5G Radio Access Network Technologies: Research Advances

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***Abstract*—In order to adequately cater for the disruptive and paradigm shift in business models, new architectures, and techniques are expected to be introduced into the fifth generation (5G) cellular networks. In recent time, there have been a lot of research progress as related to 5G radio access network technologies. This will ensure the full standardization and implementation of the next generation of mobile networks by 2020. In this paper, we present a concise review of the research advances in the key technologies of 5G radio access network. The study focuses on ultra-dense heterogeneous networks, mobile data traffic offloading, millimeter wave communications, and massive multiple-input multiple-output (massive MIMO). In conclusion, we identify the need to consider the extreme factors that are peculiar to emerging markets in the ongoing 5G research and standardization.**

***Index Terms*—heterogeneous networks, mobile data offloading, millimeter wave communications, massive MIMO**

I. INTRODUCTION

THE high proliferation of mobile devices, services, and applications across the globe increasingly tend to place a serious strain on conventional cellular systems. About 100 billion devices are expected to be connected to the Internet by 2020 [1]. Most of the emerging technologies now rely on Internet connections and require large bandwidth for optimal performance. Unfortunately, the deployment of optical wired networks to meet these huge mobile data traffic demands is quite expensive. However, 5G wireless network promises a rich-content support with high performance and better quality of service in a cost-effective manner.

Unlike previous generations (2G/3G/4G), future 5G network will not be a simple evolution of 4G network architecture. New architectures, technologies, and techniques are expected to be introduced in order to adequately cater for the paradigm shift in business models. For instance, there is no support for bursty mobile data traffic in 4G networks [2, 3]. Also, the processing capabilities of a base station is often underutilized [4, 5]. Furthermore, there is no adequate provision to combat co-channel interference in previous technologies [6, 7]. Although, heterogeneous networks are standardized in fourth generation networks, they lack the capacity to support their functionalities [8].

Technically, 5G networks are expected to efficiently support massive (10 to 100 times) ubiquitous connections, provide extremely low (1 millisecond) latency, and deliver significantly high (1000 times) network capacity, when compared to 4G networks [9, 10].

The next-generation mobile network is still in the developmental stage. Both the academia and the wireless communication industry are currently engaged in active research to ensure that the technology is fully implemented by 2020 as earlier scheduled.

In this paper, we provide a short review on the recent research progress in the development of 5G radio access network. The review focuses on the key technologies of 5G radio access networks. Section II highlights the use cases and scenarios of 5G. Section III discusses the recent development in ultra-dense heterogeneous networks, particularly as it relates to energy efficiency. Section IV presents the techniques for mobile data traffic offloading. Section V explains the development in the area of millimeter wave communications. Section VI presents the new work on massive MIMO technology. Section VII concludes the paper.

II. 5G USE CASES AND SCENARIOS

The components of 5G will not be limited to existing systems alone but it will encompass emerging systems and technologies. Also, the advent of 5G wireless communications will introduce new use cases and create new business models.

One of the primary targets of 5G is to provide the communication infrastructure for a fully mobile and connected society. The next-generation network promises to consolidate the existing mobile broadband technologies to deliver higher data rates and lower latency for several emerging applications and services. Beyond the conventional human-to-human communications, 5G will extend communication capabilities to things and machines. Interconnections of humans, sensors, and actuators will facilitate the realization of smart homes and offices, Machine-to-Machine (M2M) communications, virtual and augmented realities, electronic Health (e-Health), electronic Governance (e-Governance), smart and connected

Manuscript received July 09, 2017; revised August 01, 2017.

The authors wish to acknowledge the funding received from the Center for Research, Innovation, and Discovery (CU-CRID) of Covenant University, Ota, Nigeria.

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communities, electronic Learning (e-Learning), industrial automation among many other use cases.

