Praise Worthy Prize

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5G Wireless Communication Network Architecture and Its Key Enabling Technologies

Olabode Idowu-Bismark[1], Okokpujie Kennedy[1], Ryan Husbands[2], Michael Adedokun[1]

Abstract - *The wireless mobile communication systems have developed from the second generation (2G) through to the current fourth generation (4G) wireless system, transforming from simply telephony system to a network transporting rich multimedia contents including video conferencing, 3-D gaming and in-flight broadband connectivity (IFBC) where airline crew use augmented reality headsets to address passengers personally. However, there are still many challenges that are beyond the capabilities of the 4G as the demand for higher data rate, lower latency, and mobility requirement by new wireless applications sores leading to mixed content-centric communication service. The fifth generation (5G) wireless system has thus been suggested, and research is ongoing for its deployment beyond 2020. In this article, we investigate the various challenges of 4G and propose an indoor, outdoor segregated cellular architecture with cloud-based Radio Access Network (C-RAN) for 5G, we review some of its key emerging wireless technologies needed in meeting the new demands of users including massive multiple input multiple output (mMIMO) system, Device-to-Device (D2D), Visible Light Communication (VLC), Ultra-dense network, Spatial Modulation and Millimeter wave technology. It is also shown how the benefits of the emerging technologies can be optimized using the Software Defined Networks/Network Functions Virtualization (SDN/NFV) as a tool in C-RAN. We conclude that the new 5G wireless architecture will derive its strength from leveraging on the benefits of the emerging hardware technologies been managed by reconfigurable SDN/NFV via the C-RAN. This work will be of immense help to those who will engage in further research expedition and network operators in the search for a smooth evolution of the current state of the art networks toward 5G networks.*

Keywords*: 5G Architecture, 5G Key Emerging Wireless Technologies, Massive MIMO, Ultra-Dense Network, Millimeter Wave Technology, Visible Light Communication*

Nomenclature

BBU	Baseband Processing Unit
BS	Base Station
CAS	Central Antenna System
C-RAN	Cloud-based Radio Access Network
CSG	Close Subscriber Group
D2D	Device-to-Device
DAS	Distributed Antenna System
E2E	End to End
H2H	Human to Human
H2M	Human to Machine
ICT	Information and Communication Technologies
IFBC	In-flight Broadband Connectivity
LOS	Line of Sight
IoT	Internet of Things
LTE/LTE-A	Long Term Evolution
M2M	Machine-to-Machine
MIMO	Multiple-input multiple-output
mSC	Mobile Small Cell
NFV	Network Functions Virtualization
OFDM	Orthogonal Frequency Division Multiplexing
OSG	Open Subscriber Group
OSI	Open System Interconnection
OTP	Open Transport Protocol
OWA	Open Wireless Architecture
QoE	Quality of End user Experience
QoS	Quality of Service
RAT	Radio Access Technology
RRHs	Remote Radio Heads
SDN	Software Defined Networking
VLC	Visible Light Communication
W	Base station signal bandwidth
n	Load factor
M	Spatial multiplexing factor which is the number of spatial streams between the uses devices and the BS
s	Desired signal power
N	Noise
I	Interference power
C	Network capacity

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I. Introduction

The wireless communication systems are arguably the single most important component in the global information and communication technologies (ICT); including the aviation industry, it is also the most dynamic and fastest growing sector in the world economy surpassing the aerospace and the pharmaceutical sector [1]. The evolution of the wireless mobile communication network leading to the current LTE/LTE-A has consistently not been able to meet the ever demanding users urge for more data rate as the user's needs continue to move from mere telephony to data communication including video streaming, video conferencing, fast train user applications and the emerging internet of things (IoT) applications where a high number of devices in the billions and trillions are expected to interact via the machine-to-machine (M2M) communication paradigm. This requires stringent quality of service (QoS), better delay, higher spectral efficiency, energy efficiency and better reliability [2].

All these requirements are putting a lot of pressure on the cellular service providers as they struggle to provide increase demand for higher data rates, increase their network capacity, provide higher spectral, and energy efficiency as well as higher mobility required by the emerging new wireless applications.

To this end, researchers have started to investigate the 5G wireless techniques where some potential 5G technologies were identified to provide solutions to the above enumerated challenges [1], [4]. It is commonly believed that the 5G must address six of the challenges plaguing the 4G which are higher data rate, higher network capacity, massive device connectivity, lower end-to-end latency, consistent quality of user experience provisioning (QoE) and reduced cost [3], [4].

These will be discussed in detail in section III. The goal of the 5G network is to achieve 10,000 times network capacity improvement, with 100 times higher data rates compared with LTE giving us between 5Gbps to 10Gbps while end-to-end latency is about 1ms and spectral/energy efficiency will be 5 times higher, moreover spectrum extension application is envisaged to be a 20 times higher and network densification should offer a network improvement factor of 50 while supporting 1000 times more connected devices [5], [6].

The 5G Network Capacity enhancement technologies is shown in Fig. 1.

It is commonly agreed by researchers in academia and the industry that 5G will be a combination of networks of different types, transmit powers, sizes, various radio access technologies (RATs), and backhaul connections which can be accessed by a huge number of heterogeneous and smart devices. 5G is expected to provide ubiquitous connections between human-to-human (H2H), human-to-machine (H2M) and machine-to-machine (M2M) anywhere, anytime and anyhow [6].

In order for the use of 5G to solve the enumerated 4G challenges and meet the new user demands, the 5G architecture is important and proper attention should be paid to its design.

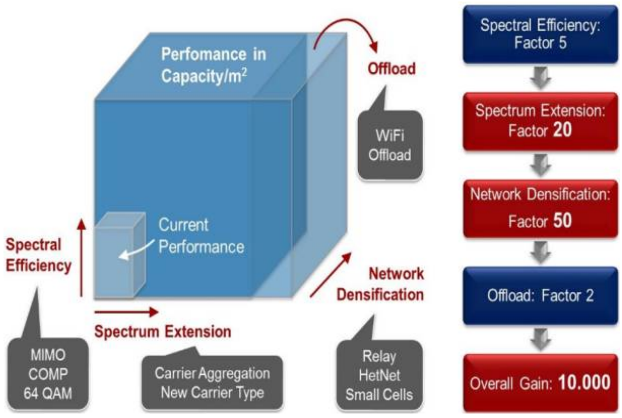

Fig. 1. 5G Network Capacity enhancement technologies

I.1. 5G Network Architecture

The basic protocol that will run on the 5G is the IPv6.5G which aims to provide ability to share data anytime, anywhere, and by anyone, it also provide unlimited access to information on the network. The physical and data link layers define the 5G wireless network technology as an Open Wireless Architecture (OWA). In order for the 5G to maintain virtual multi-wireless network, the network layer is divided into upper and lower network layers.

