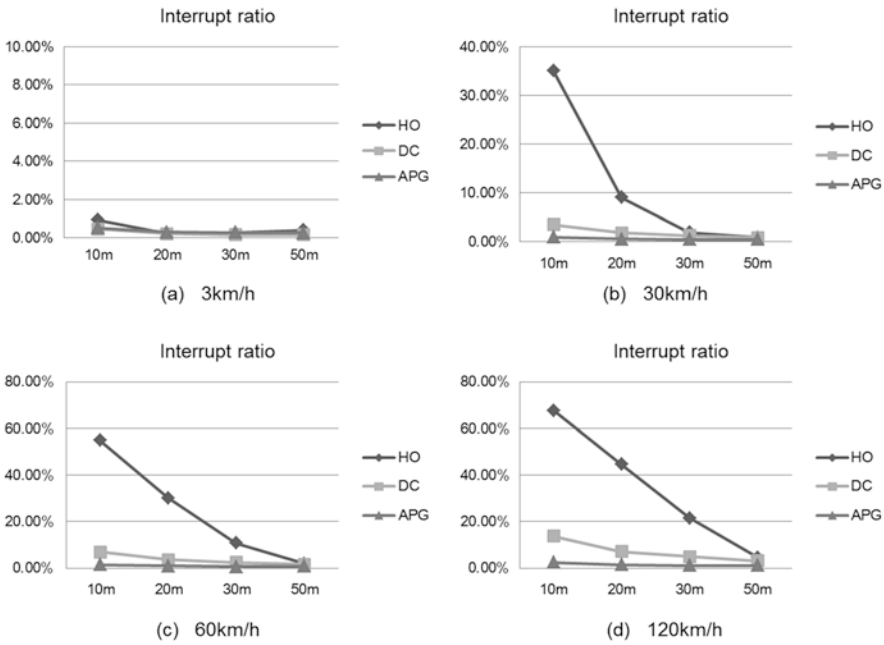

Fig. 7.1 Interrupt ratio

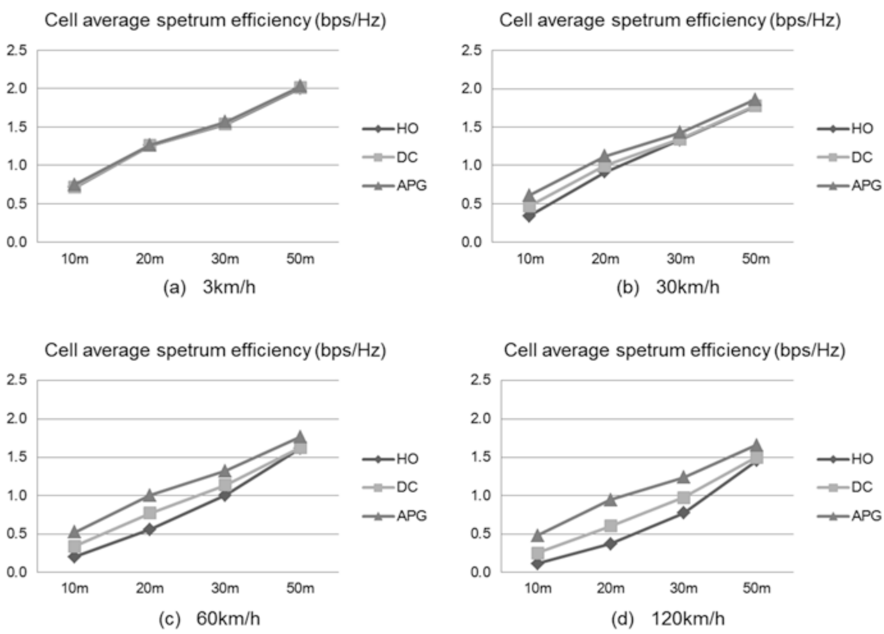

Fig. 7.2 Cell average spectrum efficiency

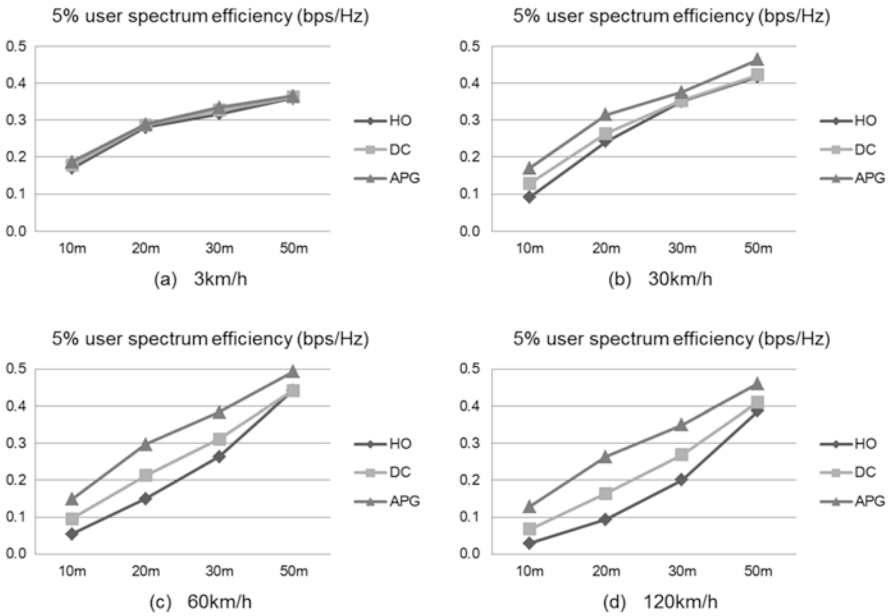

Fig. 7.3 The 5% user spectrum efficiency

The following Fig. 7.3 shows the simulation results of the 5% user spectrum efficiency of different ISD, in where UE speeds are 3, 30, 60 and 120 km/h.

We can see that the larger the ISD is, the higher the 5% user spectral efficiency will be. The AP average spectral efficiency of APG is higher than those of legacy handover and dual connection, and when ISD is small the gain is very obvious. At the same time, the AP average spectrum efficiency of dual connection is slightly higher than that of legacy handover when ISD is small, and the former is slightly higher than the latter or both are basically the same when ISD is large.

The following Fig. 7.4 is the spectral efficiency gain of three simulation solutions.

We can see that for the cell average spectral efficiency gain and 5% user spectral efficiency gain, the smaller ISD is, the larger the gain is; and the higher UE speed is, the larger the gain is. When the ISD is 50 m the gain is small, and when the UE speed is 3 km/h the gain is not obvious. The reason is that when the ISD is small or UE speed is high, the interrupt ratio of APG is small and UE is always served by the best service node. Compared with legacy handover and dual connection, no handover/changing failure happens while UE is moving in APG with smooth changing among multiple service nodes, which avoids trough of data throughput and could greatly improve user experience. In summary, APG in the ultra-dense deployment scenario with high UE speed could obtain a significant system performance improvements and better user experience.

