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A Novel Method to Manage Inter-Cell Interference for Ultra-Dense Heterogeneous Networks in 5G

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Abstract

The Ultra-dense Heterogeneous Network (HetNet), which consists of macro-cells and pico-cells, has been recognized as a key way of doing things to improve network performance. However, the increasing number of pico-cells also causes extreme interference including inter-cell interference and intra-cell interference. Therefore, interference management has become an important issue in ultra-dense HetNets, and the usual improved inter-cell interference coordination (eICIC) big plan/layout/dishonest plan is no longer fit for the high density of small cells. In this paper, a combination of two things/gas-electric vehicle interference management method based on energetic/changing eICIC and coordinated multi-point transmission (CoMP) is proposed. Firstly, a virtual cell is established based on the (features/ qualities/ traits) of ultra dense HetNets. Then, a novel joint energetic/changing eICIC big plan/layout/dishonest plan combined with multi-user beamforming is (sent out and used) to eliminate the inter-cell interference, and improve the throughput of virtual cell significantly without sharp decrease of throughput of macro-cell. What's more, a virtual cell based joint transmission big plan/layout/dishonest plan is (sent out and used) with a power control set of computer instructions, which can obviously increase the spectrum (wasting very little while working or producing something) of virtual cell edge. Test run (that appears or feels close to the real thing) results (check for truth/prove true) that the proposed big plan/layout/dishonest plan can (accomplish or gain with effort) better spectrum (wasting very little while working or producing something) both at macro-cell and virtual cell edges, and the network throughput is also improved.

INTRODUCTION

With the rapid development and innovations of mobile networking technologies, an entirely new era of mobile communications, i.e., the fifth generation (5G) of mobile communication systems, is coming. There is a consensus that 5G systems can be rolled out around 2020. 5G systems are expected to provide the society with full connection, which can break through the limitations of time and space to create all-dimensional, user-centered or service-centric interconnections between people and things [1].

5G networks aim to meet various user quality-of-service (QoS) requirements in different application scenarios, e.g., in terms of data transmission rate and latency [2]. In scenarios where seamless wide-area coverage is needed, 5G systems should provide users with seamless high-data-rate services anytime and anywhere, even at cell edges or with high-speed (up to 500 km/h) mobility. In metropolitan areas where the density and volume of wireless traffic demand are both very high, 5G networks should provide dense hot-spot coverage with high capacity. In scenarios where reliable connections of a large number of widespread low-power nodes, e.g., wireless sensors, are needed, 5G networks should be able to connect millions of devices under the constraints of low power consumption and low cost per device.

Extremely low latency and high reliability of 5G networks are required to meet the performance requirements of real-time, reliable and secure

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communications in some vertical industries such as interconnected vehicles and industrial production control.

Faced with the abundant, distinct, customized service requirements and in new application scenarios as mentioned above, the network architecture and networking technologies need to be revisited for 5G systems [3]. This has become the focus of research and development activities of operators, equipment vendors and research institutes all over the world. In order to provide customized reliable services using limited network resources while reducing capital expenditure and operating expense of 5G networks, network slicing has recently been proposed by the wireless industry as a main enabler of network service convergence and on-demand customized services [4]–[6]. By slicing a physical network into several logical networks, network slicing can support on-demand tailored services for distinct application scenarios at the same time using the same physical network. Supported by network slicing, network resources can be dynamically and efficiently allocated to logical network slices according to the corresponding QoS demands. Network slicing has also attracted a lot of research interests from the academia. In [7], user- centric service slicing strategy considering different QoS requirements was proposed based on software defined networking (SDN), and a genetic algorithm was devised to optimize the virtualized radio resource management based on resource pooling. In [8], a network slicing mechanism was introduced for network edge nodes to offer low-latency services to users, where the centralized core network (CN) entities and related applications are shifted to the network edge to reduce delays and burdens on the backhaul. The authors [8] also proposed mobility management schemes and an optimal gateway selection algorithm to support seamless handover. A resource allocation scheme with the consideration of interference management was presented in [9], where heterogeneous QoS requirements were guaranteed by optimizing power and subchannel allocation jointly. In [10], an agile and flexible SDN based 5G network architecture was proposed to allocate physical network resources to virtual slices within a local area and to perform scheduling among slices. The SDN based network architecture features an unified control plane, where hierarchical controllers are used to achieve differentiated services in user access layers close to the base stations, radio access network (RAN) and CN, respectively. The research on mobility management in network slicing systems has mainly been focused on SDN based control and handover procedures [10]–[12]. In the existing literature, mobility management and virtualized resource allocation have not been sufficiently studied for network slicing based 5G networks.

