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# Heterogeneous Network: An Evolutionary Path to 5G

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***Abstract*—In this paper, we will first motivate the heterogeneous network as an evolutionary path to the fifth generation (5G) communications. We then present an agile software defined heterogeneous network architecture which virtualizes the various radio access networks such as cellular basestations and Wi-Fi access points and the various carrier frequencies from both licensed and unlicensed bands. The software defined heterogeneous network architecture can therefore support much more efficient resource utilization and meet the quality of service requirement. We will also share our work in context-aware Wi-Fi-cellular network traffic steering and mobility management as two use cases in the software defined heterogeneous network.**

***Index Terms*—Heterogeneous network, 5G, large-scale distributed antenna systems, software-defined radio access network (SDRAN), context-aware network management, Wi-Fi offloading**

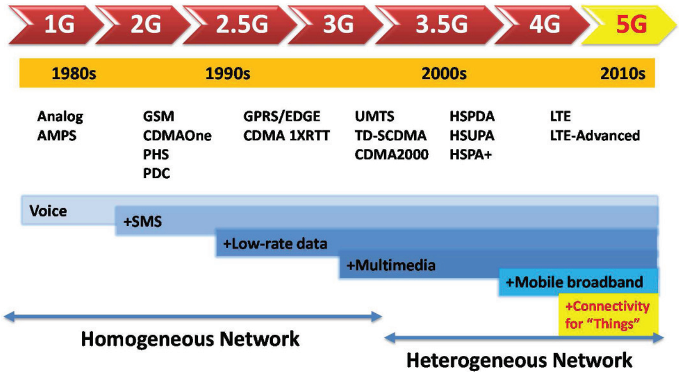


Fig. 1. The cellular evolution.

## I. Introduction

Since the introduction of the first generation of cellular mobile communications in the 1980s, we have witnessed tremendous progress in both the research and technology development, as well as the successful deployment of wireless communications. As illustrated in Fig. 1, from the simple voice phone calls in the first generation, to text messaging services in the second generation, low-rate data and multimedia services in the third generation, and mobile internet and mobile social network in the fourth generation, wireless communications have penetrated into our daily work, study, and social lives and greatly influenced our life styles.

The popular adoption of wireless communications and smart devices has contributed significantly to the exponential network traffic growth over the last seven to eight years, and it will continue to be one main contributor to the network traffic growth. In addition to the demand generated for the conventional human-to-human and human-to-content communications, the emerging tactile internet [1] and internet of things (IoT) [2] will be another important driver to wireless communications and push for higher capacity offered by the networks. The global compound annual growth rate (CAGR) has been predicted to be 57%, by a ten fold increase from 2014 to 2019 [3]. The new application cases from tactile internet require the 5G network to support mission-critical machine-type communications (MTC) with ultra-low latency [1], while IoT requires the 5G network to support massive MTC with billions of devices.

Motivated by the above, major efforts have started from both academia and industry on the fifth generation (5G) wireless communications research. Compared with the first four generations, which have focused primarily on human-to-human and human-to-content communications, human-to-machine and machine-to-machine (M2M) communications will be new areas of focus in 5G to support the tactile internet and IoT. Another related differentiator in 5G from the legacy generations is "*heterogeneity*" and "interoperability", which are exhibited in different parts of the 5G network, as illustrated in Fig. 2. For example, different "component" networks need to work together to serve the various types of traffic demand with different qualities of service (QoS) and different coverage requirements; the 5G systems and network should support the agile use of different spectrums, from both licensed and unlicensed bands. In addition, advancement of computational capability and processing power at both the network infrastructure and the devices enables enhanced cognitive learning and intelligent resource and network management. To support this, multiple context information on the network may be used for context-aware resource and network management. Therefore, instead of a much simpler "homogeneous" network, "heterogeneous" network (HetNet) will be an important and key enabling technology for 5G, as indicated in Fig. 1.