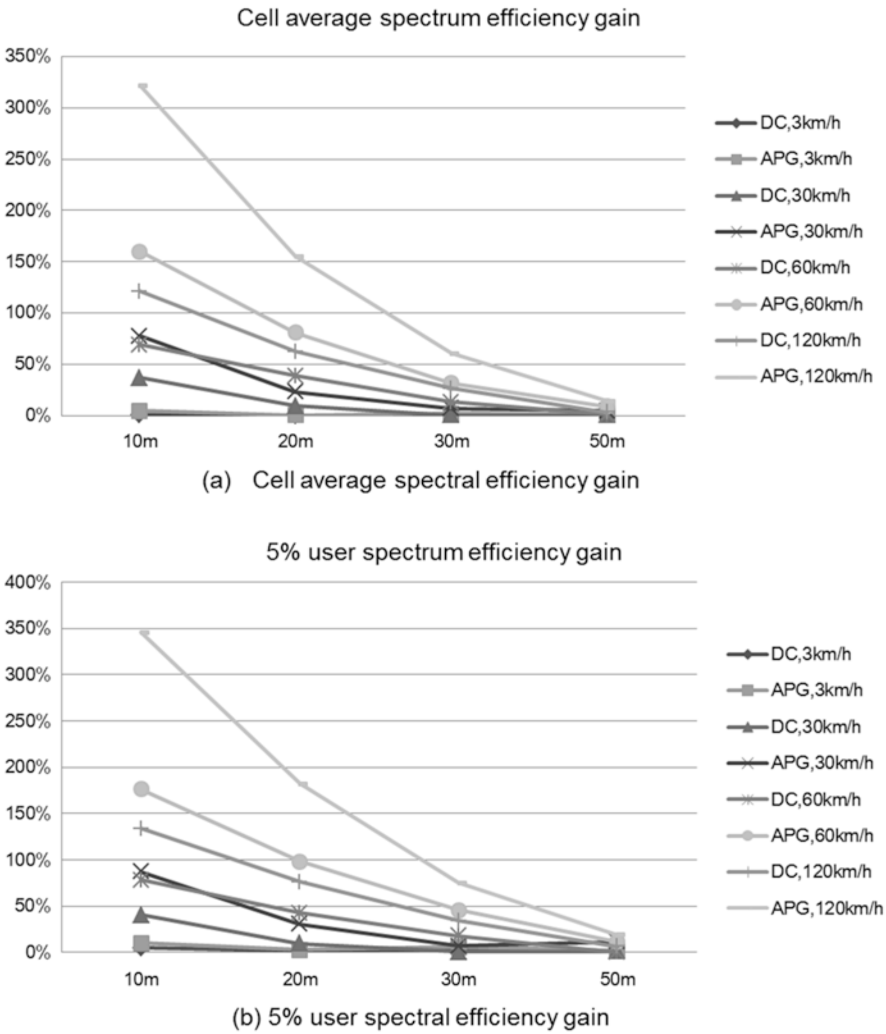

Fig. 7.4 Spectrum efficiency gain

7.2 Advanced Interference Management

When the APs are deployed more and more densely, inter AP interference becomes the key factors to restrict the improvement of system performance. Elimination of this interference needs efficient radio resource management methods. One may convert the interference signal into the useful signal for the coordination transmission of data to the users.

The main way of interference evaluation is to make a system level performance simulation and analysis through the detailed modeling of the typical scenarios. Application scenarios and models are derived from the IMT-2020 promotion group, in which the office scenario has high priority and much challenge due to the requirements of high traffic density and user experience rate. In the performance analysis, the spectrum efficiency on system level is focused on. At present, the research on simulation algorithms is mainly based on interference management and coordination algorithms such as the multi-user coherent joint transmission in CoMP.

7.2.1 Simulation Assumptions

In the office scenario, the APs are regularly deployed with the ideal backhaul (one-way delay <2.5 μs and throughput >10 Gbps). Therefore, through Centralized RAN (baseband pool and APs) architecture, the coordination among the APs can be achieved, it enhances the spectrum efficiency and system capacity shown as following Fig. 7.5 and Table 7.5.

In 1000 m^2 office area, 10 APs or 40 APs are regularly deployed, and ISD is 10 m or 5 m. Simulation parameters for office scenario are shown in the following Table 7.5.