In this article, we present a logical architecture for network slicing based 5G systems, including an introduction of the fundamental concepts of network slicing. Based on the proposed net-work architecture, we investigate mobility management and virtualized radio resource allocation technologies in network slicing based 5G systems. Due to the diversity and complexity of 5G scenarios, it is vital to study proper mobility management for different mobility scenarios. Accordingly, we present a handover management scheme for handovers between different access networks. Virtualized resource management is responsible for inter-slice and intra-slice allocation of network resources in a dynamic and efficient manner. We propose a joint power and subchannel allocation scheme for network slicing based spectrum-sharing two-tier networks, where both the co-tier interference and cross-tier interference are taken into account. Simulation results will show that the proposed resource allocation scheme can flexibly allocate network resources between different slices, thereby realizing the efficient sharing of network resources in 5G systems. Finally, we highlight the future challenges and open issues on network slicing in 5G systems.

NETWORK SLICING BASED 5G SYSTEM ARCHITECTURE

The design of 5G network architecture should be based on a comprehensive consideration of software control and hardware infrastructure and the interworking between them. Network slicing, which can fulfil diversity of network requirements based on the unified physical infrastructure and sharing network resources, is considered as a key paradigm to provide several independently operating instances for a specific network function [5]. SDN has been widely accepted as a promising technique to implement network slicing on the basis of network function virtualization (NFV) [10]. NFV replaces the traditional network elements (such as mobility management entity (MME), policy and charging rules function (PCRF), packet/service-gateway (P/S-GW)) in the CN and the RAN with commercial off-the-shelf servers, which also host the functions of dedicated physical infrastructures. Each such server can be considered as a pool of virtual machines (VM) running on commercial off-the-shelf hardware and software. The traditional RAN is divided into centralized processing units (e.g., baseband units (BBU) in cloud RAN (C-RAN)) and radio access units. The centralized processing units are largely virtualized, where resource pooling is introduced to perform service slicing in accordance with different QoS requirements [13].

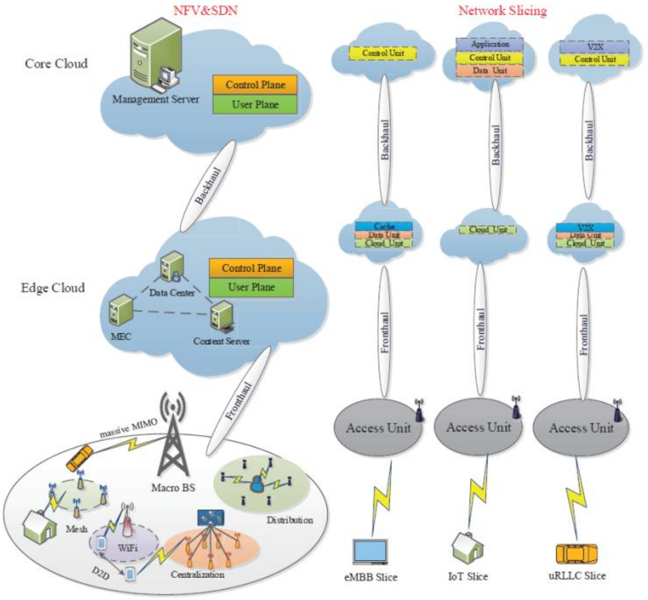

Fig. 1. Network slicing based 5G system architecture.

The logical architecture of a 5G system based on network slicing is given in Fig. 1. In the radio access plane of the 5G system, a heterogeneous network accommodates multiple radio access technologies (RATs) and supports the efficient cooperation between them. Small cells and WiFi access points are densely deployed to meet the increasing data traffic demand in 5G systems [14]. Furthermore, device-to-device (D2D) communications are used to increase system capacity and improve energy- and spectrum-efficiency while reducing communication delays and relieving backhaul burden of macrocells [10]. D2D communications will play a critical role in network slicing based 5G systems, especially for improving quality of local services, emergency communications and Internet of things (IoT).