While the upper layer is for mobile terminals, the lower layer is for interface. In the network layers all the routing are based on IP addresses.

The session and transport layers in the 5G network OSI, support the open transport protocol (OTP) which is used to overcome higher bit rate losses while quality of service management across various types of networks is handled by the application layer [7]. The OSI (Open System Interconnection) layers for the 5G network is shown in Fig. 2. In 5G network, the 5G terminal is expected to be software radio driven with modulation and error control schemes that are downloadable from the internet.

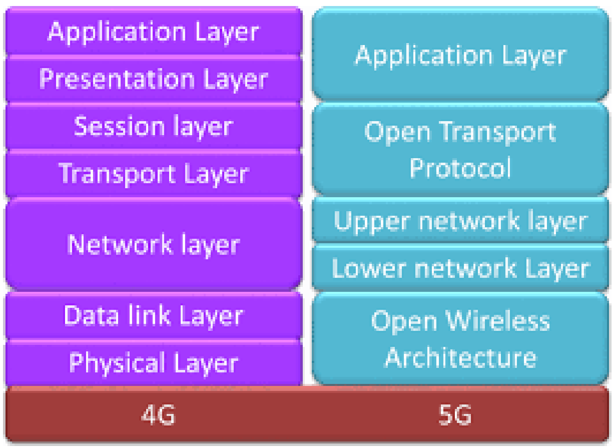

Fig. 2. 5G Network OSI Layers

Having access to different wireless technologies simultaneously, the 5G terminal should be able to combine different flows from various technologies with each network been responsible for user-mobility handling and the terminal having the responsibility for final choice of wireless access network provider for a particular service thus making the terminal as a focus of the 5G mobile networks [8]. In the design of 5G cellular network architecture, it is important for us to consider the indoor versus outdoor scenario as 80% of cellular network usage is carried out indoor with only 20% done outdoor [9] where the propagation environment is different and indoor users communicating with the current outdoor base station has to go through walls, partitions etc, leading to high penetration loss causing damage to the wireless transmission parameters including data rate, spectral and energy efficiency which also leads to poor quality of end user experience (QoE).

Therefore, it can be said that the present cellular wireless architecture contributes to the enumerated challenges plaguing the 4G. From the above, proposing a 5G cellular network architecture with separated indoor and outdoor scenario is a good way to go which afford us the benefit of avoiding the penetration loss through building walls and partitions associated with indoor users trying to make connections with outdoor BS as enumerated by [1], [3]. In this proposed architecture for 5G, the outdoor BS will be fitted with large scale central antenna or distributed antenna system (CAS or DAS respectively) otherwise called the massive MIMO technology which serves outdoor users [10]. In addition, large scale arrays are installed on each building externally to communicate with the outdoor BS via LOS component and with indoor access point via cables. This way indoor user's traffic is evacuated to the external BS via the indoor access point thereby improving the energy and spectral efficiency, data rate, and cell average throughput. Meanwhile, Wi-Fi, visible light communication (VLC), millimeter wave communication, small cells etc can be used by users indoor to communicate with each other [3], [10]. In order to cater for high mobility users inside automobiles and high speed trains, mobile small cells (mSC) are integrated as part of the 5G wireless cellular networks with such mSC communicating with the external BS via a local mMIMO unit placed outside the automobile or train [3]. A 5G cellular network architecture is shown below in Fig. 3.

Although many proposals on enabling technologies for 5G network architecture as abovementioned have been introduced in literature. However, how all these technologies will be functionally applied, controlled, and managed to achieve the required 5G capacity and also what the 5G network architecture will ultimately look like in order to attain the target capacity remain an open research issue. A few studies have been carried out in this field such as [1]-[6],[10]-[12]. The work of [1], [6] was based on the indoor, outdoor separated scenario architecture and the various enabling technologies for enhancing network capacity based on the dichotomy, while the authors in [2], [3], [11] considered the enabling technologies for network capacity enhancement as well as the cloud technologies for 5G RAN and SDN.

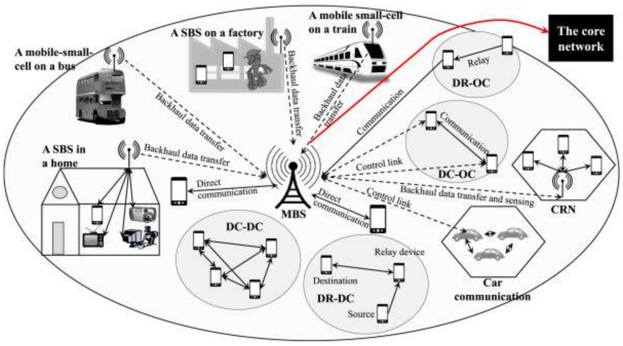

Fig. 3. 5G Cellular Network Architecture

The 5G architecture on a radio network and a network cloud two-layer format was considered in [4] and the enabling technologies were discussed on this bases. The authors in [10]considered the 5G architecture based on a three evolutionary path of RAN node and capacity performance enabler, network programming capability for network control and finally, backhaul network platform for enabling coordination between nodes for cost efficient QoE performance. In the indoor, outdoor scenario, the issues of 5G backhaul networks are important for traffic evacuation in an ultra-dense HetNet 5G network environment, these issues remain mostly unaddressed in the existing literatures such as [1], [2], [3], [6]. In addition, there is a lack of an architectural evolution framework for 5G networks that can capture most of the dominant enabling technologies in a structured manner. In this paper, we address these issues through a systematic structure that considers the leading enabling technologies of the 5G network architectural evolution from a broad set of perspectives.

The remainder of this paper is organized as follows: Section II reviews the evolution of the wireless technologies Section II. Section III looks at the six challenges of 4G to be solved by 5G. In section IV, the various enabling technologies proposed for 5G, their challenges and future trends are considered as well as how their softwarization and application in C-RAN through SDN/NFV is used to optimized the 5G network performance. Finally, conclusions are drawn in section V.