The 5G HetNet should integrate *intelligently* and *seamlessly* multiple "component" networks, including the cellular radio access network (RAN) and wireless fidelity (Wi-Fi) network using different radio access technologies (RATs) over differ-

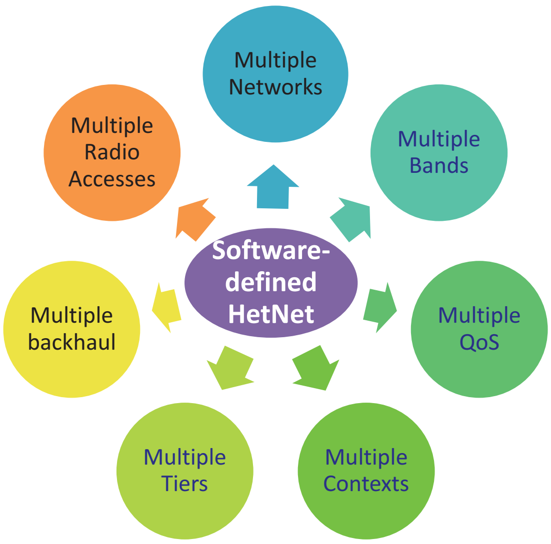


Fig. 2. The heterogeneity in 5G.

ent carrier frequencies, to achieve the QoS and quality of experience (QoE)-guaranteed, as well as spectrum-, energy-, and cost-efficient (SE, EE, and CE) *"Anywhere, Anytime, Any One, Any Device"* connectivity. A software-defined HetNet is therefore motivated to virtualize the "component" networks and spectrum resources, and allocate resources based on SE/EE/CE criteria to meet the service demand. While the software-defined HetNet serves the need for large amount of data to traverse in the network, more intelligence may need to be harvested from the "big data" in the network in order to enable a much more efficient resource utilization and network management. Therefore, many challenges need to be tackled. In this paper, we will share some of our work in HetNet with the focus on an agile software defined radio access network (SDRAN) architecture, intelligent Wi-Fi-cellular network traffic steering, and context-aware HetNet management.

The rest of the paper is organized as follows. In Section II, we will introduce the software-defined HetNet with the focus on SDRAN. We will then present a context-aware Wi-Fi-cellular traffic steering design in Section III, and a context-aware mobility management scheme in Section IV, and finally in Section V, we will summarize the paper and discuss on a number of research challenges in 5G HetNet design.

## II. Software Defined HetNet

As an evolutionary approach to 5G, we consider a number of "component" radio access networks (RANs) operating at different carrier frequencies in the software-defined HetNet:

- Macrocell base station (MBS): An MBS has a large coverage area and may host the baseband processing unit (BBU) pool and the mobility controller. Within the coverage area of one MBS, there may be multiple Wi-Fi access points (APs), small cell base stations (SBS), and distributed antenna (DA) ports.
- Small cell base station (SBS): An SBS may share the same spectrum with the MBS, or use other spectrums, e.g., the unlicensed 3.5GHz band, the millimeter-wave (mmwave) band, etc. For mmwave-supporting SBS, massive multiple-input multiple-out (M-MIMO) technology may be used in order to achieve a good coverage area and eliminate the inter-cell interference (ICI).
- Wi-Fi: Wi-Fi is an effective complementary network to offload the cellular traffic and mitigate the cellular network congestion due to its different operating frequency bands from the cellular networks. Wi-Fi can achieve high transmission data rate achieved by using multiple-input multiple-out (MIMO) orthogonal frequency division multiplexing (OFDM) in IEEE 802.11n/11ac [4], [5] at the 2.4GHz unlicensed industrial, scientific, and medical (ISM) band and the 5GHz unlicensed national information infrastructure (U-NII) band, or the ultra-wide mmwave bandwidth at the 60GHz ISM band in IEEE 802.11ad [6], or the long range transmission of IEEE 802.11ah [7] achieved by using the sub-1GHz band.
- Distributed antennas (DAs): As presented in [8], large-scale distributed antenna system (L-DAS) has much more superior energy-and-spectral efficiency tradeoff performance over the co-located M-MIMO, due to the much lower propagation loss in L-DAS with its short separation distance of the DA port to the users [8]. Deployment of DAs in some critical locations will help to prove better coverage for both the human-to-human traffic and the M2M communications. The frequency band of the DAs may be re-configurable.

An example of the proposed SDRAN with the above component networks is illustrated in Fig. 3.

The control unit for radio access will be residing at the MBS due to the following considerations:

- The MBS can collect various radio resource usage, the radio spectrums usage, the traffic and load information within its coverage area, including that for the other component networks such as SBS and Wi-Fi. These network operation data can be used as context information to enable context-aware resource and network management, details to be presented in Section IV. Therefore, the control unit at the MBS can facilitate the MBS-centralized resource scheduling and load balancing among the component networks;
- The MBS facilitates more efficient mobility management and handover. This has been shared in [9].

