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USER-CENTRIC MULTI-RATs COORDINATION FOR 5G HETEROGENEOUS ULTRA-DENSE NETWORKS

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INTRODUCTION

It is undoubtful that deploying very dense access nodes (e.g., small cells and remote radio heads) is a key approach for 5G to tackle the foreseeable surging mobile traffic. In such an ultra-dense networking (UDN) scenario, the distance between a user and its associated access node is greatly reduced, so the system performance can be significantly enhanced due to stronger radio link gain as well as better spatial reuse of the spectrum [1]. Furthermore, UDN generally provides a more ideal propagation environment for millimeter-wave (mmWave) bands, namely shorter propagation paths with probable presence of a line of sight (LoS) channel. All these benefits illustrate the potential of deploying UDN in future mobile communications, especially in urban areas that expect very heavy traffic, such as downtown train stations and commercial districts. In spite of these promising advantages of UDN, deployment of dense access nodes naturally creates dense cell boundaries at the same time. Under such circumstances, users may experience more inter-cell interference since the signal strength from neighboring cells is on the same order as that of the serving cells. Another downside is the overhead caused by mobility management due to frequent handover as a moving user traverses cell boundaries several times in a short time span. These drawbacks may eventually diminish the promised benefits of UDN.

Against the backdrop of these issues in UDN, the concept of user-centric access (UCA) [2–6] has been proposed in recent years. By exploiting the fact that a user in UDN may simultaneously see more than one access node in proximity, a user-specific *virtual cell* may be constructed by the network via joint operation of multiple access nodes. The composition of a virtual cell should be continuously reconfigured in order to “follow” the user’s movement. Therefore, from the

user perspective, he/she is always in the center of a logical radio coverage, and hence handover is no longer required. Indeed, UCA represents a major departure from the classical cellular networks. While most of the previous works in the literature have only examined UCA in cellular networks, it is plausible that a 5G UDN comprises heterogeneous radio access technologies (RATs) including 5G, 4G, WiFi, and many other Internet of Things (IoT)-oriented connectivity. A user may be exposed to multiple different RATs at the same time in so called heterogeneous UDN. Therefore, this article aims to introduce multi-RAT coordination as a new element that may streamline the UCA concept by utilizing an edge/fog computing framework which allows multiple RATs to exchange information. Remarkably, instead of merely considering the resultant signal quality as in conventional UCA, different coordination patterns between RATs within a virtual cell may be applied by taking the further context information of the user (mobility, battery status, etc.) into account.

REVIEW OF USER-CENTRIC ACCESS THE CONCEPT

As aforementioned, the concept of UCA is motivated by the dense cell boundary issues such as inter-cell interference and frequent handover that may plague UDN operation in practice. In the existing literature on UCA, coordinated multipoint (CoMP), also known as network multiple-input multiple-output (MIMO) techniques, have been widely leveraged to facilitate virtual cell construction [2–4]. CoMP is basically cooperative joint transmission or reception of multiple access nodes surrounding the user, which in turn converts heavy interference at the cell edge into useful signal power. Ideally, the performance gap between the cell center and the cell edge will vanish, leading to a “virtual” cell center despite the physical location of the user. In order to support user mobility and maintain a seamless radio link, the network should adaptively change the access nodes involved in the virtual cell composition tailored for this user (by adding or removing some of the participant access nodes [4]), aiming to maintain a logical cell that follows the movement of the user with a constant quality of service (QoS), as illustrated in Fig. 1. More specifically, each user can be assigned a virtual cell ID that is decoupled from the physical serving access nodes, so this ID remains the same even if the physical access nodes serving this user have changed due to, for example, user mobility. It is worth noting that some industrial participants in the Third Generation Partnership Project (3GPP) have also exhibited interest in standardizing UCA in 5G New Radio (NR) [7], wherein the notion of a *HyperCell* has been proposed to initiate a logical cell and update it flexibly in a user-specific manner.

FACILITATION BY EDGE/FOG COMPUTING

With UCA, users on the move may retain their communication links to the network without bearing the burdens that are typically required in conventional systems, and the mobility support is thereby largely hinged on agile and dynamic resource allocation by the network intelligence. Hence, powerful computing infrastructures are needed to carry out intense processing for the sake of efficient UCA operations. Specifically, for each user, the network has to jointly decide the access nodes to be involved and radio resources (in time, frequency, code, and spatial domains) to be allocated