II. Evolution of Wireless Technologies

About three decades ago, cellular mobile networks came into operations with the first generation (1G) which is analog and is basically used for voice communication, shortly afterwards came the second generation (2G) called the Global System for Mobile telecommunications (GSM) which solves some of the 1G challenges since it is digital and can transmit data, even speech which is analog was digitized making GSM compatible with

ISDN technology. The circuit switched techniques of the GSM was modified for higher data speed with the introduction of the General Packet Radio Services (GPRS) which is a packet switched system lifting the network to 2.5G [13]. Following the GPRS is the Enhanced Data Rate for GSM Evolution (EDGE) offering data rate of about 384kbps. Known as the 2.75G, the EDGE gave way to the 3G UMTS with a theoretical data rate of 2Mbps in 3GPP Release 99 and moving up to 10Mbps in HSDPA Release 5. Due to the demand for higher data rate by users, the Evolved High speed Packet Access (HSPA+) in 3.5G [7], [8] [14] providing about 56Mbps for download and 22Mbps for upload data rate [15]. With the advent of the IoT, the industry came up with IEEE 802.16 standard called the Worldwide Interoperability for Microwave Access (WiMAX) as well as the 3GPP standard LTE/LTE-A which are the 4G network standards aimed to provide for higher data rates used in video conferencing, high mobility broadband services meant to also increase the system capacity [10].

Fig. 4 shows the evolution of the various wireless technologies. The WiMAX, LTE/LTE-A 4G wireless communication standards were planned to use internet protocol (IP) for all its services coupled with advanced modulation schemes such as the orthogonal frequency-division multiplexing (OFDM) for higher data rate, multiple-input multiple-output (MIMO) for link reliability, increased multiplexing and transmit diversity gain as well as spectral efficiency [16]-[18]. In addition, link adaptation technologies were introduced in 4G which provides up to 1 Gbps of data rate for users with low mobility, and data rate of about 100 Mbps for users with high mobility [1], [15] . Nonetheless, we are still experiencing dramatic upsurge in the number of applicants subscribing to mobile broadband usage yearly and with the humongous devices requiring connection and communication in the IoTs environment, the need for the 5G network becomes an urgent requirement. Table I is a comparative table of the features of the different wireless technologies. Fig. 5 shows the 5G challenge, facilitators, and design fundamental.

III. 4G Network Challenges

III.1. Network Capacity and Data Rate

The 5G wireless communication system is expected to support a 1000 fold increase in traffic compared to the 4G network with a 10 to 100 fold increase in data rate in hotspot, dense urban areas and even by high mobility users [4].

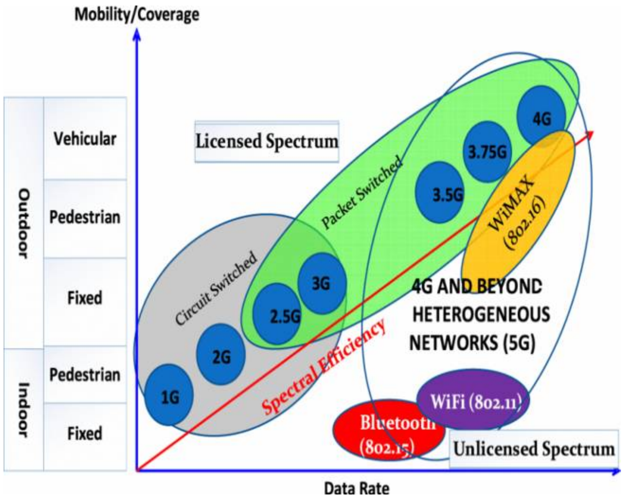

Fig. 4. Evolution of wireless communication technologies

The achievement of such growth requires more capacity in the fronthaul, backhaul and back-bone which can be achieved by a combination of increased spectrum usage, higher spectrum efficiency, network densification and traffic offloading using small cells [4], [19]. The above requirement can be sum up with equation (1) below:

$$C = M\left(\frac{w}{n}\right)\log_2\left[1+\frac{s}{(1+N)}\right] \quad (1)$$

where W is the Base station signal bandwidth, n (load factor) denotes the number of users sharing the particular BS, M is the Spatial multiplexing factor which is the number of spatial streams between the uses devices and the BS, s is the desired signal power, N and I are the noise and interference power, respectively and C is the network capacity.

From equation (1) above, it can be seen that the use of higher frequency band as in mmWave, and aggregation of spectrum resources via carrier aggregation methods leads to a linear increase in the network capacity, n which is the load factor can be minimized by cell splitting and the use of small cells which decreases path loss and increases S the desired signal power, thus increasing network capacity.

TABLE I
DIFFERENT WIRELESS TECHNOLOGIES

S/N	TECHNOLOGY	WI-FI	WiMAX	3G	4G
1	Standard	IEEE802.11n	IEEE802.16d/m	WCDMA/HSPA+	LTE
2	Frequency	2.4 and 5GHz	2 - 11 GHz	2100MHz	2-8GHz
3	Multiplexing	OFDM	OFDM	WCDMA	OFDM & OFCDM
4	Antenna Technology	MIMO	MIMO	MIMO	MIMO
5	Throughput	> 200Mbps	75Mbps	48Mbps	200Mbps
6	Modulation	16/64QAM	16/64QAM	QPSK,16/64QAM	64QAM
7	Air Interface	OFDMA	OFDMA/FDD	WCDMA	OFDMA/OFCDMA
8	Usage	WLAN	WMAN	WMAN	WMAN
9	Services	Fixed BWA	Fixed and Mobile BWA	Mobile BWA	Mobile BWA

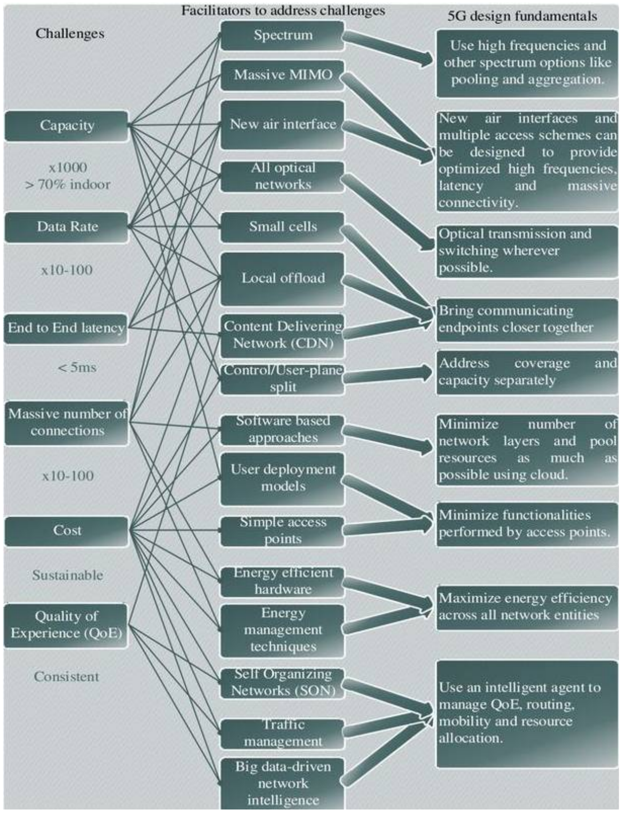

Fig. 5. 5G Challenge, Facilitators, and Design Fundamental [4]

It is also seen that the spatial multiplexing factor *M* can be increased to increase network capacity with the use of large antenna array (massive MIMO).