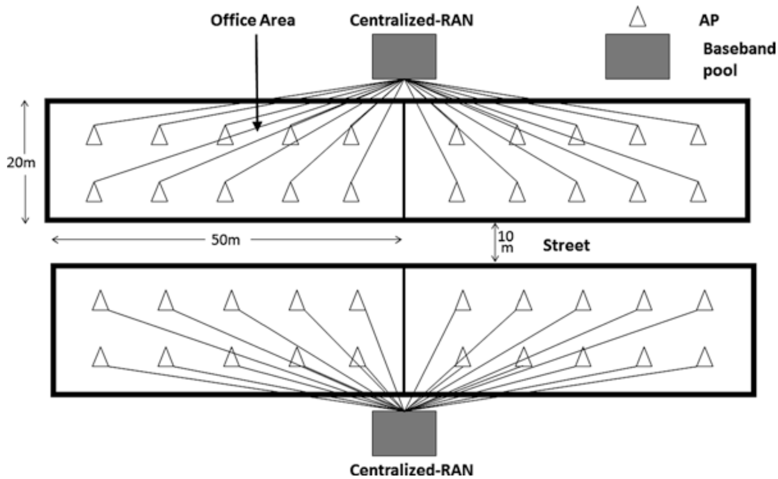

Fig. 7.5 Illustration of office scenario

Table 7.5 Simulation parameters for office scenario

	AP
Layout	Two office buildings are in the 5000 m^2 block area with 10 m street. Each office building has six floors, and office area is 1000 m^2 with 10 or 40 APs regularly deployed in each floor
System bandwidth per carrier	10 MHz
Carrier frequency	3.5 GHz
Carrier number	1
Total BS TX power	24 dBm
Distance-dependent path loss	3 GPP Dual Strip (referring to [3] A.1.3)
Penetration	Interior wall: 5 dB, external wall: 23 dB
Shadowing	ITU InH (referring to Table B.1.2.1–1 in [1])
Antenna pattern	2D Omni-directional
Antenna height	3 m
UE antenna height	1.5 m
Antenna gain + connector loss	5 dBi
Fast fading channel	ITU InH
Antenna configuration	2T × 2R× in DL, Cross-polarized
UE dropping	UEs are randomly and uniformly dropped within the office area
Minimum distance (2D distance)	AP-AP: 10 m or 5 m
	AP-UE: 0 m
Traffic model	Full buffer
UE receiver	MMSE-IRC
UE noise figure	9 dB
UE speed	0 km/h (no move)

7.2.2 Simulation Results and Conclusions

In the simulation, the system performances of the baseline algorithm and interference management algorithm are provided including the cell average spectral efficiency and 5% user spectral efficiency, measured by bps/Hz. The baseline algorithm is defined that all the APs are in the same frequency with no interference management, and interference management algorithm is based on the multi-user coherent joint transmission in CoMP.

The following Fig. 7.6 shows the simulation results of the spectrum efficiency of different ISD, which is 10 m or 5 m.

We can see that for the cell average spectral efficiency and 5% user spectral efficiency, the smaller ISD is, the lower the spectral efficiency will be. The reason is that when the ISD is small, the interference is more serious. Compared with baseline algorithm, the interference management algorithm can effectively improve the spectrum efficiency because of the coordination transmission, which convert the

