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Integration of Internet of Things (IOT) In 5g Technology: Enabling Technologies, Enhancement and Challenges

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***Abstract**: Internet of Things is growing and continues to be the up-to-date, most overvalued concept in the IT world and over the last few years, the term Internet of Things (IoT) has fascinated consideration by sticking out the idea of a worldwide infrastructure of networked physical items, allowing anytime, anywhere connectivity for whatever thing and not only for any one. To ensure a reliable connectivity, 5G necessitates a prototype modification that includes extremely high carrier frequency spectra with huge bandwidths (in mm-Wave), extreme base station densities (small dense cells), and extraordinary numbers of antennas to accommodate the massive increase in the volume of traffic. In this article a review of the technologies and different schemes that are used to deploy IoT applications in 5G networks have been discussed and it come out with an observation that combining all three technologies (massive MIMO, mm-Wave and dense small networks) will ultimately facilitate IoT services in 5G technology.. For future work research, the author recommends further research on eliminating the challenges facing mm-Wave, dense small cells and massive MIMO technology in deployment of IoT services.*

Keywords—5G technology, Internet of Things, mmWave technology, massive MIMO, spectral efficiency, energy efficiency, network capacity, dense small cells**.**

I. Introduction

Forthcoming generation of communications (communication infrastructure) predicts excess of wireless, connected, occasionally 'smart' computer based devices intended to communicate in real time. Such computer based devices will be pertinent for human communication and it is anticipated that there will be a substantial need for machine to machine type communication [1-3].

These devices increase gradually prompting a necessity of reliable and efficient wireless connections, high speed data transfer and low latency. This therefore encourages greater coverage and high reliability of data.

By definition, Internet of Things (IoT) is the linkage of computer based devices, automobiles, home appliances and other items implanted with integrated circuit technology, software, sensors, actuators, and connectivity which allows these components to connect and exchange data in which each object is distinctively recognizable through its implanted computing system though it is able to inter-operate inside the existing Internet infrastructure [4]. Internet of Things (IoT) is an emerging and hopeful technology which tends to modernize the global world through connected physical objects and low-power computer based devices which interact with one another through the Internet [5].

IoT lets things to be detected or controlled distantly across present network infrastructure, generating opportunities for more direct addition of the physical world into computer-based systems, the emerging cyber physical and social systems, resulting in enhanced efficiency, correctness, economic benefit in addition to reduced human intervention, it also describes a world where just about anything can be connected and communicates in an intelligent fashion that ever before [6].

The discussion and exploration of IoT, calls for the inclusion of Body Sensor Networks (BSNs which comprises of multiple sensors that can be installed as on-body or out-body devices to support the efficient and effective management of the organs to maintain a healthy life.) which are the crucial devices to be connected as a part of IoT [7].

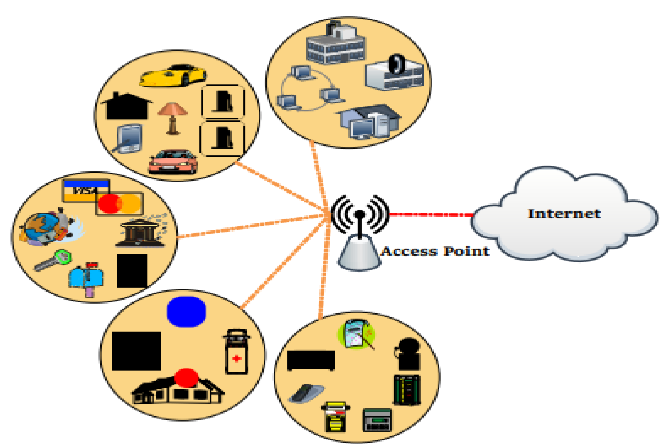

Figure 1: Diagram showing different devices or machines communicating each other via the access point which provides those devices an access to internet. In fact the