The use of optical switching and networking can be used to increase capacity in the backbone, backhaul and front haul while mMIMO can also be used in the line of sight formation to increase capacity in the backhaul [4].

III.2. Massive Device Connectivity

As a result of the IoTs and surge in the use of handheld devices, connected devices number is expected to increase a 100 fold by 2020 [4].

Aside this increase in number of connected devices, another challenge is the support for the diversity of devices and their service requirement in a scalable and efficient manner. A suggested way of solving this particular challenge is the use of femtocell configured in either open subscriber group (OSG) mode or closed subscribed group (CSG) mode used indoor, femtocell can be targeted at static UEs, IoT sensor, Actuators etc. which provide 80% of today's data traffic carried indoor [10]. Because much of MTC devices are static indoor, femtocell can be used for M2M connectivity to the BS using small cells (femtocell) for massive MTC connectivity instead of direct macro-cells in the RAN also ensures stronger separation of MTC/M2M communication and H2H traffic. Since the 5G will be an HetNet, other machines belonging to non-3GPP networks such as the IEEE802.11ah (Low Power Wi-Fi) can also be used for enhancing the massive device connectivity [20].

III.3. Lower E2E Latency

New real time mission critical applications such as remote controlled robots, vehicle to vehicle (V2V), vehicle to infrastructure (V2I) [4], latency critical IoT applications such as factory automation, smart grids, machine tools etc. [21] requires critical end to end (E2E) latency in order to function well. For the achievement of these applications, 5G networks must be able to provide coupled with high reliability, which the present 4G did not offer with its average 100ms latency [22]. Meeting the above E2E latency requirement will mean innovations in the design of air interface, the hard-protocol stack as well as the network architecture [4].

III.4. QoE and Cost

Quality of end-user experience (QoE) is a subjective metric as it depends on the user perception, however in spite of the diversity of QoE requirements, ensuring high bandwidth and low E2E latency in general will improve QoE therefore those enablers earlier mentioned can improve QoE. QoE is related to cost as delivering an application with low QoE can lead to end-user dissatisfaction whereas if the QoE is too high unnecessary radio and transport network resource as well as BS power is wasted on the side of the operator while device battery is wasted on the side of the user. Talking about cost, deploying the enabling technologies to achieve connectivity anywhere, anytime and anyhow will be expensive and there is a need to reduce infrastructural cost as well as the cost of management, operation and maintenance if we are to make the connectivity universally available, affordable and sustainable [4].

Solving the cost problem may require implementing layers L1 and L2 at the base station while other layers functionality are moved to a network cloud that serves many other base stations thereby reducing operational cost. This design also improves flexibility in traffic and network management. Cloud radio access network (C-RAN) as it is described allows cloud computing, software defined networking and network virtualization to be implemented in 5G. With C-RAN various network functionalities in different layers of the network protocol stack and various network algorithms now take place in the cloud for centralized processing resulting in improvement of the capital expenditure (CAPEX) as well as operational expenditure (OPEX) cost [2].

IV. 5G Emerging Technologies

5G network is expected to be flexible enough to handle H2H, H2M and M2M communication, this complex scenarios makes it very difficult and challenging for network operators to manage the network resourcefully with the demanded varying QoS for these complex communication scenarios. Thus, scalability and flexibility of the network is required to meet the needs of the individual services [23]. One way of providing this scalability and flexibility is to provide a new network architectural design which integrate legacy systems with new standards, and this can be achieved with the use of cloud-based wireless network architecture which encompasses mobile cloud, cloud-based radio access network (Cloud-RAN), reconfigurable network and big data centre that is able to provide the flexibility and adaptability required via virtualized, reconfigurable and smart wireless network [24] [1], which provide platform for other 5G technologies such as massive MIMO, D2D/M2M communication etc.

IV.1. Dense Heterogeneous Networks/Multiple Radio Access Technologies

According to the 3GPP definition, heterogeneous networks are concurrent operation of different types of base stations, nevertheless, we see heterogeneous networks in 5G as a mixture of different radio access technologies as well, which will consist of macro cells, small cells, relay's remote radio heads (RRHs) and wireless local area network (WLAN) along with provisioning for D2D and M2M communication [25], [26]. The multi-tier deployments of heterogeneous nodes in 5G systems will give higher density than the current single-tier networks. Dense deployment of heterogeneous nodes is a condition for reducing the load-factor 'n' in equation (1) as well as for improving the signal power 'S' by reducing path loss [19]. Deploying small cells outdoor with a typical transmit power of 30dBm offers lower CAPEX and OPEX compared with macro cells, while relays nodes with wireless/cellular spectrum can be deployed where wired backhaul is not available.

Overlapping various types of base stations will provide a solution for the growing data traffic, particularly when the data traffic evacuation is optimized to take advantage of the characteristics of heterogeneous networks [25]. According to [10], [19] overlapping the operational boundary of small cells can generate significant interference among cells, which can be mitigated by the use of orthogonal frequencies among the small cells. This however, gives rise to limited and expensive system bandwidth and by extension limited system capacity. Another solution is to ensure tight coordination between the cells in order to reuse same frequency with the necessary cooperation, which will play a major role in the achievable network capacity, higher spectral efficiency and energy efficiency for 5G network[10], [26]. Also installing small cells indoors can be used to overcome indoor-to-outdoor penetration loss which can be as high as between 10dB to 20dB [12].

This indoor small cells are connected via cables to local large antenna arrays for indoor user traffic evacuation which significantly enhance cell average throughput, data rate, energy efficiency and spectral efficiency of the 5G cellular system [3], [27]. Finally, in order to take care of high-speed mobile users, mobile small cells (mSC) with high speed wireless backhaul links using mMIMO can be installed in vehicles and high-speed trains. The mSC can connect with the vehicle safety information systems as well as the intelligent transport system infrastructure in the case of public transportation application [12]. A mobile HetNet with the use of mSC is a potential 5G HetNet solution for high speed mobile users, however, before it can be deployed it has a lot of interference challenges to overcome including inter-cell interference, inter-tier interference e.g. interference between Small Cell and Macrocell, intra-tier interference e.g. interference between Small Cell and Small Cell etc. [12].