As shown in Fig. 1, the traditional centralized architecture of the CN has evolved into a core cloud, which separates the control plane from the user plane so as to reduce control signaling and delays of data transmissions. The core cloud provides some important functions of the control plane, such as mobility management, virtualized resource management, interference management, and so on. The servers and other functions of the RAN are located in the edge cloud, which is a centralized pool of virtualized functionalities. The edge cloud mainly performs data forwarding and control plane functions such as baseband processing. The user-plane functions in P/S-GW are also shifted to the edge cloud, to provide low-latency services and to reduce the burden on the backhaul. Mobile edge computing platforms are also deployed in the edge cloud, in conjunction with data forwarding and content storage servers, which can collaboratively execute the storage, computing, transmission of massive data in a real-time and efficient way. The corresponding VMs will distribute in core cloud and edge cloud to execute virtualized network functionalities. By utilize SDN, 5G networks can connect the VMs distributed in core cloud and edge cloud, creating the mapping between core cloud and edge cloud. Furthermore, the SDN controllers can control network slicing in a centralized fashion.

After the virtualization and software redefinition of system architecture as described above, network slicing can be implemented. An example of network slicing operating on a set of generic physical infrastructures is

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illustrated in Fig. 2. An end-to-end network slice is a specific collection of network functions and resource allocation modules isolated from other network slices [5]. For example, the enhanced mobile broadband (eMBB) slice requires a large bandwidth to support high-data-rate services, such as high-definition video streaming and augmented reality. Caching function, data unit and cloud unit are also needed to assist control functions in implementing eMMB slicing services. Reliability, low-latency and security will be critical for the ultra-reliable and low-latency communication (uRLLC) slice to provide services that are extremely sensitive to latency, such as autonomous driving and Internet of vehicles (V2X). For uRLLC slice, all dedicated functions should be instantiated at the edge cloud. For IoT slice that serves a large number of static or dynamic machine type devices (such as sensors and monitors), the vertical applications will be placed on the upper layer to support the external services demanded by different commercial tenants.

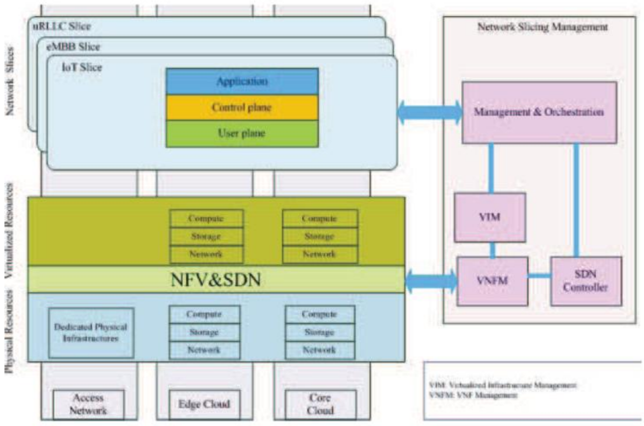

Fig. 2. Network slicing management.

In network slicing management, the control parts interact with each other through controllers or some kind of interfaces. The virtualized network function manager is responsible for the mapping of physical network functions to VMs. Coordinated with virtualized network function management (VNFM), the SDN controller operates and controls the entire virtual network by connecting the data layer and vertical applications through the interface protocols. Virtualized infrastructure management (VIM), as the center of the virtualized infrastructure, allocates virtual- ized resources to VMs by monitoring their resource utilization status. The network management and orchestration unit is the core part of slicing management, because it is responsible for creating, activating or deleting network slices according to customized service requirements.

The network slicing based 5G network architecture will radically change the traditional net- work planning and deployment patterns. Network slicing is driven by and tailored for the network applications and user requirements. By avoiding mapping each application to a single pipeline in the physical network, 5G networks can provide end-to-end tailored services according to customized application requirements.