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Vol. 2 Issue 11, November – 2018, Pages: 65-78

devices can communicate themselves without involving human interactions [7].
For the Internet of Things idea to magnificently materialize, the computing standard will need to go further than traditional mobile computing (WiFi and 4G-LTE wireless Internet access) circumstances that use smart phones and portables, and advance into connecting everyday current objects and embedding intelligence into our environment.
For technology to disappear from the perception of the user, the Internet of Things needs [8]:

- a shared understanding of the condition of its users and their machines,
- software architectures and prevalent communication networks to route and deliver the appropriate information to where it is applicable,
- the analytics devices in the Internet of Things that aim for self-directed and smart behavior.

With those three vital demands above in place, smart connectivity and context-aware mobile computation are highly needed though, the current 4G networks have been extensively used in the Internet of Things (IoT) and is endlessly growing to match the needs of the future Internet of Things (IoT) applications but the existing IoT solutions are facing a large number of challenges such as large number of connection of nodes, security, and new standards to be incorporated in IoT, so the 5G networks are anticipated to massively magnify today's IoT that can increase cellular operations, IoT security, and network challenges and pouring the Internet future to the upper hand [1].
It can easily be predicted that, in coming years, billions of users in a large cities will need to transmit and receive (communicate) holographic video more or less constantly, about 100 Mbps per consumer in each direction, so this will need noticeable increase of data rates and the spectral efficiency of the radio transmission [9].
The new necessities of applications in the future IoT (like currently an estimated 7620 new computer based devices connects to the Internet every minute) and the evolving of 5G wireless technology are two substantial developments that are driving the 5G enabled IoT.

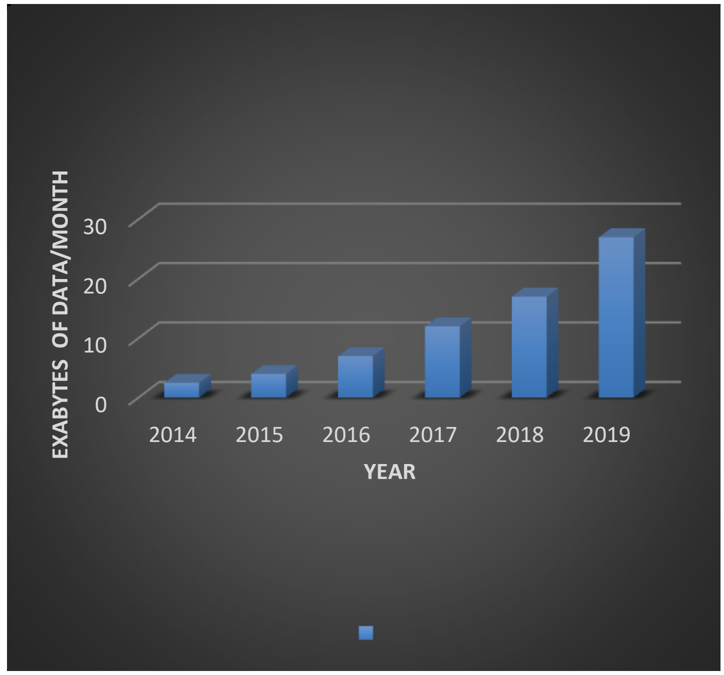

Figure 2: Showing the state of data volumes of data usage per year from 2014 – 2019 in Exabytes (1 Exabyte = 10^{18} Bytes) [10].

Initially intended for human-to-human wireless communications, current wireless networks fail to fulfil the massive connectivity and unpredictable data traffic requests of IoT so the Next generation 5G wireless networks are anticipated to exploit the emerging technologies, like mmWave, massive MIMO, and C-RAN, for providing the massive connectivity, resource sharing, and energy efficiency necessary to back up the commercial rollout of IoT [11].
This will enable many features of IoT to be integrated without feeling any disadvantages in data traffic movements between machine to machine and human to machine as the 5G wireless network is capable of handling high data requirements with high reliability and high spectral efficincy.
The diagram below show different technologies in which IoT can be integrated also, even though for the case of this paper we chose 5G.
Improving the wireless networks do not only improves the data rates for users but also it increases the chance of connecting more and more devices which can be connected to utilize the same or sometimes different bandwidths as other connected devices without causing any interferences.