IV.2. Cloud-Based RAN

The major challenges of the current traditional RAN is limited capacity, insufficient expandability and low utilization [24] which are solved by the cloud-based radio access network (C-RAN). The notion of C-RAN comes from the distributed base station architecture. In the current 4G architecture the baseband processing and the radio functionality are performed in the BS while the BS to BS coordination is done by the X2 interface[26] , however, in the proposed 5G architecture, the baseband processing unit (BBUs) are separated from the analog radio access unit referred to as the RRHs and relocated to the cloud termed BBU pool where centralized signal processing and management is performed (Fig. 6).

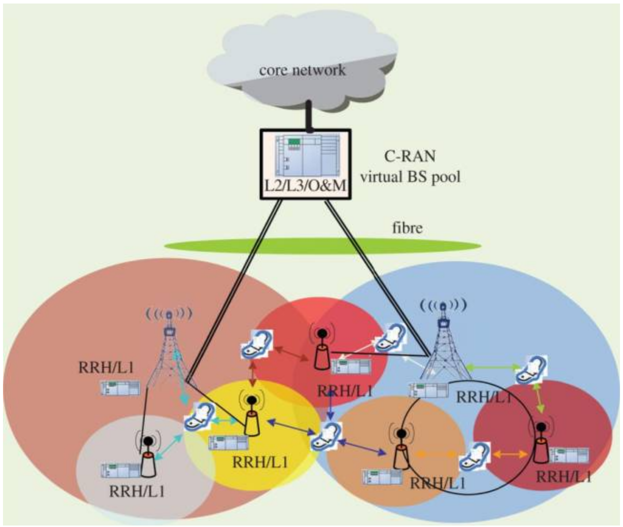

Fig. 6. C-RAN configuration for 5G Cellular Network

A single BBU pool serves a region with a number of RRH of small cells and macro cells, therefore the transmission of radio signal to users by the RRHs is carried out based on baseband signals received from the BBU (in the cloud). In this configuration, the backhaul connects the cloud to the core network while front haul using optical transport link connect the RRHs to the cloud for the purpose of transmitting digital baseband signals [26], [28].

C-RAN offers a key paradigm shift in the design of upcoming wireless systems where various access and core network functionalities are realized in the cloud. Because of its high cost-efficiency, flexibility, and utilization efficiency, C-RAN is believed to be one of the most promising solutions to meet the huge capacity demand in 5G wireless networks [2]. There are many open research issues asking to be addressed in the application of C-RAN for 5G network, including efficient radio resource management such as bandwidth allocation, power control and beamforming designing. Also requiring research attention is front-haul compression as well as the efficient design and utilization of computing resource in the cloud etc [2].

IV.3. Device-to-Device Communication

In device-to-device communication (D2D), nearby devices are allowed to establish local links with each other so that traffic flow between them rather than routing traffic through the base station[19], [61], [62], [63], this reduces power consumption, latency as well as increases the peak data rates. D2D communication is particularly useful in a situation where there is very high density of user's terminal per cell, which may lead to poor throughput [25]. In D2D communication, the BS no longer constitute traffic bottleneck as multiple D2D connections concurrently share same bandwidth which leads to increased spectral reuse per cell [25], reduced interference particularly in unlicensed frequency band as shown in Fig. 7.

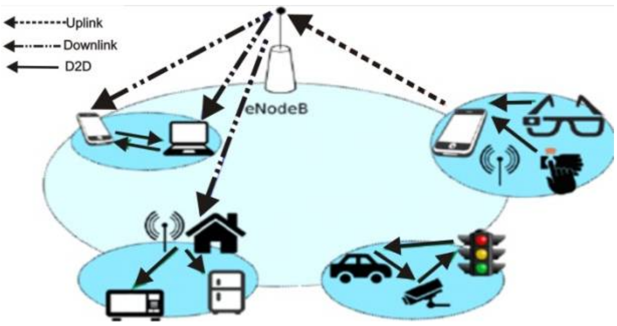

Fig. 7. D2D Communication Architecture

When combined with small cells, a new underlay tier of low-cost architecture can be formed by D2D communication with the aim of achieving increase capacity, coverage, fallback connectivity and offload backhaul [6]. D2D communication can be classified into two which are in-band and out-band where the main difference is that in-band D2D communication occurs in licensed spectrum using cellular spectrum for high reliability and control, while out-band D2D communication uses unlicensed spectrum such as the industrial, scientific and medical (ISM) bands, this helps to eliminate the issue of interference between the cellular link and the D2D link (Fig. 8). In-band D2D communication can be used in underlay or overlay configuration while out-band D2D communication is further divided into controlled and autonomous communication, the difference being that in autonomous out-band class, the control of the second interface/technology is not achieved by the cellular network but left to the users unlike in the controlled out-band [6] Machine-to-machine (M2M) communications which involve a large number of low power intelligent sensors and actuators sharing information and making mutual decisions without human intervention is a field that may benefit from D2D scheme. Declared as one of the five disruptive technology directions for the 5G networks [6], the M2M communication, which is, similarly to D2D communication and focuses on data exchange between nodes and between nodes and infrastructure unlike D2D communication does not have any requirements on the distances between the nodes.

Therefore, M2M communication is application-oriented and technology-independent, unlike D2D communication, which aims at proximity services in technology-dependent manner [6].

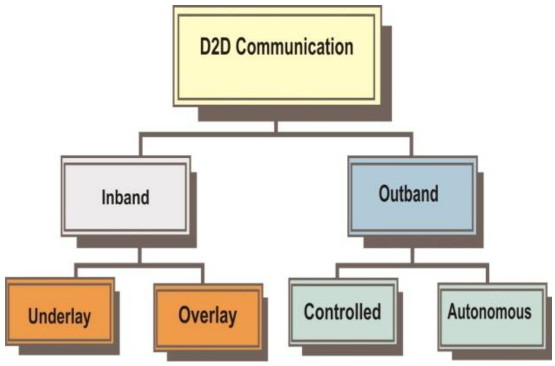

Fig. 8. D2D Classification

IV.4. Massive MIMO

Multiple input multiple output technology uses multiple antennas at the transmitter and or receiver to overcome fading and improve spectral efficiency, power efficiency, link reliability and cell edge improvement [16]. Massive MIMO achieve all the above on a larger scale and much more. In mMIMO systems, the transmitter and or receiver have more number of antenna elements in the order of tens or hundreds where the transmitter antennas can be co-located (CAS) or distributed (DAS) depending on the application [29].

Another configuration is the cell free mMIMO which is a type of distributed system where several antennas at each BS are connected to C-RAN for centralized baseband processing, a system that is proposed in 5G.