The proposed SDRAN also provides the flexibility of performing centralized baseband processing by BBU pool at the MBS or distributed baseband processing at the individual component network, e.g., SBS and Wi-Fi AP, etc., or in a hybrid form, so as to achieve the best tradeoff depending on the QoS and QoE requirements.

In addition to the radio access network, the software-defined HetNet will also enable tighter integration of radio access with the fronthaul and backhaul.

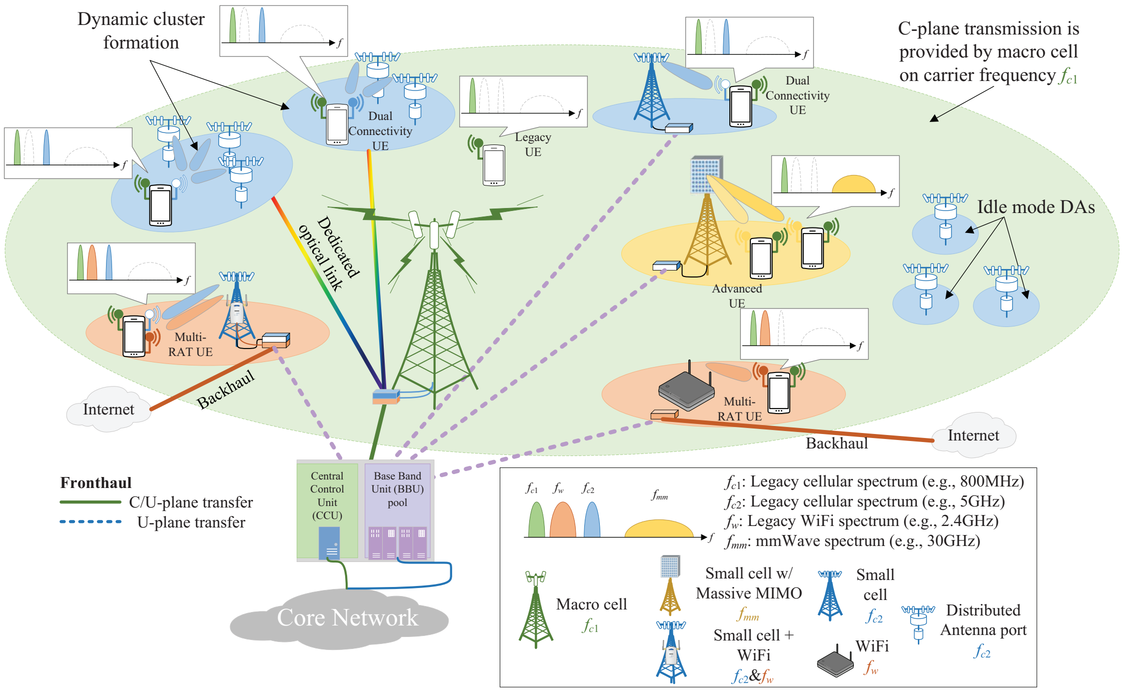


Fig. 3. Illustration of the software-defined radio access network (SDRAN).

## III. Intelligent Wi-Fi Offloading

Wi-Fi offloading has been an effective approach to offload the mobile traffic and mitigate the cellular network congestion. There have been a number of research studies to look into (i) the network association of users to either the Wi-Fi AP or the cellular base station in, e.g., [10], [11], (ii) the utility maximization and load balancing in, e.g., [12], and (iii) energy minimization in, e.g., [13]. The authors in [14], [16] study the real-time traffic steering between Wi-Fi and cellular networks to optimize the network throughput and enhance the quality of experience for the users.

If a number of users are offloaded to Wi-Fi beyond its capacity, traffic congestion happens at the Wi-Fi network. Therefore, the intelligent Wi-Fi offloading that takes into account the user context information and network status information is essential [15].

Here, user context information includes traffic type and QoS history etc. Network status information may capture the traffic load of different networks. In our proposed scheme [15], the WiFi access point learns the environment including network status information based on Q-learning and selects the proper network for the UEs. It determines whether the Wi-Fi network should accept or reject a UE when it attempts to connect and periodically evaluates whether to send any of the UEs back to the LTE network. No changes on the eNB and UE sides are needed. Fig. 4 shows the user outage probability of intelligent Wi-Fi offloading schemes with 10 users in the system. Fig. 5 illustrates the number of network switching required. The LTE system follows 3GPP standard with 10 MHz system bandwidth and the WLAN system modelling follows the 802.11ac PHY/MAC layer specifications with 20 MHz system bandwidth.