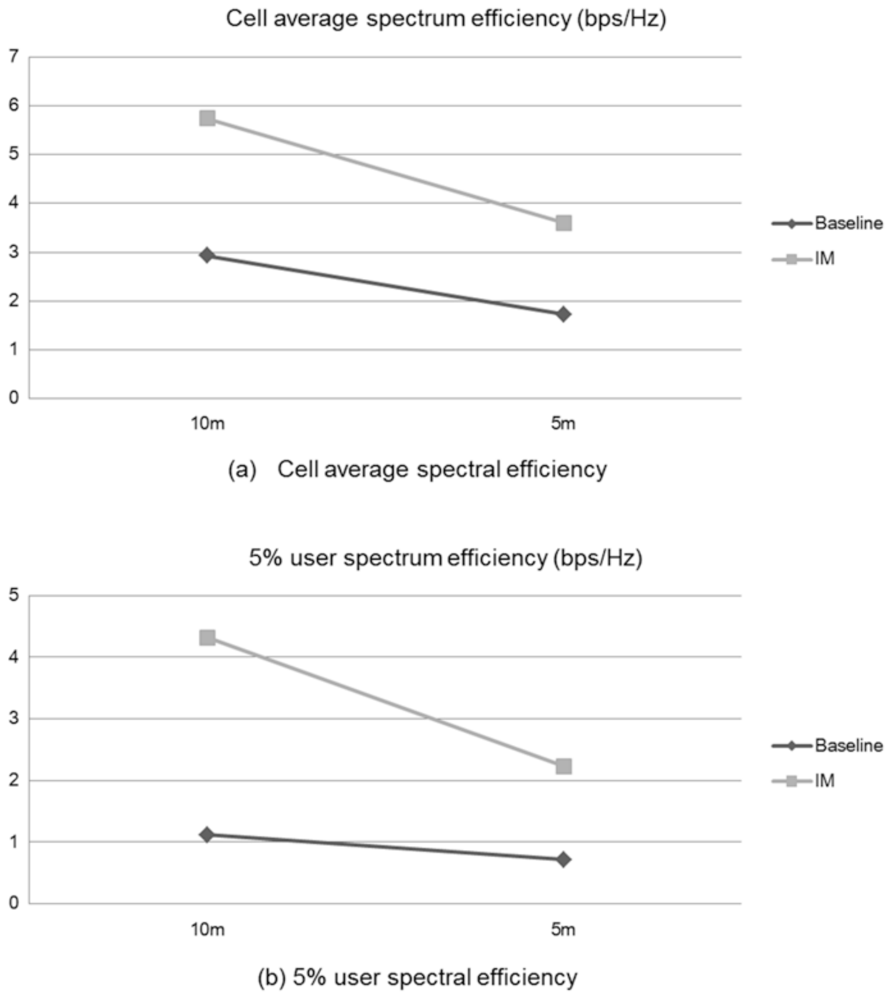

Fig. 7.6 Spectrum efficiency

interference signal into the useful signal and greatly improve user experience. In summary, the interference management such as the multi-user coherent joint transmission in the ultra-dense deployment scenario could obtain a significant system performance improvements and better user experience.

7.3 Solution Example

7.3.1 Deployment Scenarios

In order to verify the UUDN technologies, a demo system is deployed in China Academy of Telecommunication Technology (CATT). Both indoor and outdoor scenarios are considered for performance testing.

As shown in Fig. 7.7, the demo system was located initially in the exhibition hall of the first floor of CATT's main building, with a size of 25 m*13 m. Totally eight APs are deployed in the hall, and the average distance between adjacent APs is