MOBILITY MANAGEMENT IN NETWORK SLICING BASED 5G SYSTEMS

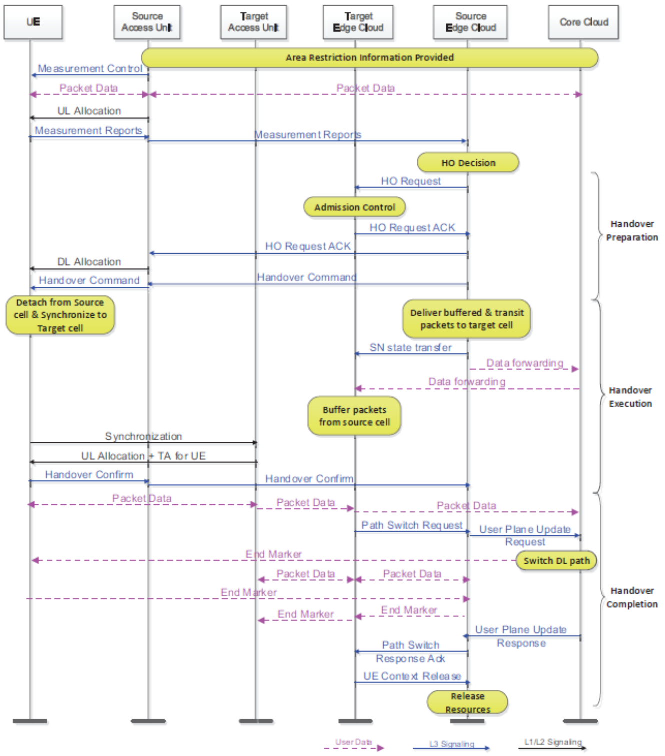

Fig. 3. Handover procedure based on 5G network slicing systems.

Mobility management in mobile communications has evolved from handling simple and single- RAT handover cases to managing complex, multi-RAT mobility scenarios. Based on SDN, the control plane and the user plane are split and decoupled at the gateway in the CN, and the integrated control functions can reduce control signaling even for a large number of distributed network nodes. However, network slicing based 5G systems will still face mobility management challenges caused by the potentially ultra high density of 5G networks combined with high mobility and high density of end devices. Consequently, new mobility management schemes need to be developed for network slicing based 5G systems to support seamless user experience with quality, continuity and scalability [12]. Different network slices have different characteristics and requirements in terms of mobility, latency and reliability. For instance, in railway communications, many handovers could be triggered by a high-speed train during a short time [11]; while in IoT applications, reliable and/or low-latency communications should be guaranteed for many devices with low or no mobility. In the following, we study the on-demand and scalable mobility management mechanism under network slicing for customized service scenarios.

There are two main procedures in mobility management: location registration and handover management.

A. Location registration

Mobile devices register their locations when they first connect to the network, and then report their location information to the network periodically. In 5G networks, the home subscriber servers will be distributed into the edge cloud, making them closer to end devices to shorten registration delays and reduce backhaul burdens. 5G networks will aggregate multiple hetero- geneous RATs. To achieve unified multi-RAT access and seamless mobility in 5G networks, multi-RAT coordination is needed for different RATs to share location information of their mobile devices.

B. Handover management

In conventional cellular networks, handovers are mainly event-triggered. The base station controls the user terminals to execute the measurement and report the measured network status information to serving base station. However, in our proposed network slicing based 5G systems, mobility related events need to be redefined. For instance, handovers may occur in different slicing scenarios. Flexible handover mechanisms and adaptive handover thresholds should be exploited to support mobility management in service-tailored scenarios.

In the proposed mobility management scheme for network slicing based 5G systems, the SDN is introduced into the RAN, generating the software-defined wireless network (SDWN). In SDWN, the single or hierarchical control plane is deployed closed to the edge cloud to support centralized control plane handover decisions. One SDN controller can handle handovers in a single network slice. In a hierarchical control plane within SDN, it is necessary for controllers to cooperate [10]. A handover signaling procedure in network slicing based 5G systems is given in Fig. 3. The user supported by one of the slices is communicating with other terminals through core cloud when the handover is triggered. After handover is executed successfully, the data will be transmitted through target edge cloud and target access unit to the user from core cloud. Due to virtualization, physical network elements are replaced by corresponding logical servers in core cloud and edge cloud. Moreover, in order to simplify multi-RAT cooperation, only IP protocols are used to support signaling interactions in the control plane. Existing interfaces are made open so that an unified interface protocol can operate flexibly. The SDN controllers located in the core cloud, the edge cloud and the access plane cooperatively carry out handover management in complex application scenarios.