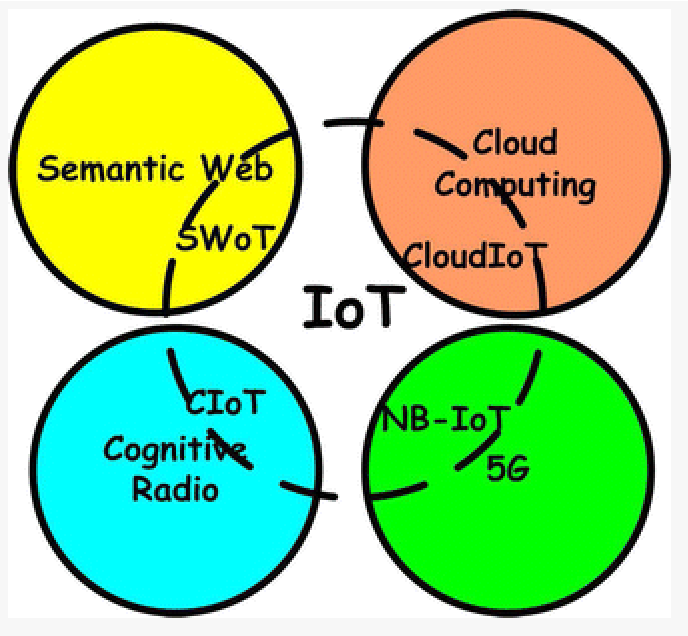

Figure 3: Enabling technologies of IoT integration [12].

5G is anticipated to be deployed around 2020 and has been well-thought-out a significant building block for the consolidation of the Internet of Things (IoT).

With the imminent coming of the 5G technology, it will be very easy to support a large number of devices in IoT and BSNs concurrently at higher and reliable data rates that is due to the fact that IoT and BSNs requires separate channel or bandwidth to communicate which is very possible in 5G because it comprises of a large number of access points.

The extraordinary necessities and new features of the upcoming Internet of Things (IoT), machine-to-machine (M2M) and correspondingly many other machine type IT-systems have led to an innovation in designing exceptionally green flexible with low-cost technologies for coming 5G wireless systems which will be capable of reaching in real time the performance extremums, trade-off targets and ultimate boundaries [13].

The aim of this paper was to review the existing technology behind the integration of IoT in 5G infrastructures which will soon be deployed in the year of 2020, 5G enhancement for IoT requirements design, enabling technology of 5G for IoT accommodation and challenges facing the deployment of massive MIMo, mmWave and dense small cells for 5G.

II. BACKGROUND AND LITERATURE SURVEY

Using the emerging features like mmWave, massive MIMO, and C-RAN, Saxena *et* al [11], developed a 5G-enabled IoT gateways to communicate with the RRHs of 5G C-RAN in which the gateways are endowed with efficient compression schemes to significantly improve uplink resource utilization, their 5G C-RAN prototyping and laboratory experimental results pointed out a gigantic opportunity for supporting a huge number of IoT-enabled devices by classy 5G C-RAN deployment and efficient IoT gateway improvement.

Munoz *et* al [14], proposed SDN/NFV solutions to enable the development and testing of end-to-end 5G and IoT services supporting an extensive diversity of use cases from different vertical industries, such as automotive, e-health, energy, media or smart cities and their ADRENALINE testbed adopted the high-capacity, elastic and cost/energy-efficient software-defined optical transmission technologies for access, metro and core networks which are strict requirements of 5G and IoT.

IoT middleware has been accepted as the system that can deliver the services for devices abstraction and data management, and also supports the growth of applications essential infrastructures of services and which has become progressively imperative for IoT over the last years but despite all these advantages it have security as one of its main challenges, and, with the arrival of the 5G, these systems will be target of new security threats [15].

