Challenges and Trends in 5G Deployment: A Nigerian Case Study

Conference Paper · October 2019

DOI: 10.1109/NigeriaComputConf45974.2019.8949675

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***Abstract*—In recent years, we have witnessed a paradigm shift in mobile operator deployment from Long Term Evolution Advanced (LTE-A) to fifth generation (5G) networks. With the completion of the 3GPP Release 15 standards supporting "Non-Standalone 5G" in late 2018, attention has shifted to Standalone 5G, whilst operators across the globe continue to accelerate deployment of 5G based on the latest specifications. This paper addresses the global trends and challenges for early 5G rollout with focus on the Nigeria market. It also provides solutions to guide Nigerian mobile operator on pitfalls and barriers to entry, to allow smooth transitioning from 4G to 5G technology in Nigeria. Finally, the paper provides empirical evidence suggesting UE connected to the small cells use lower transmit power, hence improving uplink performance.**

Keywords—5G, Massive MIMO, Software Defined Networking Spectrum sharing, NFV, URLLC, eMBB, NB-IoT, small cells.

I. Introduction

In view of the recent exponential growth in wireless data traffic, it has become imperative that the existing cellular network infrastructure in Nigeria, comprising legacy technologies such as 2G, 3G and 4G cannot sustainably, meet user's requirements. Worldwide, network operators are increasing looking for ways to minimise cost of network provisioning, whilst maintaining excellent Quality of Experience (QoE) for mobile consumers. Estimates of about nine and twenty five billion devices were recorded to have been connected to the Internet in 2013 and 2015 respectively, within and outside Nigeria. This progression will see over 50 billion connected things in a couple of more years, all over the globe, Nigeria inclusive [1]. Internet of Things (IoT) is the evolution of mobiles, homes, businesses, industries and embedded applications connected to the Internet. These connected devices grow into an intelligent system of systems that share, analyse data and consequently transform our lives and businesses in inestimable ways. Thus, the quest for the appropriate networking paradigm provides unique opportunities to consumers, manufacturers and service providers. Section II and III looks at network densification and MIMO, and how mobile operators in Nigeria can take advantage of these technologies. Section IV and V highlights backhauling options and the millimetre wave physical layer security issues. Section VI and VII investigates spectrum sharing and software defined networking. Section VIII and IX discusses NB-IoT and 5G small cells. The paper concludes with empirical evidence that reduced uplink power in low powered small cells, is beneficial to minimising the overall uplink interference within the system.

II. Network Densification

Most recent data from GSMA in 2019 [1], indicate that Nigeria with a population of about two hundred million, has approximately ninety eight million unique subscribers (projected to reach one hundred and thirty million by 2025), forty nine percent Mobile connection penetration, and thirty nine percent Mobile broadband connection penetration [1]. Therefore, to accommodate the anticipated exponential growth in wireless traffic demand in Nigeria, it is expected that Network Densification will play an important role in fifth generation mobile deployment in Nigeria. Densifying the network could occur either in the space or frequency dimensions [2]. In the spatial dimensions, reusing the allocated 5G frequency spectrum over smaller areas could occur through, pico-cells, mini-macros and macro cell splitting. Increasing the number of spatial antennas is an alternative solution. Massive MIMO discussed in later section of this paper has featured significantly in early deployment across Europe, Asia and North America. It is expected that Nigerian mobile operators will also adopt this in the early deployment of 5G. Similarly, small cells have become an attractive way of increasing coverage and capacity, hence helping to achieve traffic offload from congested macro cells. Small cells are low powered devices capable of re-using either the licensed or unlicensed spectrum over smaller ranges, usually in the order of few tens of meters. The unlicensed spectrum usually serves as the secondary component carrier using Licensed Assisted Access (LAA), similar to carrier aggregation. They are typical installed in indoor hotspot locations, such as shopping malls, airports, cafes, stadium and event venues and other areas with heavy human footfalls.

Furthermore, along the frequency dimension, new carriers from existing allocations (2G, 3G and 4G) can be re-purposed (also called spectrum re-farming) to consolidate existing 5G allocations. Operators are starting to reduce legacy RAN assets especially 2G and 3G for re-allocation to 5G. The primary goal of densification is to provide increased levels of both the desired signal (S) and interfering signal (I) over small coverage footprint, thereby increasing capacity and throughput [2]. Some form of interference coordination and cancellation techniques are required to maximise the benefits due to the proliferation of these small cell devices. Several trials from mobile providers across the globe show promising results, using a combination of these approaches in 5G. Particularly small cells for offloading macro traffic in heterogenous network (HETNET) type deployment. Adjusting the necessary network cell parameters, to ensure tighter interworking between legacy RAN (2G, 3G, 4G) and the 5G New radio (NR) will be crucial to successful deployment. Identified use cases below can be easily achieved by operators in Nigeria through densifying the network.