VIRTUALIZED RESOURCE ALLOCATION WITH INTERFERENCE MANAGEMENT

Network slicing facilitates dynamic and efficient allocation of network resources to meet diverse QoS requirements [5]. In SDN and NFV enabled network slicing systems, network resources are virtualized and managed in the centralized resource pools [7]. Due to limited network resources and increasingly diversified network services, it is challenging to efficiently provision network resources to network slices with different QoS requirements. Moreover, the heterogeneous nature of 5G networks (e.g., different RATs, different cell sizes) also adds com- plexities to resource allocation [9]. Especially for densely deployed spectrum-sharing small cells, efficient and flexible resource allocation schemes with interference awareness are needed [15].

In this section, we present a resource allocation scheme tailored for different QoS requirements of uRLLC slice, IoT slice and eMBB slice, which are the three fundamental categories of network slicing in 5G systems. For example in uRLLC slicing scenarios, communication devices are more sensitive to time delay and require lower transmission rate than those in other slices. There could be mutual interference between small cells and macrocells, which provide services (e.g., video streaming) for eMBB slice and for IoT slice, respectively.

A. Modeling and formulation

As shown in Fig. 1, the collocated small cells and macrocell compose a two-tier system in the radio access plane. Small cells receive two kinds of interference: cross-tier interference from the macrocell and co-tier interference from neighboring small cells. In this scenario, we model the uplink resource allocation problem as the maximization of uplink capacity on each subchannel for small cells considering the following constraints: 1) the maximum transmit power of each small cell user; 2) the minimum data rate requirement of each uRLLC user; 3) the threshold of total interference power received by the macrocell from small cell users; 4) a subchannel can be allocated to at most one user in each small cell during one transmission interval.

B. Solution based on the Lagrangian dual decomposition method

The above formulation results in a non-convex discrete objective function. By relaxing the binary subchannel allocation indictors into continuous real variables, we transform it into a convex continuous function, which can be solved using the Lagrangian dual decomposition method. To simplify the solution, we decompose the objective function into a master problem and K×N sub-problems (for K small cells and N subchannels). The Karush-Kuhn-Tucker (KKT) conditions are used to get the optimal power allocation, and the sub-gradient method is exploited to update the Lagrangian multipliers to obtain the optimal subchannel allocation.

C. Simulation results

We present simulation results to demonstrate the performance of a network slicing based 5G network (in conjunction with the proposed subchannel and power allocation scheme), where a suburban environment is considered with small cells randomly distributed in the macrocell coverage area. The macrocell coverage radius is 500 meters and that of a small cell is 10 m. Other system parameters are set as follows: the carrier frequency is 2 GHz, the 10 MHz channel is divided into 50 subchannels, the minimum inter-small-cell distance is 20 meters, the maximal transmission power (of small cell and macrocell users) is 23dBm, the threshold of interference per subchannel (received by the macrocell) is -101.2 dBm, and the power spectral density of additive white Gaussian noise (AWGN) is -174 dBm/Hz.

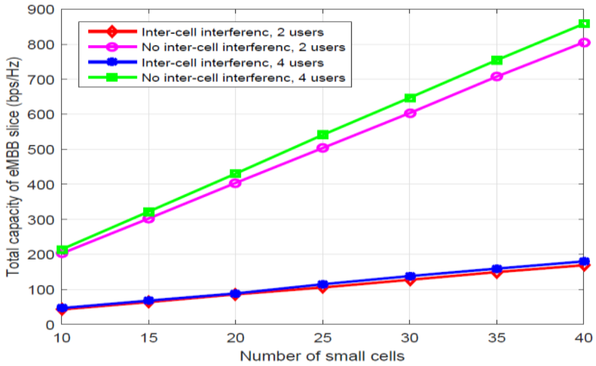

Fig. 4. Total capacity of eMBB slice versus the number of small cells.