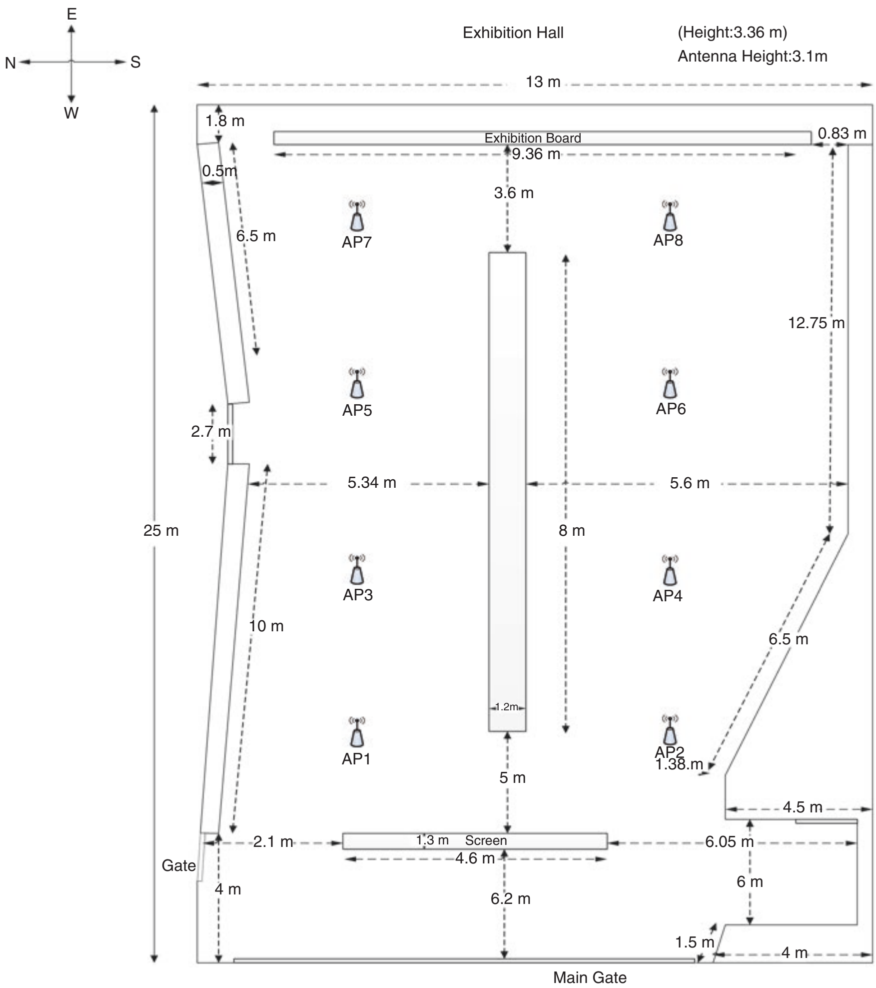

Fig. 7.7 Layout of UUDN testbed in the exhibition hall of CATT's main building

Fig. 7.8 Deployment of UUDN trial on the balcony of CATT's main building

about 6 m. A ceiling type antenna with the height about 3.1 m is installed for each AP, covering the ground in an omnidirectional way. In addition, the antenna number for each AP is 8, the antenna gain is 5 dBi, the transmitted power for each AP is 24 dBm, and the system bandwidth is 100 MHz.

Following the indoor testing, this demo system is also located on the open balcony of the fourth floor of CATT's main building, with an area of about 300 m^2, as shown in Fig. 7.8. Similar to the indoor case, totally eight APs are deployed. Every two APs share the same pole but radiate toward different directions, and the distance between adjacent poles is about 10 m. Also, other parameters of the AP are the same as that in the indoor case.

7.3.2 System Architecture

Figure 7.9 shows the system architecture of the UUDN demo system. Eight APs with totally 64 antenna elements are connected to a Local GateWay, with ideal Radio over Fiber (RoF) backhaul of 25 Gbps per AP. Base Band Unit (BBU) and higher layer functions such as LSC and LDC are integrated into the Local GateWay. A Core Network emulator and high speed File Transfer Protocol (FTP) application server are co-located in a quality server offering sufficient bandwidth and ultra low latency. The transmission link data rate between Local GateWay and Core Network is 10 Gbps.

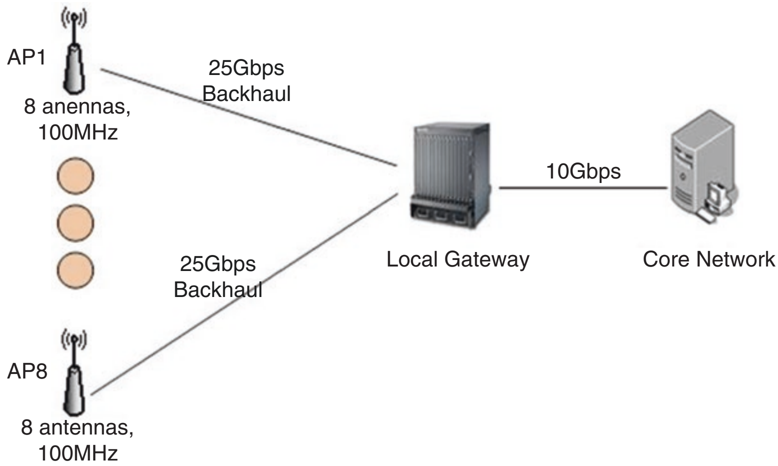

Fig. 7.9 System architecture of UUDN

7.3.3 Key Technology Characteristics

With the above system architecture, following key technologies are involved:

1. **DAPGing**

Based on the power measurement results on user pilot signals to each AP, the system dynamically selects nearest APs whose pilot signal power difference is in range of 12 dB to compose an APG. The number of APs in APG is in the range of 1–8. The APG will jointly transmit the system information and service data to each user dedicatedly.

When a user moves in the coverage area, the system will periodically detect the UE's measurement results and update the most suitable serving APG dynamically. There is no handover interruption during user's moving.

2. **Multi-AP multi-user joint transmission**

In traditional cellular structure, APs usually transmit signals independently with co-frequency, which will result in serious inter-AP interference due to superposed coverage from adjacent APs.