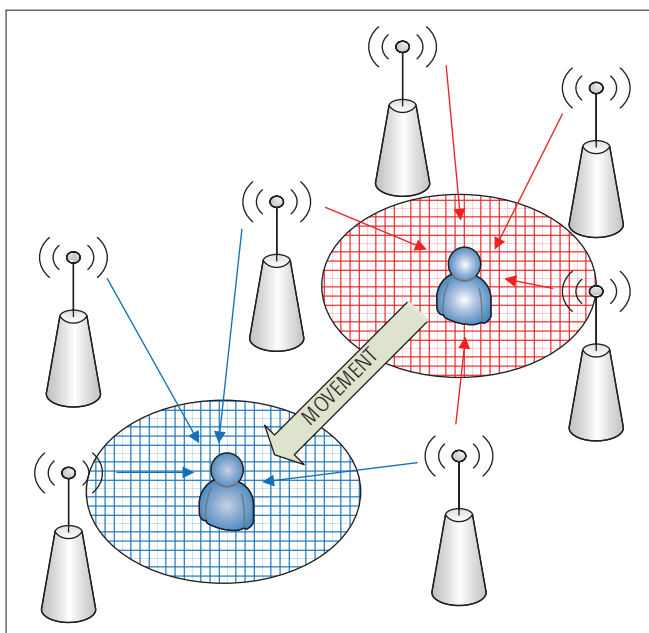


FIGURE 1. An illustration of the user-centric access concept.

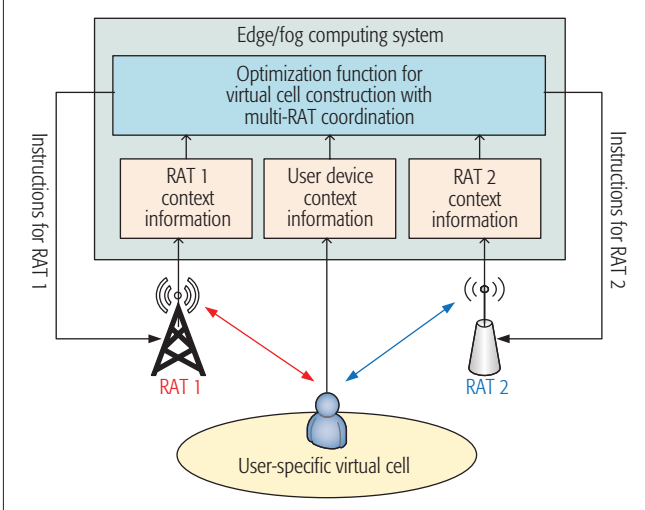


FIGURE 2. Virtual cell construction via edge/fog computing with multi-RAT coordination.

for the virtual cell composition [6]. In [2, 3], it is suggested that the virtual cell construction can be handled by a master node (typically a macrocell) within a group of slave access nodes. Some other works [4, 5] have suggested that the network intelligence required for UCA can be hosted in dedicated local edge servers, which oversee all access nodes without designation of master or slaves. All these cases can be deemed as a utilization of computing resources available at the radio access network (RAN) domain, thereby enabling low-latency RAN optimization.

Recently, a Fifth Generation Public Private Partnership (5GPPP) project, 5G-CORAL [8], has been launched with an objective of realizing multi-RAT convergence via edge/fog computing. In particular, a logically integrated computing platform supported by edge/fog computing resources will be developed, which offers a common stage to gather context information from multiple RATs as well as user devices. The collected information can be fed into a certain network optimization function that is also hosted by the edge/fog computing platform, and the performance can be enhanced through orchestration among multiple RATs. Since the edge/fog computing resources are basically local in the RAN domain, low-latency network reconfiguration can be anticipated due to small round-trip delay. Apparently, such a setting is a powerful tool to realize UCA, as coordination among multiple RATs can be applied as an ingredient for virtual cell construction in addition to CoMP. This allows the virtual cell to become even more flexible and versatile, as different characteristics of the RATs can be taken into consideration and exploited within the virtual cell in an appropriate manner. An exemplary illustration of virtual cell construction with two RATs is depicted in Fig. 2.

USER-CENTRIC ACCESS WITH MULTI-RAT COORDINATION

By leveraging the edge/fog computing system elaborated previously, a virtual cell could be constructed by not just the access nodes associating to cellular networks, but also the nodes pertaining to other RATs, such as WiFi and ZigBee. Moreover, the coordination pattern is not limited to CoMP-like joint transmission or reception, which is designed for better signal quality, but also other multi-connectivity schemes that take user status into consideration as well. More specifically, different RATs within a virtual call may play different roles, in a bid to fulfill the instantaneous need of the user device. We envisage a few