- Enhanced Mobile Broadband (eMBB): Mobile Broadband was introduced with the advent of high-speed packet access (HSPA) in 3G. The predecessor eMBB in 5G is expected to offer ultra-fast speeds in dense urban areas. eMBB is one of the three main uses cases identified by 3GPP, and is designed to offer speeds of up to 20 Gbps and 10 Gbps on downlink and uplink respectively. The minimum recommended targets for IMT-2020 are summarised by ITU-R [3]

- Ultra-Reliable Low Latency Communication (URLCC): This use case cover applications with stringent requirements in terms of reliability, latency, mobility and availability. Examples of such application include wireless control for industrial manufacturing, tactile internet applications [4], transportation safety and intelligent transport systems, remote medical surgery, smart grid and public protection/disaster relief.

- Massive machine type communication (mMTC): These class of devices are characterized by short payload, high density and sporadic transmissions. Their traffic pattern are not yet fully characterized [4], but are typically traffic non-delay sensitive data. Low powered sensor and machine type devices are expected to unleash the requirements for Internet of things.

III. MASSIVE MULTIPLE-INPUT MULTIPLE-OUTPUT (MIMO) TECHNOLOGY

The Massive Multiple-Input Multiple-Output (M-MIMO) [5] is a promising technology that involves the use of large-scale antenna system or base station antennas that serve a relatively small number of wireless devices. This technique has been proven to achieve high spectral and energy efficiency [6], and capable of addressing energy efficiency required in data centric network of the future [7]. In Nigeria and other emerging markets, the shortage of power supply has raised the need to have more energy efficient networks capable of energy savings and optimizing the overall power consumption of the network. In [8], three energy-efficient power allocation (PA) schemes for the downlink of a distributed MIMO (D-MIMO) system was proposed. The schemes when used with beamforming at the distributed antenna ports and Antenna Selection (AS) at the Mobile Station (MS) achieve considerable energy efficiency, over the single receiver antenna systems. Despite the energy efficiency promises of the MIMO system [9][10], it was found in [11] [12] [13] that increasing the transmit power level when the number of transmit antennas grows large, can be counter-effective in terms of energy efficiency. Fig.1 shows the proposed architecture of M-MIMO HetNet system [13].

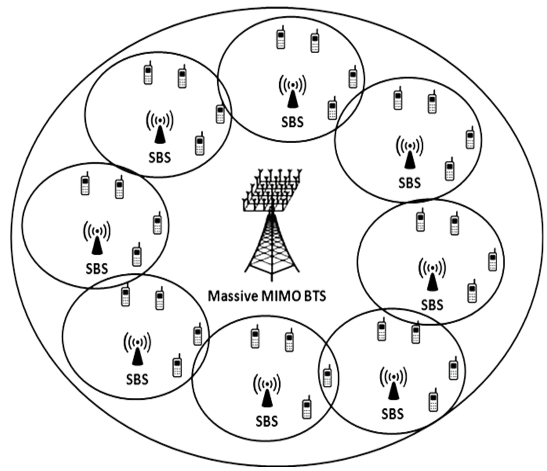

Figure 1: Proposed Architecture of M-MIMO HetNet [13]

IV. BACKHAULING SOLUTIONS FOR 5G

Efforts in the radio perspective such as the new spectrum allocation, network densification, M-MIMO, carrier aggregation, Self-Organizing Network (SON), inter-cell interference mitigation techniques, and coordinated multi-point processing [14] have been standardized towards facilitating the realization of the 5G requirements for high data rates. However, the anticipated need to supports billions of user devices, and to interconnect the access and the core networks, would require a reliable and high capacity transmission network (backhaul). Limiting factors in adequately addressing the backhaul challenges in previous cellular networks (i.e 2G to 4G) include: capacity, reliability (availability), energy consumption, deployment cost, and long-distance reach [15][16]. Despite these challenges, variety of backhaul network solutions such as the Digital Subscriber Line (DSL), fiber optics cable, Microwave and Millimeter Wave, Satellite, Long range Wi-fi and Worldwide Interoperability for Microwave Access (WiMAX) are available. Emerging solutions such as the Cloud Radio Access Network (C-RAN), Massive MIMO and Self Backhauls also exist [13][17]. Each of these solutions come with its merits and demerits.