The Next Generation Mobile Networks (NGMN) group has classified 5G use cases into eight (8) broad families namely: broadband access in dense areas; broadband access everywhere; high user mobility; massive internet of things; extreme real-time communication; lifeline communication; ultra-reliable communication; and broadcast-like services [11]. The families were further grouped into categories, as shown in Figure 1, based on service requirements.

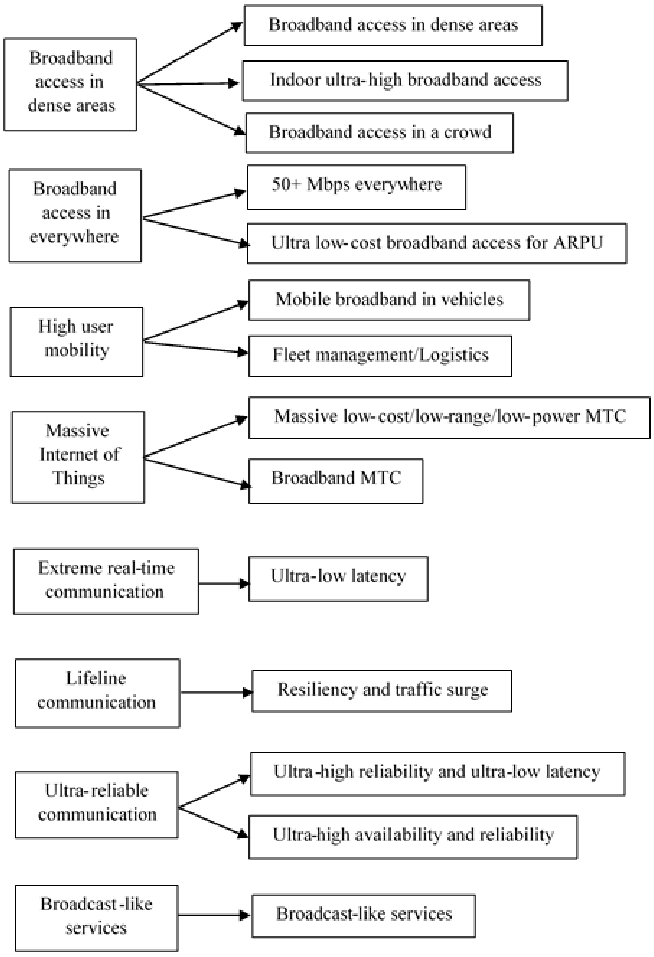

Figure 1: 5G Use Cases and Scenarios

In addition, Blanco et al. [12] identified four different 5G scenarios: residential; enterprise; urban; and rural and remote. Residential scenario covers typical indoor applications, particularly homes and offices. Enterprise scenario is an evolution of residential but it large geographic areas and high numbers of users. Urban scenario is typical of fully accessible public dense environments. The rural and remote scenario represents the underserved communities that are beyond the coverage of conventional service.

III. Ultra-Dense Heterogeneous Networks

Heterogeneous network is an emerging architecture that is proposed for 5G Radio Access Network (RAN). It utilizes multiple RANs that comprise of macro cells, small cells, relays, and distributed antenna systems to increase the overall performance of the radio network. It involves a coexistence of Base Stations (BSs) that are different in terms of coverage, radio resources, and energy requirement. However, the energy demand of heterogeneous network becomes very high as the number of small BSs in use increases.

Xiao et al. [13] suggested two sleep modes (random sleep and load-awareness dynamic sleep) to minimize the energy consumed by the small base stations (BSs). The dynamic sleep mode has higher likelihood of success and higher energy efficiency. Cooperative BS selection and BS state control can handle the challenge of poor coverage that comes with BS dormancy. Interestingly, the consequent increase in coverage can be managed, without any additional transmission power requirement, by using a cooperative energy-saving technique based on user association [14].

In the case of a hybrid heterogeneous network with femtocells overlaid on a macrocell, the energy efficiency can be maximized, with optimum network resources, based on a two-layer game theoretic framework [15]. The outer layer ensures higher data rates in the femtocells while the inner layer achieves energy efficient user association subject to the minimum rate and maximum transmission power constraints.