Spectrum and energy efficient IoT networks for 5G systems were proposed by Ercan *et* al [16], where spectrum was mutually shared with the cellular system for spectrum efficiency, energy reaping and energy transfer are exploited for energy efficiency and they also showed that for similar cellular traffic level, as the number of sensor nodes in the network grow, the IoT network exploitation rises resulting in a multi-user improvement thanks to the broadcast nature of the energy transfer.

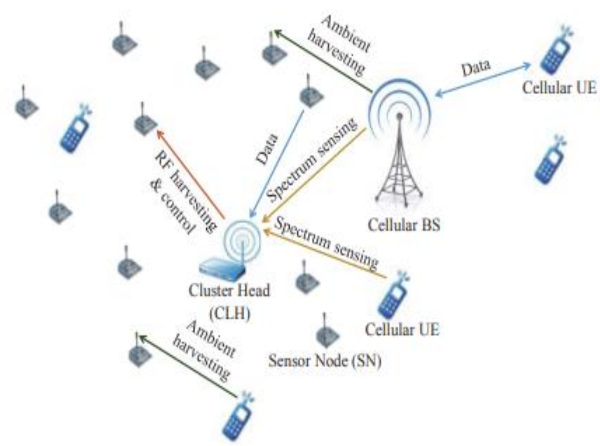

Figure 4: Spectrum sharing, energy harvesting and transmitting IoT Network proposed scheme by [16].

Based on the architecture and features of 5G wireless communication technology, Cheng *et* al [17], proposed the architecture of 5G-based industrial Internet-of-Things (IIoT), and described the implementation methods of different radical manufacturing situations and manufacturing technologies under the conditions of three typical application approaches of 5G, correspondingly, i.e., enhance mobile broadband (eMBB), massive machine type communication (mMTC), ultra-reliable and low latency communication (URLLC).

International Journal of Academic Multidisciplinary Research (IJAMR)
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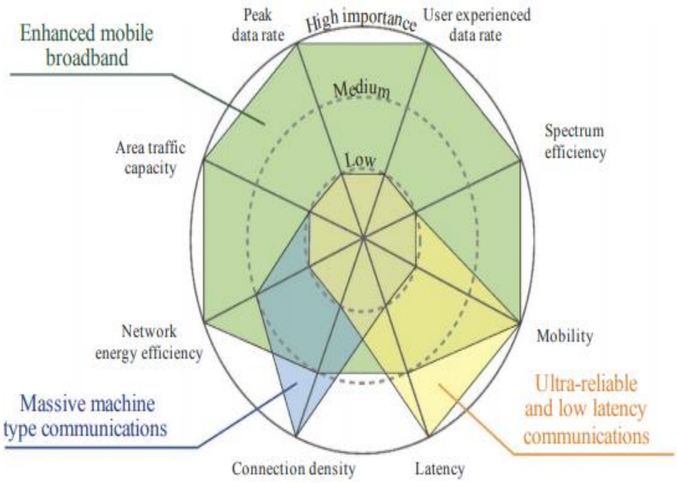

Figure 5: Showing the significance of key capabilities in different usage scenarios [18].

Lee et al [19], highlighted the key complications of the 5G-IoT network protocol as the coordination and communication between huge number of IoT devices and the base station and to solve these problems they proposed the Polarization Switching Wireless Power Transfer (PS-WPT) antenna system using polarization switchable antenna, in which the polling protocol can decrease the IoT devices' standby power consumption to encounter the requirement of battery life to last longer.

Present 4G network and protocols are incompetent in handling irregular IoT traffic which needs low-latency, low control overhead and low power, to overcome these constraints, Mathur *et* al [20], proposed a design of a PHY/MAC layer using Software Defined Radios (SDRs) that is backward well-matched with present OFDM based LTE protocols and supports CDMA based transmissions for low power IoT devices.