In Nigeria, careful consideration and planning of backhaul solution is important to the successful deployment of 5G, due to limited power supply. It is quite challenging in Nigeria to power not only the base stations but also the backhaul network with limited or unreliable access to power from the grid. In Nigeria, substantial numbers of BTSs are off grid or unreliable (bad grid) sites. This means total reliance on diesel generators or alternative power sources to the sites and thus pushing the network energy costs as high as 50% of the total network operation expenses which is far above the 15% obtainable in industrialized countries [18]. Unreliable 5G backhaul will have severe impacts on the quality of experience (QoE) for mobile customers and therefore should be properly planned. Table 1 provides feasible backhaul options for 5G deployment in Nigeria

Table 1 Feasible 5G Wireless Backhaul Solutions for Nigeria

Parameters	**Microwave (7–40 GHz)**	**V-Band (60 GHz)**	**E-Band (70/80 GHz)**	**Self backhauling**
Deployment Costs	Low	Low	Low	Low
Energy Efficiency	Moderate	Moderate	Moderate	Moderate
Quality of Service (QoS)	Guaranteed	Moderate	Moderate	Moderate
Latency	Low	Low	Low	Low
Bandwidth	Medium	High	High	Medium
Suitability for Heterogeneous Networks	Outdoor Cell-Site/Access Network	Outdoor Cell-Site/Access Network	Outdoor Cell-Site/Access Network	Outdoor Cell-Site/Access Network
Support for Mesh/ Ring Topology	Yes	Yes	Yes	Yes/No
Interference Immunity	Medium	High	High	Medium
Range (km)	5-30, ++	<1	<3	5-30, ++
Time to deploy	Weeks	Days	Days	Months
License Requirement	Yes	Licensed/ Light License	Licensed/ Light License	No

In Table 1, we provided some feasible wireless backhaul options for 5G deployments in Nigeria.

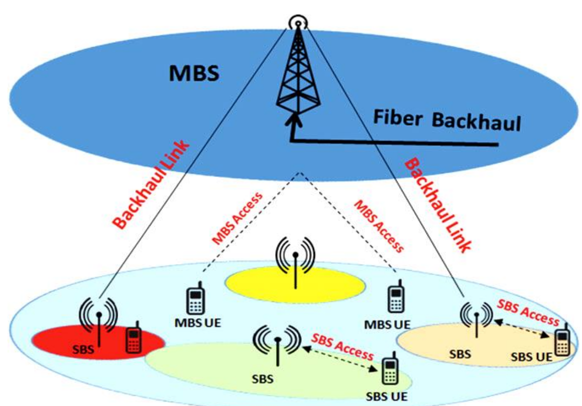

Figure 2 Proposed Architecture of self-backhauling network [13]

Due to the dense small cell deployments, the effective backhaul implementation for the SC still remains the main bottleneck, as the ever-increasing SC density will lead to a more complex backhauling and, as such, increase risk of rising both capital, and operational and network energy costs. Satellite backhaul could also be deployed for a marginal percentage mostly where existing backhaul infrastructure is unavailable, or the operators couldn't secure licenses for PTP or PTMP microwave links. In [18], it was stated that sufficient energy could be saved when self-backhauled networks are used compared to traditional homogeneous macro network deployments, however, at the detriments to the capacity of the network as shown in Fig.2

V. MILLIMETRE WAVE PHYSICAL LAYER SECURITY

The need for reliable, and secure communication for bandwidth intensive application services has motivated the exploration of the underutilised millimetre wave (mmWave) frequency spectrum for future fixed wireless fibre-like communication networks. Given the ubiquitous and pervasive need for 5G, coupled with the amount of connections in the near future, an enormous amount of sensitive and confidential information, e.g. financial data, electronic media, medical records, natural disaster, and customer files, will be transmitted via wireless channels. Thus, providing an unrivalled security service is one of the top priorities in the design and implementation of the 5G network [19][20]. Therefore, security becomes paramount and the traditional solutions to mitigating the security challenges is usually handled at the upper layer using various typed of private and public secret keys via computation-based mechanisms (cryptography) [21]. Implementing only the computational security approaches have been reported to be susceptible to attacks and it is computationally complex in HetNets [22]. Generally, security should be seen from the view point of layered network design as an add-on feature, in particular securing the physical layer as a reliable and robust pipe would help to fortify the existing cryptography techniques. The challenging propagation characteristics of the mm-wave bands such as signals do not penetrate most solid materials and are subject to high signal attenuation and reflection. For the Nigerian use case, where reliable communication in the rural and distance areas during emergency has shown to be a difficult task, mmWave technology may provide an attractive alternative in case where optical fibre infrastructure is expensive and time consuming to rollout. The mmWave technology is lightly-licensed or license-exempted spectrum which is readily accessible to most service providers and has the potential to provide the needed bandwidth for the fronthaul/backhaul communication systems with secure services.