To against the inter-AP interference, the system takes the multi-AP multi-user joint transmission technology. A multi-user virtual MIMO channel matrix A with dimension of 64 × 32 is built from eight APs with 64 antenna elements and eight users with 32 antenna elements. Singular Value Decomposition (SVD) decomposition based on the MMSE is done from the virtual matrix A and optimal beamforming vectors are achieved for multi-user, realizing the Multi-AP multi-user joint transmission.

3. **Air interface calibration**

To realize above multi-AP joint transmission, usually UE requires code book based feedback from all 64 antennas, resulting in tremendous overhead from channel measurement pilot and channel state feedback. Therefore, channel reciprocity should be used, that is, channel matrix from uplink measurement can be used for downlink. For channel reciprocity, the phase and amplitude of antennas in uplink and in downlink should be in agreement strictly, that is the so called antenna calibration.

In this deployment example, a calibration circle is used for the local eight antenna elements from the same AP, while the air interface calibration method is used for different APs by detecting calibration signals in special idle slots.

7.3.4 Testing Results

Some preliminary test cases are done in both indoor and outdoor scenarios.

First is coverage characteristic of the pilot channel. As shown in Fig. 7.10, the estimated RSRP is in the range of (−85, −40) dBm. For a UE, it can get much higher RSRP when it approaches an AP, while it gets lower and lower RSRP when it departs from an AP.

Second is the calculation of the traffic density. Eight UEs are placed uniformly in the testing area. Each AP can cover at least two UEs. Each UE can transmit dual layer data flow. The achieved average data rate for each UE is about 420 Mbps, and the total data rate in the deployed area is about 3.3 Gbps (=8*420 Mbps).

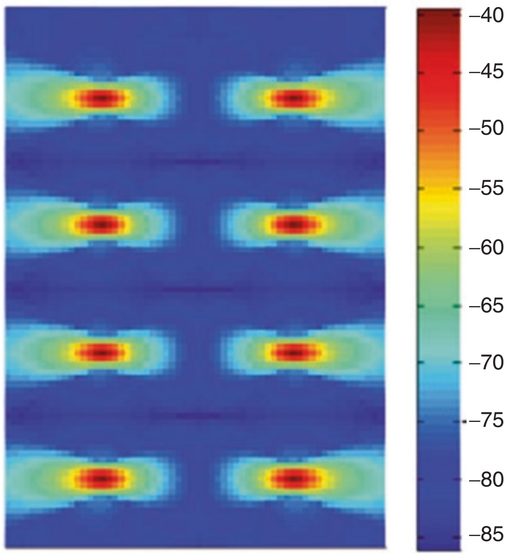

Fig. 7.10 Coverage characteristic of pilot channel (RSRP, dBm)

Divided by the area 300 m^2, the calculated traffic density is above 10 Tbps/km^2 ($\approx$3.3 Gbps/300 m^2) which can satisfy the specific requirement of 5G.

Third is the observation of UE edge throughput variation without and with inter-cell coordination. For two isolated UEs both deployed at the cell edge position, their sum throughput is less than 100 Mbps in case that only two isolated single APs are active, while the sum throughput increases up to 800 Mbps in case that more APs are active and they coordinate together for the UE.

In the future, more test cases will be taken to verify above described key technologies thoroughly.

References

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Chapter 8
Summary

In order to meet the very high traffic capacity requirement of 5G, UDN is a very promising technology direction. In this book, an UUDN concept is proposed. Based on the UUDN concept, we provide a novel network architecture. The new architecture is designed with the idea of localization, flatter, U/C separation, user-centric, intelligent and flexible networking.

Based on the new architecture and challenges analyses, many key technologies are introduced to provide high QoE, high area spectrum efficiency, low costing and green communication. Four promising technology directions are discussed in details, including DAPGing, intelligent networking, advanced interference management and security.

Simulation results of virtual cell show the significant gain on user mobility experience. And with the advanced interference process technologies in open office environment deployed with very dense APs, there are two times of average spectrum efficiency and 3–4 times of user experience data rate achieved.

For future works, detailed DAPGing, intelligent networking use cases and solutions, advanced interference management solutions and security solutions with real deployment limitation need to be further studied.