Elastic traffic in a single macrocell that is supported by a number of small cells usually affect load balancing. Taboada et al. [16] developed static and dynamic load balancing policies that consider setup delay to minimize the weighted sum of the average delay and the average power consumption. However, dynamic policy performs better in practical scenarios.

According to Xiao et al. [17], there is an optimal small cell BS density ratio that can be applied to maximize both the energy efficiency and the system performance concurrently. This should assist in the design of optimally efficient multi-tier heterogeneous networks. Chavarria-Reyes et al. [18] characterized the tradeoffs between energy minimization and capacity maximization in a multi-layer heterogeneous network in 5G systems that support multi-stream carrier aggregation.

Heterogeneous networks may have to depend on hybrid energy sources in 5G systems. SuÃ¡rez et al. [19] suggested a BS switching-off and offloading technique for this 5G use case. This technique introduced a set of metrics with an adjustable priority hierarchy. These metrics are used to filter, sort and select the BS neighbours that receive traffic during redistribution and offloading of the BSs to be put into sleep mode. This method will facilitate the attainment of network performance objectives that address QoS energy savings and green equipment utilization.

Saeed et al. [20] developed an energy efficient technique for Orthogonal Frequency Division Multiple Access (OFDMA) heterogeneous networks using a combination of linear binary integer programming and progressive analysis based heuristic algorithm. This scheme allows small cells to share spectrum access and still maintain a certain level of quality of service for the macrocell users. In addition, this method reduces the interference caused by small cells to macrocell served users.

IV. Mobile Data Offloading

High density of mobile data traffic demand in 5G can be

ISBN: 978-988-14047-5-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

managed by reducing the burden on the cellular network through data traffic offloading. In this way, part of the data traffic is shed to other complementary wireless systems as a means of achieving higher data rates, improved network capacity, and better QoS user performance.

Nowadays, smart wireless devices are capable of both cellular networks and WiFi, making data offloading from cellular networks to WiFi a potential solution to the anticipated explosive mobile data traffic. A complex heterogeneous network can be well managed in a dynamic manner by implementing WiFi offloading using Software-Defined Networking (SDN). Anbalagan et al. [21] suggested a new technique that offers better Quality of Experience (QoE) using the unlicensed spectrum of the access points. In vehicular communications, an active connection can be sustained while driving through an urban area through an opportunistic access that is based on Beacon Interval Whitetime to macro-cellular WiFi access points. Third Generation Partnership Project (3GPP) has introduced multi-mode Integrated Femto-Wi-Fi (IFW) small cells, which is capable of using both licensed bands and unlicensed bands through cellular and Wi-Fi interfaces respectively. An extensive investigation on various incentives of Wi-Fi offloading such as cost minimization, energy consumption saving, and data rate improvement were highlighted [22] from both operators' and users' points of view.

Developing such a new hybrid network paradigm that exploits the availability of multiple alternative communication channels requires significant modifications in the way data are handled. Macro BSs offer economic incentive to small BSs as the scheme reduces the load on the macro BSs and consequently improve the spectral efficiency. The macro BSs ensure control coverage while the small BSs are solely responsible for data transmission. With the inherent capability to dynamically turn off the small BSs whenever the traffic load reduces, the energy requirement of the heterogeneous network can be further reduced by decoupling the control signaling and data transmission functionalities. However, the wide power gap between macro cells and small cells in heterogeneous networks limits the number of mobile devices that can be served simultaneously by an individual small cell, thereby degrading the traffic offloading performance. Likewise, traditional cell attachment techniques affect spectral efficiency since they do not incorporate uplink channel states.