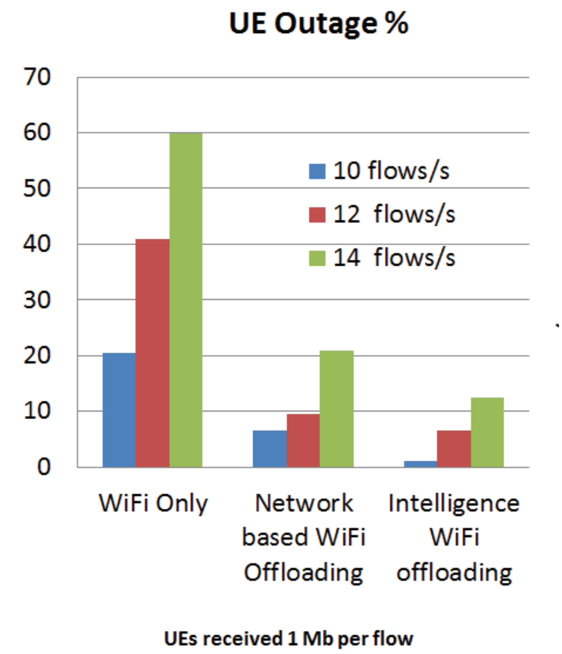


Fig. 4. User outage probability with intelligent Wi-Fi offloading.

For comparison, the performances of "Wi-Fi only" and "network based Wi-Fi offloading" [14] are provided. Fig. 4 clearly illustrates the significant improvement of user outage

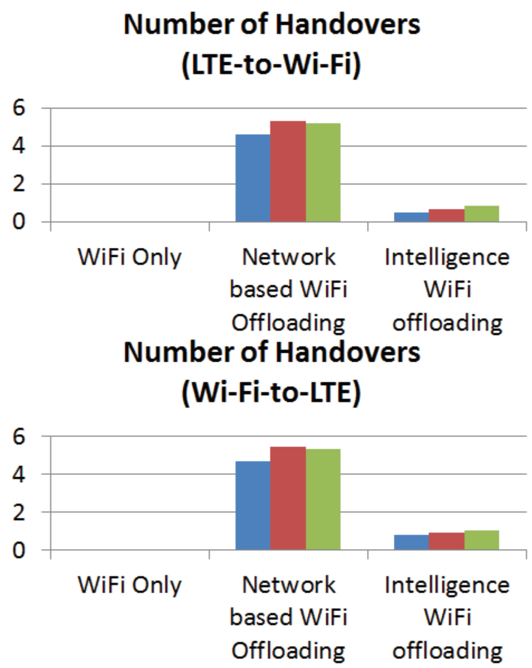


Fig. 5. Number of handovers with intelligent Wi-Fi offloading.

performance obtained by the Wi-Fi offloading. By the network based Wi-Fi offloading, the user outage probability can be reduced by about half. Further improvement can be achieved by intelligent Wi-Fi offloading, i.e., about 50% improvement. In addition, intelligent Wi-Fi offloading requires only 25% of network switching as shown in Fig. 5.

## IV. Context-Aware HetNet Management

Advancement of the computing and storage capability at the network infrastructure and the devices calls for another development in the HetNet, i.e., the context-aware (CA) HetNet management. CA HetNet management will need the following elements as shown in Fig. 6:

- Context information collection: This can be achieved from the huge amount of traffic traversed in the network, and it should be a continuous process.
- Context information analysis: This can be done by either real-time analytics or offline by using the big data analytics tools. Network operation statistics, such as the traffic flow and network load distribution in both the geographical (or spatial) domain and temporal domain, will be obtained, e.g., [18], [19]. This context information may be used to assist scheduling the base station sleeping and napping mode, as described in [18], [20]. Another example of context information is the popularity ranking of the mobile Internet content information with which popular contents can be pre-fetched to the HetNet edge to reduce the network congestion at the backhaul. Some related works can be found in [21], [22]. Context information analysis should be updated with the newly collected information to track the changes.