Besides above area, more directions need to be studied to bring the UUDN into a realistic deployment. For those very high density deployment scenarios, it is very difficult to connect each AP with ideal wired backhaul. A flexible backhauling to support ideal/non-ideal, wired/wireless backhaul is very important to ensure the deployment of UUDN.

Heterogeneous and cooperative networking is another problem to be further investigated. It's a big challenge to support UUDN with complex multi-tier scenario, multi-RATs, and irregular coverage.

In UUDN scenario, the use of mmWave bands is a promising way to provide very high data rate with very wide bandwidth. Many new features will be introduced due to very high frequency band, such as beamforming, coverage enhancement, integration of high and low band network, etc. Those will impact the mobility management, interference management and radio resource management.

S. Chen et al., *User-Centric Ultra-Dense Networks for 5G*, SpringerBriefs in Electrical and Computer Engineering, DOI 10.1007/978-3-319-61201-0_8

Appendix

Abbreviations

1G, 2G, 3G, 4G, 5G	The 1st, 2nd, 3rd, 4th, 5th Generation Mobile Communication System
3GPP	3rd Generation Partnership Project
AKA	Authentication and key agreement
AP	Access point
APG	APs Group
APG-ID	APG-identity
AuC	Authentication center
BBU	Base band unit
BS	Base station
CoMP	Coordinated multipoint transmission and reception
CRS	Cell-specific reference signal
D2D	Device-to-device
D-ICIC	Dynamic ICIC
DAPGing	Dynamic APs Grouping
DGR	Dynamic group refreshment
DoF	Degrees of freedom
EEA	EPS encryption algorithms
EIA	EPS integrity algorithms
eMBB	enhanced Mobile Broadband
eNB	evolved Node B
EPS	Evolved Packet System
FFR	Fractional frequency reuse
FTP	File transfer protocol
GSA	Group shared authentication
HeNB	Home evolved Node B
IA	Interference alignment

S. Chen et al., *User-Centric Ultra-Dense Networks for 5G*, SpringerBriefs in Electrical and Computer Engineering, DOI 10.1007/978-3-319-61201-0

ICIC	Inter-cell Interference Coordination
IMT	International mobile telecommunications
IP	Internet protocol
IPSec	Internet Protocol Security
ISD	Inter-Site Distances
ITU	International telecommunications union
ITU-R	International Telecommunications Union-Radio Communications Sector
JP	Joint processing
JT	Joint transmission
KPI	Key performance indicators
LDC	Local data center
LGW	Local gateway
LSC	Local service center
LTE	Long term evolution
LTE-A	LTE-Advanced
MAC	Media access control
MCU	Management/Control/User Plane
MDT	Minimization of drive tests
MeNB	Master evolved Node B
MIMO	Multiple input multiple output
MME	Mobility management entity
MMSE-IRC	Minimum mean square error-interference rejection combining
mMTC	massive Machine Type Communications
NDC	Network data center
NFV	Network function virtualization
NRL	Neighbor relation list
NSC	Network service center
O&M	Operations & maintenance
PCI	Physical cell identity
PHY	Physical layer
PGW	Packet data network gateway
PSS	Primary synchronization signal
QoS	Quality of service
QoE	Quality of experience
RAN	Radio access network
RATs	Radio access technologies
RF	Radio frequency
RLF	Radio link failure
RoF	Radio over fiber
RRC	Radio resource control
RRH	Remote Radio Head
RRM	Radio resource management

RSRP	Reference signal received power
SDN	Software defined network
SeNB	Secondary evolved Node B
SFR	Soft frequency reuse
SGW	Serving GateWay
SINR	Signal to interference plus noise ratio
SNR	Signal noise ratio
SON	Self-organized network
SSS	Secondary synchronization signal
SVD	Singular value decomposition
TDD	Time division duplex
U/C	User/control plane
UE	User equipment
UDN	Ultra-dense network
URLLC	Ultra-reliable and low latency communications
UUDN	User-centric Ultra-dense Network
VSM	Visual security supervision management
WLAN	Wireless local area network
WP5D	Working Party 5D