Khalfi *et* al [21], discussed the challenges facing the support of IoTs through 5G systems, in their paper they showed how sparsity can be used for addressing these challenges, specifically in terms of facilitating wideband spectrum management and treatment of the connectivity by exploiting device-to-device communications and edge cloud.

In order to increase large amount of data in massive scale IoT applications, Lei *et* al [22], applied a network coding techniques into Named Data Networking (NDN) so as to improve IoT network throughput and efficiency of content delivery for 5G, they integrated network coding into a NDN streaming media system employed in the ndnSIM simulator and the experimental results undoubtedly and fairly demonstrated that considering network coding in 5G NDN can expressively improve the performance, reliability and QoS of IoT so this method has favorable potentials in delivering developing IoT applications that comprises high-quality streaming video services.

Condoluci *et* al [23], proposed the machine-type multicast service (MtMS), which aim to enable the concurrent transmission of data towards a large set of machine-type communications (MTC) devices enabled in 5G and they then presented the architectural components and the procedures to be accepted by MtMS to reduce or if possible eliminate delay, energy consumption and control overhead in which the efficiency of their proposal has been testified through evaluations piloted by considering LTE-M deployments.

Frame structure and design, which definitely targets the Internet of Things (IoT) establishment in 5G wireless communication systems was presented by Ijaz *et* al [24], they designed a suitable radio numerology which supports the distinctive characteristics, that is, massive connection density and small and bursts packet transmissions with the constraint of low-cost and low complexity operation of IoT devices, their proposed design was validated by link level simulation results to demonstrate that the suggested numerology can survive with transceiver imperfections and channel impairments.

Duan *et* al [25], presented a space-reserved cooperative caching in the 5th generation (5G) mobile heterogeneous networks for Industrial Internet of Things (IIoT), where the caching space in base stations (BSs) is mostly exploited to store the fixed caching data (FCD) pre-fetched from the servers, and the reserved space is to temporarily store the data to be wirelessly transmitted (DWT), they proposed an algorithm to get the optimal fraction between the two parts of the caching space with the aim of reducing the average energy consumption and their simulation results proved that the proposed caching scheme is more effective and efficient than the conventional one with respect to the average energy consumption.

PHY/MAC layer design for CDMA based communication for IoT devices was proposed by Sagari *et* al [26] which expressively reduces the access time for low power underlay CDMA access for IoT devices, their proposed protocol integrates IoT data traffic with legacy system by minimal alteration at the edge network, essentially eNodeB and at the end the underlay CDMA IoT network met IoT data traffic requirements with slight degradation (~ 3%) to the LTE throughput.

A new protocol for the crucial formation without any prior trust association between an UE and a Machine Type Communication (MTC) device, building security from 5G towards the IoT was proposed by Conceicao *et* al [27], the proposed protocol eradicates the need of MTCd or GWs sending data to a server, saving substantial amounts of energy, bandwidth and reducing latency, they also introduced the ProSe standard to improve the coverage of 5G by means of interaction between two UEs, or one UE and a GW and thus proves the security of their solution.

Integrated structure was proposed by Zhang *et* al [28], in order to improve the energy efficiency (EE) performance of fifth generation (5G) Internet of Things systems, for wireless communications, they proposed one cellular partition zooming (CPZ) mechanism and through computer-based simulation results it was found that the proposed scheme display better EE performance.

QoS-aware channel assignment mechanism for smart building with heterogeneous IoT devices was proposed by Hasan *et* al [29], in which they formulated an optimization problem for channel assignment in order to maximize the utility of IoT devices while sustaining the data rate, latency, and bit error rate (BER) requirements, their simulation results showed that the approach is quite efficient and operative in assigning the channels to each link in terms data rate, latency, and BER requirements.