Wang et al. [23] proposed a dynamic traffic offloading technique, which considers the delay tolerance of data traffic, to improve the energy efficiency of heterogeneous cellular networks. Ho et al. [24] suggested a game based data offloading technique which decide on the amount of economic incentive that the macro BS should offer to small BSs. Also, the technique regulates the volume of data traffic that each small BS should accept from the macro BS. Yang et al. [25] considered both channel quality and cell load in best-fit techniques for downlink and uplink cell attachment that effectively perform data traffic offloading with significant improvement in cell-edge data rates. Here, the downlink and the uplink are decoupled and attached to cell independently.

V. Millimeter Wave Communications

The need for more spectrum bandwidth has led to the exploration of the millimeter wave band for 5G communications. Millimeter wave communications offer potential solutions to the anticipated high capacity requirements of future 5G cellular networks owing to the large available spectrum in the frequency band beyond the microwave range. However, the range of cell coverage of millimeter wave radios is limited by the propagation characteristics at these higher frequencies. The 57-64 GHz and 164-200 GHz bands are found to be more susceptible to severe oxygen absorption and water vapour absorption respectively. Nevertheless, about 252 GHz spectrum of the 3-300 GHz millimeter wave band can be exploited for mobile broadband communications [26].

Khan [27] presented a scalable radio architecture that enables low-cost ultra-high speed wireless communications, utilizing both microwave and millimeter wave spectrum bands. Ng et al. [28] proposed a shared user equipment-side distributed antenna system (SUDAS) which concurrently employs both microwave and millimeter wave frequency bands to enable a spatial multiplexing gain for single-antenna user equipment. This improves the energy efficiency and increases the data rate of 5G outdoor-to-indoor communication.

An extensive use of millimeter wave uplink bandwidth can lead to excessive power consumption and large peak-to-average power ratio at mobile receiver. Therefore, in a bid to save more energy during time division duplex (TDD) millimeter wave operations in future 5G heterogeneous cellular network, millimeter wave band should be mainly utilized for downlink transmissions while microwave bandwidth complements uplink transmissions.

In most cases, the number of radio frequency (RF) chains is usually much smaller than that of antennas in millimeter wave massive MIMO with hybrid precoding. This creates more difficulties for channel estimation in practical mmWave channels which exhibit the frequency-selective fading. Therefore, the angle domain structured sparsity of millimeter wave frequency-selective fading channels may be exploited to perform channel estimation based on distributed compressive sensing [29]. Also, power leakage caused by the continuous Angles of Arrival or Departure (AoA/AoD) can be blocked using grid matching pursuit approach with adaptive measurement matrix [29].

For single-carrier frequency-domain equalization (SC-FDE) based millimeter wave communication systems, channel estimation is done by performing an iterative calculation of small perturbations with the first-order approximation. In addition, an iterative receiver compensates for the phase noise in signal demodulation with the decision feedback result [30]. To reduce the high power consumption in the reception chain due to the sampling rates of high-resolution analog-to-digital converters (ADCs) at millimeter wave bandwidths, low-resolution ADCs are highly needed. Adaptive one-bit compressed sensing channel estimation can be employed at low-resolution millimeter wave receivers [30, 31].

ISBN: 978-988-14047-5-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

Dussopt et al. [32] designed integrated antennas, antenna arrays and high-directivity quasi-optical antennas for high data-rate 60-GHz communications. Considering recent advances in low cost sub-terahertz semiconductor circuitry, the use of repeaters is a promising strategy of enabling systems operating at millimeter wave bands, which suffers high transmission during transmission, with seamless coverage.

VI. Massive MIMO

Large-scale MIMO (LS-MIMO) antenna system entails the use of a large number of base station antennas to serve a relatively small number of wireless devices for efficient spectral efficiency [33]. LS-MIMO is one of the main technologies that will productively address the highly envisaged future mobile data traffic explosion with high energy efficiency [34]. In K-tier heterogeneous cellular networks where macro base stations are equipped with large number of antennas and support multi-user transmission, the implementation of massive MIMO in macro cells can significantly enhance the network coverage and data rate as macro BSs with large antenna arrays decrease the demands for small cells [35].