There are 50 users (requesting IoT services) distributed randomly in the macrocell, and 2 or 4 users (requesting uRLLC or eMBB services) camping on each small cell. The channel model includes path loss (indoor and outdoor) and frequency-selective fading. Round-robin scheduling is used in each cell, and uniform power allocation is adopted for macrocell users.

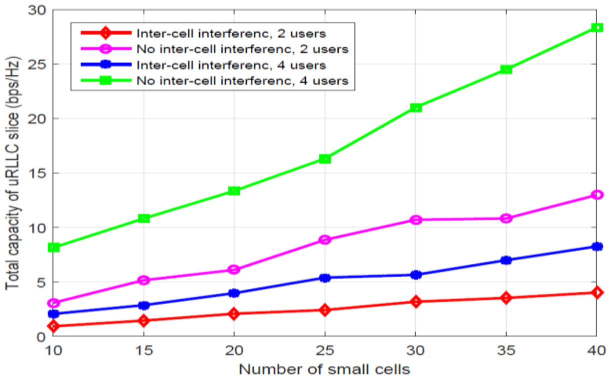

Fig. 5. Total capacity of uRLLC slice versus the number of small cells.

Fig. 4 shows the total capacity of the eMBB slice versus the number of small cells per macrocell. We can see that the eMBB slice capacity rises nearly linearly with the density of small cells and increases slightly with the number of users per small cell. However, the eMBB slice capacity decreases significantly due to the inter-cell interference between small cells, especially at high small cell densities.

Fig. 5 shows that the total capacity of uRLLC slice also increases with the number of small cells, but the capacity of uRLLC slice is 20 times less than that of eMBB slice. This is because the eMBB slice uses large bandwidths to transmit massive data, while the uRLLC slice only transmits low-volume control messages or data under low-latency constraints.

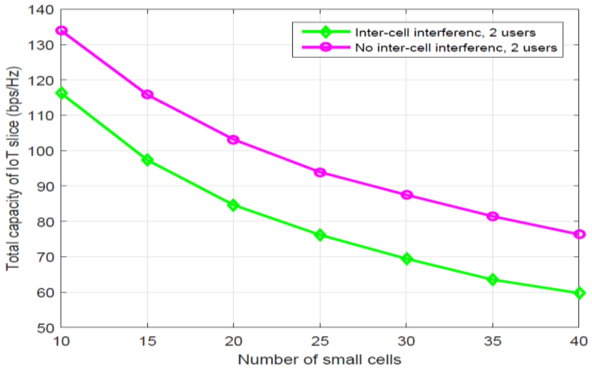

Fig. 6. Total capacity of IoT slice versus the number of small cells.

Fig. 6 shows the total capacity of the IoT slice supported by the macrocell, which suffers from cross-tier interference from small cells supporting the eMBB and uRLLC slices. The total capacity of the IoT slice decreases with the number of small cells, due to the increasing cross-tier interference caused. The capacity of IoT slice will further decrease due to co-tier interference between macrocells and between small cells. This is because with channel quality affected by increased inter-small-cell interference, small cell users will adaptively increase their transmit power leading to an increase of cross-tier interference from small cells.

The simulation results have shown that in both latency-sensitive and latency-tolerant network slicing scenarios, the proposed resource allocation scheme can allocate network resources prop- erly and efficiently, and can improve system capacity of dense heterogeneous networks. Due to the space limitation, we will discuss other metrics (such as latency) in future works.

CONCLUSION

In this article, we have presented a logical architecture for network slicing based 5G systems, and discussed the evolution of network architecture based on SDN and NFV technologies, as well as the implementation of network slicing. Based on the network slicing architecture, we revised handover procedures in mobility management, and discussed mobility management mechanisms to offer flexible and agile customized services in network slicing based 5G systems. Moreover, considering various network slicing scenarios, we introduced a resource allocation mechanism tailored for QoS requirements and interference constraints of uRLLC, eMBB and IoT service slices. The promising performance of network slicing based 5G networks has been demonstrated through computer simulations.

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