The optimal use of resources of heterogeneous networks 4G/5G in terms of M2M/IoT traffic growth, which takes into account the requirements of QoS was proposed by Klymash *et* al [30], in which the schedulers on the base station must determine the optimal radio resource allocation approach based on the stated requirements for bandwidth and parameters of H2H users and M2M devices.

Non-orthogonal multiple access (NOMA) was proposed by Shirvanimoghaddam *et* al [31], as the potential multiple access technology for upcoming cellular systems to house the incredible growth of M2M applications and traffic. Massive NOMA offers high throughput efficiency with simple system structure, which is predominantly valuable for massive IoT applications with low-cost, low-power, and low-complexity devices, and can afford system scalability to support the huge number of devices involved in M2M communications.

Yerrapragada *et* al [32], introduced an IoT architecture capable of 5G interference alignment and a spatial dimensioning algorithm that accounts for estimation error in the 5G channel state associated with interference cancellation in which a self-organizing Internet of Things (IoT) network infrastructure for protecting the future 5G communication system network from self-induced co-channel interference was introduced in the such architecture.

The METIS 5G system idea consists of three general 5G services and four mojor enablers, the three general 5G services were mentioned as Extreme Mobile BroadBand (xMBB), Massive Machine-Type Communications (mMTC), and Ultra-reliable Machine-Type Communication (uMTC) while the four major enablers are Lean System Control Plane (LSCP), Dynamic RAN, Localized Contents and Traffic Flows, and Spectrum Toolbox all these to support the concept of IoT [33].

III. 5G ENHANCEMENT FOR IoT REQUIREMENTS DESIGN

For the purpose of ensuring IoT enabled computer based devices are able to interact with each other and with efficient connectivity, there are some requirements that are needed for deployments of IoT applications in such devices for example the devices must have low device cost, extended coverage area, low deployment cost, support for huge number of connected devices, low power, and security and privacy as discussed below.

i. Low power

Machine-to-machine (M2M) communications have an extensive range of features and requirements like high data rates, low latency, and cost effective that differs substantially from those of human-centric communication so they need to use low amount of power in order to stay connected for long time or in other words the battery usage must be designed to last longer this is because IoT which most of them are battery powered are anticipated to be in operational for a long time without any human interference.

So in designing the hardware and software of IoT devices, energy efficiency must be given the first priority even though there are some medium access control (MAC) protocols which allows the radio to be sleep mode (i.e. low power mode) for the times when they are not anticipating to receive data, and hence extend battery life.

ii. Low Device Cost

The major requirement for supporting IoT is the availability of low device cost which implies that reduction in the device complexity will be a key enabler for massive-volume, mass-market applications, which will therefore allow most of the IoT applications. Because as the design and manufacturing complexity increases also the cost of manufacturing becomes very high so this will cause the IoT enabled devices to be very expensive.

iii. Low cost of deployment

Using software upgrades on current cellular networks to integrate IoT connectivity solution will at first reduce the whole cost of new hardware and site planning but later on launching the 5G, the initial deployment cost is expected to go high but thereafter it must be reduced to the best minimum in order to deploy massive IoT applications.

So it is vital to reduce the infrastructure cost in addition to the costs associated with their deployment, management, and operation in order to make connectivity a globally accessible, reasonable, and maintainable utility.

iv. Extended Coverage area

Another major requirements for 5G enhancement for IoT will be to provide connectivity for 300,000 devices within one cell and at any time, this can be achieved only if more BSs are deployed within one cell that is to say there may be macro cell covering the devices as well as micro or pico- cell all covering those devices, so the simple term to use here is that there must be designed the structure which will provide the coverage of a cell within the cell and hence the term extended coverage.

v. Support for Huge Number of Devices

5G networks is required to provide multiple streams to multiple users concurrently and they also required to support a variety of different applications with numerous delay and bit rate requirements because it has been predicted that by

International Journal of Academic Multidisciplinary Research (IJAMR)
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Vol. 2 Issue 11, November – 2018, Pages: 65-78

2020, the number of connected smart devices will reach around five billion in an IoT technologies. This tells us that some sectors will have massive number of smart devices connected.

vi. Ensuring the Security and Privacy

For an efficient and effective deployment of IoT in 5G security of the user data should be given first priority as because most of the time the communications will be between machines some hackers may hack the information and use them for their benefits, also the privacy of mobile user real identity must be kept and respected.