VI. DYNAMIC SPECTRUM SHARING (DSS)

With practical advances in software defined radio and cognitive radio technologies, it is expected that DSS will play a pivotal role in 5G rollout in Nigeria. Dynamic spectrum sharing involves the intelligent re-use of spectrum based on spatial and temporal variation in traffic demand. In recent past, techniques such as Carrier Aggregation (CA) in contiguous and non-contiguous band, Channel Bonding (CB), License Assisted Access (LAA), Spectrum Access System (SAS) have been investigated with the aim of improving spectrum utilization. Centralized approach involving a network centric decision authority versus cognitive approaches have also been studied [23]. More recent research focused on addressing challenges associated with Full Duplex enabled DSS [24]. The secondary spectrum user, 5G, will intelligently sense spectrum opportunity on 4G. A number of spectrum sensing/detection techniques have been described in literature [24] such as Energy detection, Matched Filter and Featured based detection [25]. It is expected that 5G deployment of DSS will use POLITE protocols such as Listen Before Talk (LBT) to protect primary users of licensed spectrum.

VII. SDN/NFV

Software Defined Networking (SDN) and Network Function Virtualisation (NFV) are prominent technology enablers for 5G. The main idea behind SDN is to isolate the control plane (logical entity that manages all the control functions in the network) from the data plane (entity responsible for packet forwarding). The combination of both SDN and NFV will allow 5G network slicing, instead of the "one size fits all" approach used today. Different market verticals such as automobile, industry manufacturing can be served through a slice of the network and assigned end to end virtual connectivity. NFV allows multiple service provider to form multiple separate and isolated network [26]. This helps to achieve significant capital expenditure (CAPEX) and operating expenditure (OPEX)savings through flexible customization, easy programmability, and improved time to market for new application

VIII. NARROW BAND-INTENET OF THINGS

Narrowband Internet of Things which is a narrowband LTE technology was designed to introduce machine type communication (MTC) in cellular networks, making use of 200 kHz bandwidth with 20 kHz guard bands, at an extended coverage of about 40 km [27]. There are three configurations: standalone, guard-band and in-band in the deployment of NB-IoT technology using Low-Power Wide Area networks (LPWAN). New bandwidth which is independent of existing LTE network, is used in the standalone deployment. Reserved guard bands on existing LTE network or the same resource block of LTE carriers are used in the deployment of the guard band and in-band deployments respectively [28].
NB-IoT is one of the leading emergent technologies and is recommended for Nigeria Service providers looking to deploy smart grids, smart city applications. The technical requirements are summarized in Table 2 [29].

Table 2 Technical Requirements of LPWAN technology for NB-IoT

Parameters	**NB-IoT**
Modulation	Quadrature Phase Shift Keying
Frequency	Licensed LTE frequency bands
Bandwidth	200 kHz
Maximum data rate	200 kbps
Bidirectional	Yes / Half-duplex
Maximum messages/day	Unlimited
Maximum payload length	1600 bytes
Range	1 km (Urban) , 10km (Rural)
Interference Immunity	Low
Authentication and encryption	Yes (LTE encryption)
Adaptive data rate	No
Handover	End devices join a single base station
Localization	No (under specification)
Allow private network	No
Standardization	3GPP