Favorable propagation condition is assumed in mMIMO which is to mean a sufficiently complex scattering environment is experienced by the users as the BS antenna increases to large number causing the user channels to become pair wise orthogonal. In this scenario as dimensions become large, matrix operations like inversion becomes less operationally complex and simple series expansion techniques can be used to calculate it [17]. This is what makes linear algorithms like ZF and MMSE where matrix inversion operation is used to be near optimal in performance [30], a situation that is almost impossible without mMIMO favorable propagation condition [31]. In 5G HetNet, wireless backhaul is preferred to wire backhaul and mMIMO readily provide this service because of its ease of deployment compared to wired backhaul. mMIMO is therefore used in macro cells because of its high degree of freedom (DoF) and ease of deployment to support multiple wireless backhaul [32]. As the location of small cells is usually fixed (except mSC), the wireless backhaul channel may be treated as Quasi-static time varying and thus the macro-cell can eliminate interference that may occur between the wireless backhaul and the small cells with the use of precoding [32]. Another technology of the MIMO system application for the 5G network is the 3D mMIMO which uses 3D beamforming for traffic backhauling from indoor access points connected to building mounted large scale antenna arrays as well as for connection with users on different levels of high-rise buildings [33], termed 3D for vertical sectorization (Fig. 9 [25], [34]). However, there are many challenges that should be overcome before mMIMO can be applied in 5G network including the provision of mmWave massive MIMO channel models for various scenarios etc.

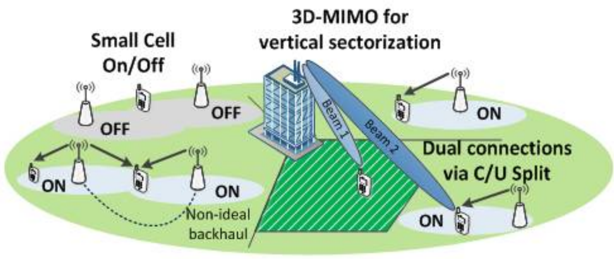

Fig. 9. 3D MIMO for vertical sectorization

IV.5. Spatial Modulation

A key challenge in massive MIMO is striking a balance between spectral efficiency (SE) and energy efficiency (EE). This is leading to a new approach and proposal for single radio-frequency (RF) large scale MIMO system called spatial modulation massive MIMO (SM-MIMO). This is coming as a result of massive MIMO full deployment in 5G network and operators concern about the increasing capital and operational expenses as a result of its large number of RF-chain and power amplifiers leading to high energy consumption [35], [36]. Massive SM-MIMO is a novel MIMO concept that uses a large number of antenna elements than the number of RF-chains, the distinguishing feature of SM-MIMO from conventional MIMO is that it map extra information bits into what is called the "SM constellation diagram" in which case each constellation part is made up of either one or a subset of antenna elements [37]. Here the modulator uses amplitude or phase modulation methods such as quadrature amplitude modulation (QAM) or phase shift keying (PSK) as well as the antenna index to convey information, while only one antenna is active during transmission (Fig. 10). This method avoid inter channel interference (ICI) while inter-antenna synchronization is no longer required unlike the case of V-BLAST [38], [39]. This novel method facilitates high-rate MIMO deployment with reduced signal processing and reduced circuitry complexity while improving energy efficiency [37], [38]

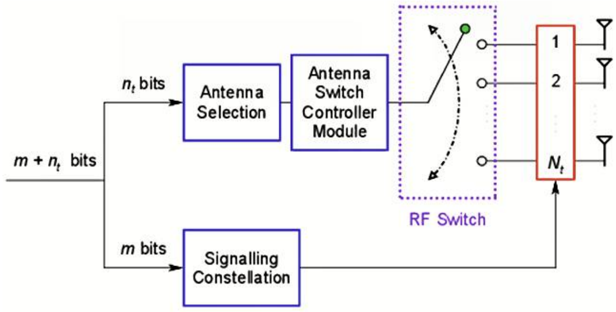

Fig. 10. SM-MIMO Transmitter Schematic Diagram

Since there are two information carrying sets in SM-MIMO as indicated above; indices of the transmit antenna and the M-ary constellation symbols, then, it can be said that for each signaling period, the total is:

$$\log_2(N_T) + \log_2(M) \tag{2}$$

bits entering its transmitter where M is the size of the considered signal constellation e.g. 8PSK or 16QAM etc, thus it uses the $\log_2(M)$ bits to modulate the amplitude and or the phase of the carrier signal while the $\log_2(N_T)$ bits are reserved for the selection of the index of the active transmitting antenna at the base station, the receiver then uses the optimal maximum likelihood (*ML*) detection to decode the signal received [1], [40]. Another advantage of SM-MIMO is that low complexity receivers can be designed for any number of antennas, which is unachievable in conventional MIMO. It should be noted that SM-MIMO multiplexing gain increases logarithmically as the number of transmit antenna becomes large unlike in conventional MIMO where it increases linearly, thus the achieved low implementation complexity in SM-MIMO is at the cost of losing some degree of freedom [1]. Since SM-MIMO uses single RF-chain thereby eliminating huge power consumption at the BS, it therefore has potential not only to lower the CAPEX but also lower the OPEX offering itself as a candidate technology for the application of massive SM-MIMO in 5G network.

IV.6. Millimeter Wave Communication

The mm-wave frequencies has been recommended for cellular network communication systems for its availability of frequency bandwidth that is not available in below 6Ghz band [41] and its strong potential as candidate bands for next generation cellular services.

According to [42] mmWave frequencies could be available to support the presently saturated 700 MHz to 2.6 GHz radio spectrum bands for 3G/4G wireless communication networks. In addition, the mm-wave allows for bigger carrier frequencies bandwidth allocations, resulting in higher data transfer rates and allowing system operators expand their channel bandwidths ahead of the present 20 MHz channels used by the 4G network. Increasing bandwidth decreases latency for digital traffic thereby sustaining better internet-based access and applications that require minimal latency such as factory/process automation, smart grid, intelligent transport system, drone control etc. [21], [43]. Mm-wave frequencies is also useful in massive MIMO and adaptive beam forming where the very small antenna elements of mm-wave mMIMO can compactly be accommodated at the BS without antenna coupling challenges and be used for beam forming and heterogeneous network backhauling for macro-cells and small cells in 5G to enhance greater network capacity than today's 4G networks as shown in Fig. 11 [44], [45].