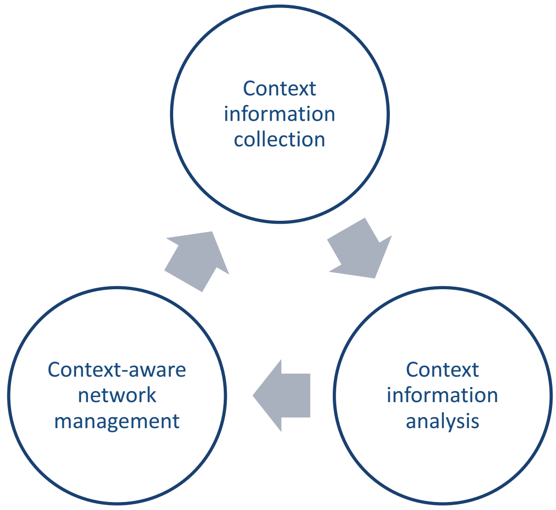


Fig. 6. The context-aware (CA) HetNet management process.

- Context-aware network management: Based on the statistical context information (SCI), and the real-time network state information (NSI), channel state information (CSI), and device state information (DSI), network management and resource scheduling mechanism can be developed. A framework is given in [23], [24].

For context-aware network management, for example, the following information can be used; the network layout and location information of the MBS and SBS as the deterministic context information, the signal strength and coverage information of the MBS and SBS as the long-term statistical information, and the location, traveling speed and traveling direction information as the real-time information. These information can be used to improve the handover performance in HetNet. We have applied the above principle of context-aware HetNet management in handover and mobility management. More details of the algorithm may be referred to [25]. The traffic load of each cell and its SCI (the locally unique identity) are used as a network context information.

Fig. 7 shows the handover failure (HOF) rate as a function of number of small cells per macro cell. For comparison, the HOF rate performance of non-context aware handover is also plotted. The main cause of high HOF rate in HetNet is the interference from neighboring cells. The handover user is generally located at the cell edge of the serving cell, therefore, it is subjected to huge interference from neighboring cells. For context aware handover, each cell first reserves specific resource for handover user based on its own SCI and NSI. Then it exchanges the traffic load among the neighboring cell. Based on the exchanged information and the measurement report from handover user, the serving cell decides the resource to transmit the handover command to the handover user. Due to the uniqueness of SCI of each cell, different resources are reserved for the neighboring cells. Thereby, the interference form neighboring cells can be significantly mitigated. It is

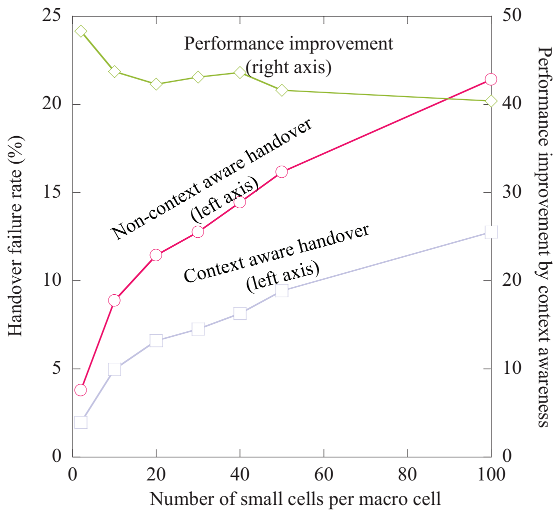


Fig. 7. Handover failure reduction by context awareness.

clearly shown that the HOF rate can be significantly reduced by context awareness irrespective of the number of the small cells.

## V. Summary and Conclusion

In this paper, we have motivated the heterogeneous network as an evolutionary path to the fifth generation (5G) communications. An agile software defined heterogeneous network architecture has been presented which virtualizes the various component radio access networks, such as cellular base stations and Wi-Fi access points, and the various carrier frequencies both from the licensed and unlicensed bands; hence, it supports more agile radio resource and mobility management. The software defined heterogeneous network architecture can also support flexible splitting of centralized and distributed processing depending on the requested quality of service of the traffic. We have also shared two HetNet use cases: the intelligent cellular-Wi-Fi traffic steering and the context-aware HetNet management. As future research, we will develop further the context-aware software defined heterogeneous network to realize a spectrum-, energy-, and cost-efficient HetNet for the 5G communications.

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