The Internet, especially the cloud computing, has become the backbone of several applications in different domains such as healthcare, transportation, energy, and agriculture. The Internet has made the interconnectivity of seemingly every object possible; human social networks and even the machine-to-machine (M2M) communications [30][31]. The impending Internet will absolutely encompass a large number of smart objects that provide information and services to the users. Indeed, the projected billions of objects will take a key active role in the future universe network and bring the physical world data into the world of digital content and services - the cloud.
However, the realization of these potentials necessitates the development of standard communication protocols and unique networking schemes for IoT [32]. The current IoT solutions rely heavily on the home Internet gateways. While the wireless implementations outperform the wired technologies, mobile networks hold brighter possibilities over the Wi-Fi LAN. Currently, a radio cell registers only a few hundred mobile phones, but a few thousand devices will be supported for normal mobile networks. The growing usage of smart connected things comes with significant resources utilization, therefore, there is a need for smart networks and providers of mobile services in Nigeria are expected to invest and support growth in this area.
This poses a huge challenge for communication networks and a far-reaching burden on the mobile networks, as the power consumption drastically increases. In response to this, the mobile industry developed and standardized a new class of low power wide area (LPWA) technologies which allow thecost, coverage and power consumption of connectivity to be tailored for IoT applications [33]. This leads to the birth of three low power wide area network (LPWAN) solutions in licensed spectrum bands - Extended Coverage GSM for IoT (EC-GSM-IoT), LTE Machine Type Communications Category M1 (LTE MTC Cat M1 or LTE-M), and Narrowband IoT (NB-IoT) [34]. The NB-IoT is considered as most beneficial to service providers in Nigeria due to limited power supply.

A. *Low Power Wide Area Network (LPWAN)*

In the industries and research institutes, the popularity of LPWAN is increasing as a result of its low power, long range, and low-cost communication characteristics. Its coverage is up to 10–40 km in rural zones while in the urban areas it is 1–5 km for long range communications [35]. It was also reported in [36], to have ten years or more battery lifetime, making it a very energy efficient technology. It is equally very economical, with a radio chipset being at less than two Euros and the operating cost for a device in a year is less than one Euro [36]

IX. 5G Small Cell Deployment

Small cells are low powered devices designed to provide coverage and capacity over smaller areas. With 5G expected to be deployed in microwave (< 6 GHz) and millimetre wave band (30 – 300 GHz), addressing inbuilding coverage and hotspot areas with higher traffic demand will become even more important. It is expected that tighter co-ordination/interworking with macro will be required to minimise interference with multiple devices. For Nigerian mobile operators, HetNET type deployment using these small cells will be an attractive way to reduce the cost per bit for delivering mobile services. It provides a cheaper way for penetrating inbuilding where traditional macro base stations are known to provide poor coverage. We provide empirical evidence in Fig. 3, from a cluster of small cells in a hotspot location suggesting that UEs generally user lower transmit power whilst connected to small cells. This is primarily due to the smaller path loss between the UEs connected to small cells compared the macro cells, which tend to cover wider areas. At the 50th percentile, there is typically up to 8dB UE transmit power differential between a UE connected to macro and a small cell. The Tx power differential depends on the degree of isolation between the small cell and the neighbouring macro. The shows better control of uplink interference since the UEs are using less power on the uplink.

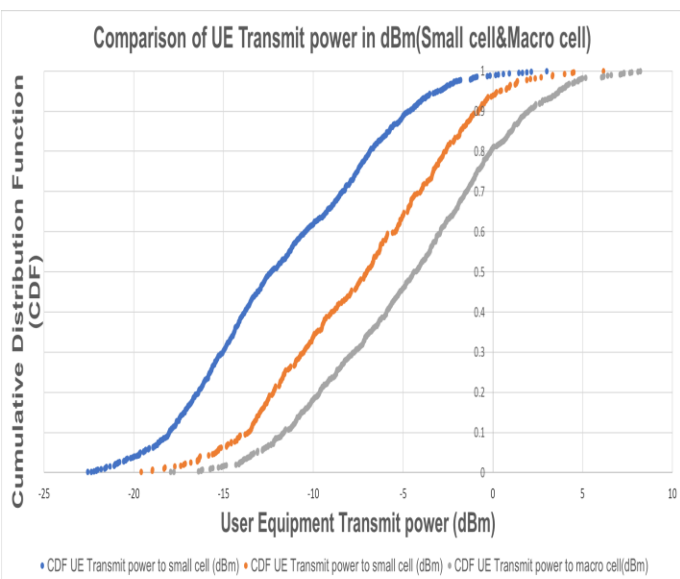

Figure 3: Comparison of UE Transmit power in dBm (Small cell and Macro cell).

CONCLUSIONS

The paper has provided insights into key trends and challenges in 5G mobile technology. It has discussed barriers to entry and offered mobile operators solution and options to accelerate rollout of this new technology. The authors have concluded with empirical evidence suggesting lower uplink transmit power is beneficial in minimizing the overall system interference.

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