IV. ENABLING TECHNOLOGIES OF 5G FOR IoT.

5G is a major enabler for IoT because of the disruptive enhancements in the radio and antenna systems, spectrum, and network architecture because of its capacity to supports the need of high density of devices based on use of small cell configurations and access based on varying types of technologies [34].
Cellular networks standards are today adding techniques to increase network performance in order to address traffic patterns produced by an increasing number of IoT devices and this mostly have led to an ongoing considerations around 5G requirements that may become the changing scenario for M2M communications since the standard will be designed, for gigantic scale IoT deployments.
The major requirements considered for 5G networks technology for IoT applications are [29]:

- It need to support huge number of connected IoT devices
- It need to support wide range of IoT applications, services, and users
- It need to guarantee lengthy battery life of IoT devices by keeping energy usage very low
- It need to guarantee coverage of IoT services in challenging locations such as vaults
- It need to be spectrum efficient by exploiting all available attached spectrum

There are numerous opportunities to improve the network capacity, for instance, by using advanced receiver techniques, new cooperative multipoint transmissions schemes, inventive multi-antenna solutions, and lastly, an effective and broad placement of heterogeneous networks (HetNets).
In order to accommodate IoT services the 5G technology must design a new air interface that does not only deal with heterogeneous traffic categories, (e.g., massive sporadic machine-type traffic, real-time mobile traffic) but also to attain ultra-low latency and ultra-reliable mission critical communication [35].
3D-MIMO will be integrated at BSs to improve the data rate and the capacity at the macro-cell level, also the system performance in terms of coverage, capacity and EE will be also improved in dead and hot spots using relay stations, hyper-dense small-cell deployments or WiFi offloading; directional mm-Wave links will be deployed for backhauling the relay and/or small-cell BSs [36, 37].

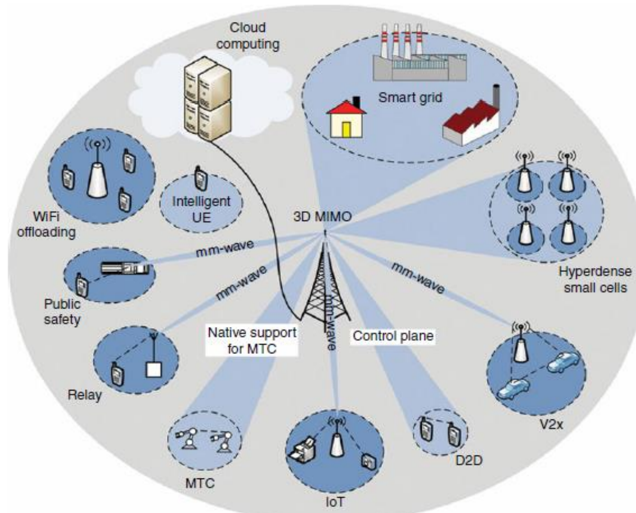

Figure 6: Showing the system architecture of the applications to be deployed in 5G [36, 37].

5G technology will be centered on new methods of modulation and transmission that will sufficiently increase the spectral efficiency compared with 4G networks and guarantee data transfer speed of more than 10 Gb/s and to provide such amount of data transfer speed in 5G technology, the use of broadband channels in the downlink (DL), and in the uplink (UL) with a continuous spectrum width of 500 to 1000 MHz will be required and it is observed that the amount of spectrum will be 25–50 times broader than the channels width used in 4G [38].