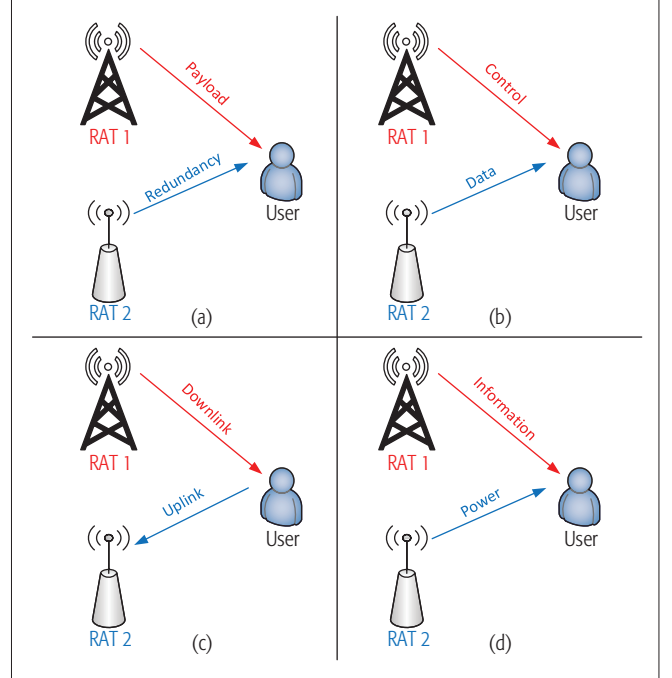


FIGURE 3. The considered multi-RAT coordination patterns for a virtual cell, including; a) payload/redundancy separation; b) control/data separation; c) downlink/uplink separation; d) information/power separation.

possible multi-RAT coordination patterns within a virtual cell, as described below.

Payload/Redundancy Separation: In order to satisfy users requiring ultra-reliable low-latency communications (URLLC), a virtual cell may be formed by tight integration between RATs in the physical layer. Specifically, a user may receive data payload packets from a primary RAT (e.g., 5G New Radio) while obtaining additional parity bits of the same packet from a secondary RAT (e.g., LTE). In this case, the primary RAT may share a set of redundant bits with the secondary RAT once the coded bits of the payload have been generated. The nodes associated with these two RATs may transmit at the same or approximately the same time as there is a latency requirement imposed. This coincides with the interface diversity approach that was recently suggested [9] for URLLC. If the user fails to decode the packet, it can immediately utilize the additional parity bits from another RAT to accomplish decoding without making a request for retransmission, which significantly curtails the delay.

Data/Control Separation: It is quite critical to ensure that high-mobility users can always acquire the important system information required to sustain proper operation despite their movement. Thus, in many cases it is desirable to have control plane connectivity via an access node with broader coverage, so the user is less likely to miss out on crucial control information from the network. For instance, for a network comprising RATs operating at sub-6 GHz and mmWave frequency bands, the low-frequency RAT is generally a more suitable node to maintain timely and robust control plane connectivity due to its broader coverage, while the vast bandwidth available in mmWave can be employed to boost data plane throughput. Thus, when the mobility level of the user is higher than a threshold, the virtual cell for this user may be formed with separate control plane and data plane connectivities.

Downlink/Uplink Separation: When the remaining battery of a user device is lower than a certain level, the virtual cell may be deliberately configured to allow the user to con-

duct downlink reception and uplink transmission with different RATs. Specifically, the virtual cell for this user may maintain the uplink transmission from this user through a low-data-rate and low-power RAT (e.g., most of the IoT-oriented connectivity schemes) in a bid to decrease power consumption, while receiving downlink traffic from high-data-rate RATs (e.g., cellular or WiFi). It is worth noting that such setting also allows more flexible resource allocation, as the resource pools from different RATs can be jointly considered when conducting traffic scheduling for downlink and uplink.

Information/Power Separation: Wireless power transfer has targeted enabling “over-the-air” battery charging via radio waves. In recent years, many efforts have been made aiming to allow simultaneous reception of wireless information and power, so the user device may enjoy data services without rapidly depleting the battery. In particular, this can be fulfilled by decoupling the power source from the information source, wherein power and information signals are transmitted by distinct radio nodes [10]. Hence, we may envision a virtual cell that contains both power and information nodes for a user with depleting battery, and the roles could be played by different RATs. For example, an indoor user may maintain its communication link with an outdoor LTE base station while receiving wireless power from a nearby WiFi access point. More interestingly, we may coordinate multiple access nodes and/or RATs to create *intentional interference* toward a user in idle mode (and hence no impact on data reception) by configuring downlink beamforming matrices of these nodes, which in turn maximizes the wireless charging efficiency of this targeted user. Essentially, this leads to a *user-centric wireless battery charger*.

CONCLUSIONS

This column reviews the concept of user-centric access, which permits the network to tailor a “follow me” virtual cell for a user via multipoint coordination in a UDN environment. We further

discuss the feasibility of extending such a virtual cell by considering tight integration of heterogeneous RATs exposed to the user, by taking the context information and instantaneous status of the user device into account. In particular, we conceive an edge/fog computing platform capable of acquiring and jointly processing information from multiple heterogeneous RATs and the users. Such a framework may have great potential to play key roles in 5G and beyond, in terms of realizing truly flexible radio access that can be customized for each individual user in the network.

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