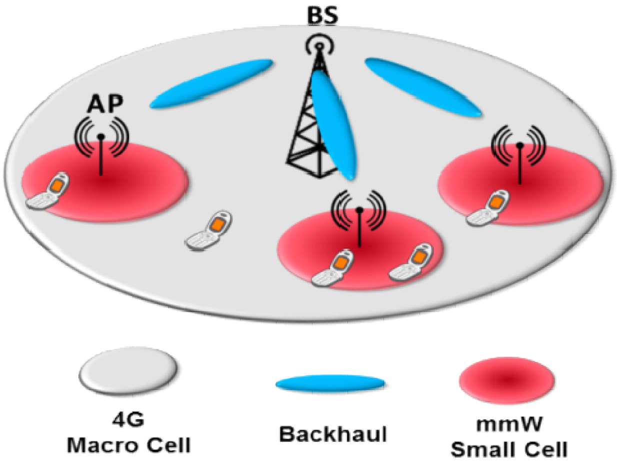

Fig. 11. MmWave for small cell backhauling

However, increasing the carrier frequency in mmWave 5G network leads to propagation conditions challenges e.g. higher penetration losses due to concrete buildings etc. Another challenge particularly for mobile scenarios is that of initial access [46] where each UE is expected to establish a physical link connection with the BS which is necessary to access the network, however mmWave communication requires directionality for connection whereas the current LTE uses omni-directional channels for connection which is very fast as compared to directionality connection which can greatly delay the cell search and access procedure particularly when you consider the fact that beam forming and other directional transmissions cannot be performed until the initial access connection is made. It is therefore necessary that a solution be provided for the above challenge in order to use mmWave in 5G network [47].

IV.7. Visible Light Communication

One of the candidate technologies proposed for the indoor wireless communication system earlier enumerated to be used for the indoor/outdoor dichotomy in the 5G network is the visible light communication otherwise called the optical wireless communication.

VLC has edge over the current RF networks in the indoor environment since it has unregulated spectrum with huge license free bandwidth for very high data rate and there is no interference between indoor and outdoor users nor between users in different enclosures due to different spectra. Fig. 12 shows typical use in the indoor environment [48], [49]. MIMO multiplexing gain [16] can be used in VLC to increase data rate.

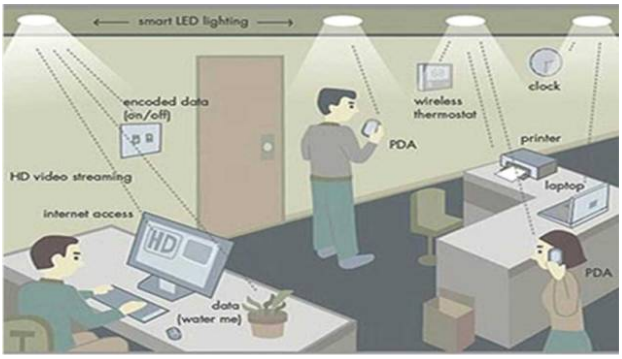

Fig. 12. Application of VLC for Indoor use

VLC can be used for vehicle-to-vehicle communication in pre-crash sensing and accident avoidance; it can be used for robotic control in hospitals and underwater communication to mention a few with potentially up to 10Gbps speed [50]. One major challenge of VLC among many others is its less feasibility of embedded UL LED transmitters with enough transmission power in the UE, it is therefore likely that VLC systems may depend on other UL transmission access techniques such as Bluetooth or infrared for low rate UL services while Wi-Fi can be used for high rate UL services in the indoor environment [51], [52].

IV.8. Virtualized, Reconfigurable and Smart Wireless 5G Network Using SDN/NFV

Reconfigurable networking is about constructing adaptive networking firmware that can deal with varying network topologies or application requests [53]. The current mobile cellular systems from 2G (GSM) to the 4G (LTE-A) were designed and deployed as a connection-centric network with an inflexible RAN that is non-reconfigurable and thus not effective to provide the necessary flexibility needed for the present day mixed content-centric communication services such as the H2H, H2M and M2M. However, 5G networks are expected to be able to cleverly identify the communication scenarios and dynamically assign network resources as well as offer the best connectivity and network performance as needed to improve the efficiency of existing resources [54]. The evolution towards content-centric communication network can be achieved through new hardware and software platform.

The purpose of this hardware/software platform is to leverage on the potentials of the earlier discussed key 5G enabling technologies for achieving the content-centric network with flexibility and reconfigurable capability [55]. The most critical and core concept technique in achieving the above is the use of the Software Defined Network (SDN) and the Network Functions Virtualization (NFV). The 5G is a heterogeneous ultra dense network (UDN) with deployment of small cells without proper cell planning aside the various different operating frequencies from 2G to 4G leading to interference. There are various classes of interference expected within the HetNet with the major challenge been the interference from a small cell (SC) to a macro-cell user within the coverage of the SC [56]. It is also expected that the 5G will operate with the 300MHz to 300GHz band since the mmWave technology has been included as one of the enabling technologies for the 5G, (Fig. 13).

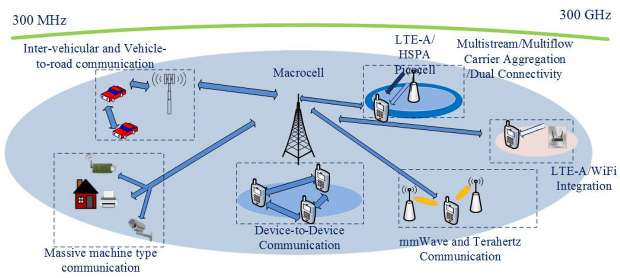

Fig. 13. 5G range of operating frequency

To solve the interference problem in the 5G network as well as provide seamless connectivity of the smart UE/device across networks with different operating frequencies as well as solve the integration challenges between various frequency bands, the software defined radio (SDR) will be ideal. Unlike in hardware radios, the SDR based UE/device can scan the frequency bands available and incorporate different connection technologies such as the WiMAX, Wi-Fi, HSPA+, GSM, LTE/LTE-A in a single interface as shown in Fig. 14.

Currently, all the networks, services, devices and protocols have dedicated frequency bands and with the non-reconfigurable bottleneck in hardware radio switches, the current HetNet has not been able to converge. It is therefore believed that the convergence nature of the future 5G network will commence from spectrum sharing capability offered by SDR [57]. A similar technology is the Cognitive Radio (CR) which is defined as an "intelligent communication system with surrounding environment awareness capability, the knowledge of which is used to adjust its internal states to the incoming RF stimuli variations by creating resultant changes in its operating parameters such as the transmit power, carrier-frequency, and modulation strategy in real-time with the aim of achieving reliable communication whenever and wherever needed as well as efficient utilization of the radio spectrum[58]. CR is used to take advantage of frequency holes in the cellular networks to lease addition spectrum outside the licensed cellular bands for spectrum efficiency [59].