Millimeter wave cellular access networks can be deployed in dense urban outdoor scenarios by using large antenna arrays that support high beamforming gains to compensate for the high path loss at millimeter wave frequencies since the wavelengths in the spectrum band are smaller. Hybrid analog-digital MIMO beamforming technique is found to be more suitable for massive MIMO systems because conventional fully-digital beamforming techniques which require one radio frequency (RF) chain per antenna element is not viable for large-scale antenna arrays due to the high cost and high power consumption of RF chain components in high frequencies.

Provided that the number of RF chains doubled the total number of data streams, a hybrid beamforming architecture whose overall beamformer is made up of a low-dimensional digital beamformer and an analog phase shifters based RF beamformer achieves the exact performance of fully digital beamformer, irrespective of the number of antenna elements. In cases of fewer RF chains such as a point-to-point MIMO system and a downlink multi-user multiple-input single-output (MU-MISO) system, desirable performance can be obtained using a heuristic hybrid beamforming design. These hybrid beamforming techniques are effective in practical cases where only finite resolution phase shifters are available and in scenarios where the resolution of phase shifters employed is very low [36].

Meanwhile, the hardware at the receiver can be simplified by replacing the phase shifters with switches [31]. Zhang et al. [37] handled the modulus constraints on the RF precoding and decoding matrices which phase shift network-based RF analog precoding imposed on millimeter wave massive multi-carrier single-user massive MIMO systems using two approaches: exploitation of the truncated higher order SVD of the common equivalent RF beamforming matrix available for all carriers; and performance of sequential low rank unimodular approximations for optimal unconstrained solutions.

Pilot contamination introduced by the limitation of coherence time in the use of non-orthogonal pilot schemes proposed for channel estimation in multi-cell TDD networks, hardware impairment and non-reciprocal transceiver reduce spectrum efficiency and energy efficiency of massive MIMO systems [38]. Pilot contamination occurs in single-cell massive MIMO systems when the number of active users is greater than the pilot sequence length [39]. Also, unavoidable reuse of pilot sequence from mobile receivers in different cells introduces pilot contamination which in turn limits the performance of massive MIMO systems. When the terminals are fully loaded, the interference from terminals in neighboring cells using the same pilots as in the home cell (inter-cell pilot contamination) impairs the system performance. Although inter-cell contamination can be avoided when the terminals are intermittently active by pre-allocation of pilots while same-cell terminals utilize random access to select the allocated pilot sequences, this also results in intra-cell pilot contamination.

VII. Conclusion and Research Directions

This paper has identified and reviewed the recent research work towards the full development and implementation of 5G technology. The study covered the main component technologies and techniques which include: ultra-dense heterogeneous networks; mobile data traffic offloading; millimeter wave communications; and massive MIMO. Significant progress have been made as reported in the results of the work that were examined.

However, use cases and contextual attributes that underpin the initial 5G research and standardization are still strongly influenced by early adopters in developed economies. Whereas, emerging markets have some peculiar factors that can frustrate successful deployment of the transformational technology, thereby further pushing the hope of attaining sustainable development to the far future.

Most of the developing countries are faced with potential obstacles such as a majority low-ARPU (Average Revenue per User) multi-SIM subscriber base, diverse settlement patterns ranging from low density rural areas to rapidly expanding ultra-dense urban informal settlements, highly unreliable power grid networks, pure mobile networks built without existing wired network infrastructure, and rigid regulatory frameworks that stifle business and service innovations. This is even more typical of most countries in sub-Saharan Africa.

Hence, these unique features of the operating environments must be well accommodated. To achieve such, deliberate efforts must be taken to adopt technologies, techniques, and efficient methods that adequately account for the extreme factors. Eventually, this will require disruptive changes at both node and architectural levels.

Acknowledgment

The authors wish to appreciate the Center for Research, Innovation, and Discovery (CU-CRID) of Covenant University, Ota, Nigeria, for partly funding this research.

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ISBN: 978-988-14047-5-6
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)