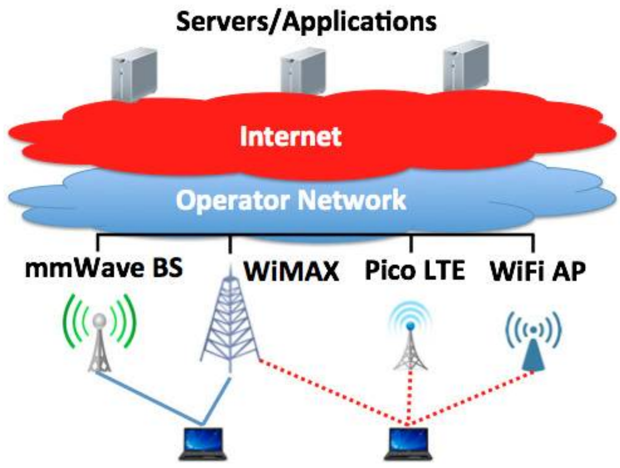

Fig. 14. Smart UE/Device Connections

Software Defined Network (SDN): As the density of networks increases, the backhaul become more heterogeneous and scenario dependent, that is various types of backhaul depending on availability are used e.g. fibre, microwave or mmWave. This will also have effect on the operation of the RAN such as latency differences on backhaul links; this will impact inter-cell harmonization and cooperation algorithms. Thus both the RAN and backhaul network have the need to be aware of limitations and capabilities of each other necessitating a new concepts on network management such as the application of Software Defined Networking (SDN) principles, which helps to accomplish fast rerouting and congestion control. SDN paradigm helps to adjust the operation of the backhaul network to the needs of the radio access network [57], [60], thus the 5G network convergence will be greatly aided by the use of the SDN.

The inclusion of intelligence in 5G can deal with the complexity of service requirements of HetNet by dictating and providing flexible solutions to accommodate network heterogeneity using SDN, which has emerged as a new intelligent architecture for network re-configurability. The main plan behind SDN is to shift the control plane external to the switches and allow external control of data through a logical software unit called the controller [61] as shown in Fig. 15. Network Functions Virtualization (NFV): is a technology that helps operators virtualizes network tools and infrastructures and control operations such as routing, switching, load balancing, unified treat management, content and spam filtering, as well as WAN acceleration and optimization rather than achieving the above via physical devices [54]. An example is the coordinated multipoint (CoMP) which can be used to improve cell edge user experience via coordinated scheduling, coordinated beam forming and interface alignment. This can be achieved by implementing the 5G network functions as software operation using NFV rather than the use of CoMP since CoMP leads to increased signaling and backhauling overhead as well as equipment cost [54], [62]. Thus in NFV, operators implement network functions in software components called Virtual network Functions (VNFs). One of the most important complementary technologies to SDN with the prospect to influence radically the 5G network is the Network Functions Virtualization (NFV). The aim of NFV is to virtualize (known also as network softwarization) a set of network functions by deploying them as software packages, creating the same services provided by legacy networks through hardware equipments. For example, it is possible to deploy a virtualized Session Border Controller used in VoIP to protect the network infrastructure more easily than installing the conventional complex and expensive network equipment [61]. NFV can also be used to enable in-flight IoT services in non-critical applications such as cargo monitoring [63]. Another application area of the NFV is its deployment on high-volume severs or cloud infrastructure in C-RAN where NFV pools the signal processing resources in cloud infrastructure rather than the use of dedicated baseband processing units (BBUs) at every base station (BS).

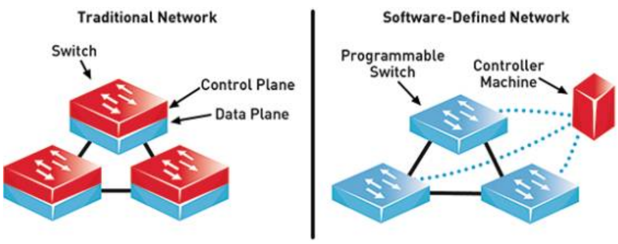

Fig. 15. SDN with external control plane compared to the Traditional Network

V. Conclusion

Looking at the evolution of the wireless cellular network and the challenges of the current 4G technologies, it can be seen that the new 5G wireless network will be able to provide solutions to the highlighted deficiencies of the 4G network using the proposed 5G indoor-outdoor architectural dichotomy and the various emerging technologies, while all the current in-flight connectivity by airlines uses satellite-based air-to-ground solutions which are limited to around 500ms latency with data rate ranging from 70-100Mbps per aircraft, the proposed 5G as enumerated above will offer about 15Mbps per user in an aircraft with 400 passengers such that Gbps download speed is offered per aircraft and a latency below 10ms. An obvious better direct air to ground services over the satellite based solution [63]. It is also shown that the 5G network will derive its strength by leveraging on the benefits of the above enumerated emerging hardware technologies which will be managed by reconfigurable SDN/NFV via the C-RAN.

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Authors' information

[1]Electrical & Information Engineering Department Covenant University, Ota Ogun State Nigeria.

[2]School of Engineering and Digital Arts University of Kent, Canterbury UK.

Olabode Idowu-Bismark is currently a PhD researcher in Covenant University, Ota, Ogun state Nigeria. He holds an M.Sc degree in Telecommunications Engineering from Birmingham University UK in 2014 and a B.Eng Electrical and Electronics Engineering from the University of Benin, Nigeria in 1990. Olabode is a ZTE University China certified RF engineer and a certified Optical Fibre/Transmission engineer, he has worked in various companies including Logic Sciences Limited and Primotek Systems Limited as an engineer, senior engineer and a technical manager, a member of the IEEE his research interest is in the area of wireless mobile communication and the Internet of Things (IoT).

Kennedy Okokpujie holds a Bachelor's of Engineering (B.Eng.) in Electrical and Electronics Engineering, a Master of Science (M.Sc.) in Electrical and Electronics Engineering, Master of Engineering (M.Eng.) in Electronics and Telecommunication Engineering and Master of Business Administration (MBA). He is currently on his Ph.D in Information and Communication Engineering/ Lecturing with the Department of Electrical and Information Engineering at Covenant University, Ota, Nigeria. He is a member of the Nigeria Society of Engineers and of the Institute of Electrical and Electronic Engineers (IEEE). His research areas of interest include Biometrics, Wireless Communication and Digital signal Processing.
E-mail: kennedy.okokpujie@covenantuniversity.edu.ng

Ryan Husbands is a researcher and a PhD student with the School of Engineering and Digital Arts, University of Kent U.K. His research interest include Digital Signal Processing, Antenna & Propagation, Cellular Communication and Coding.

Michael Adedokun is a Lecturer/ PhD student with Department of Electrical and Information Engineering at Covenant University, Ota, Nigeria. His research interests include Digital Signal Processing, Antenna & Propagation, Cellular Communication and Coding.