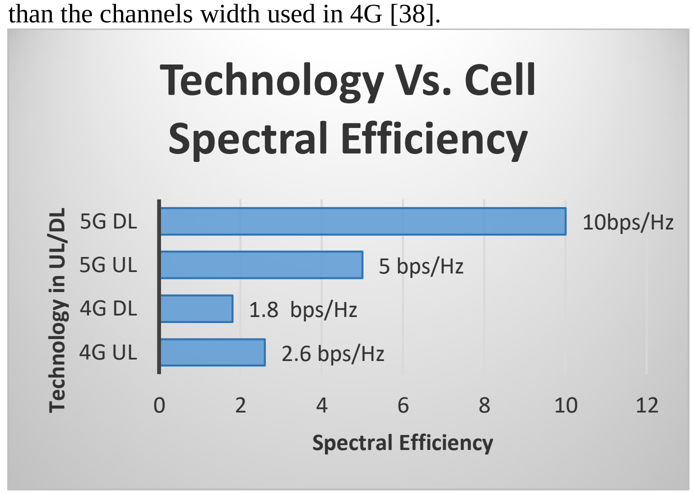

Figure 7: Showing the Cell spectral efficiency improvements from 4G technology to 5G technology [38].

International Journal of Academic Multidisciplinary Research (IJAMR)
ISSN: 2000-006X
Vol. 2 Issue 11, November – 2018, Pages: 65-78

From figure 6, it can be easily seen that there is an improvement in cell spectral efficiency for example in 4G technology for the case of uplink the SE was observed to be 2.6 bps/Hz but in 5G the SE will be 5bps/Hz it means more than 2.4 bps/Hz SE improvement which easily attracts more services to be deployed in 5G networks with high quality of services.

To achieve the above requirements the following technologies are highly suggested:

i. Massive MIMO

The use of massive MIMO antenna technology will enable most of the factors required for 5G to be easily solved. In Massive MIMO multiple antennas are used to transmit and receive data in the number of BS antennas and the number of users are very large (This feature of having a large number of antennas at the base station (BS) makes the massive MIMO to increase the network capacity and density).

Massive MIMO (also known as Large-Scale Antenna Systems, Very Large MIMO) consists of a very large number of service antennas (e.g., hundreds or thousands) that are operated fully coherently and adaptively, the additional antennas help to direct the transmission and reception of signal energy into even-smaller region of space by doing so they bring massive enhancements in throughput and energy efficiency, particularly when combined with simultaneous scheduling of a large number of receiver (user) terminals (e.g., tens or hundreds), it was originally intended for time division duplex (TDD) operation, but now it can potentially be applied also in frequency division duplex (FDD) operation [39].

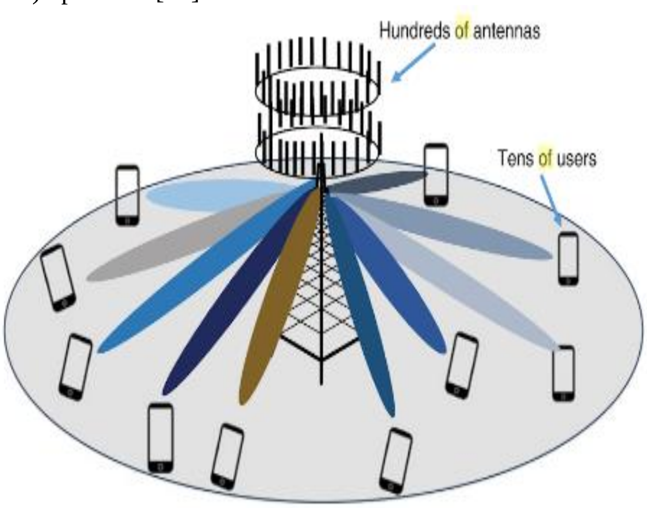

Figure 8: Massive MIMO illustrations [40].

When the resources are spatially shared, the resulting interference can be removed using pre-coders such as vector perturbation and lattice-aided approaches, and decoders like successive interference cancellation, which brings diversity per link and deliver the degrees-of-freedom (DoF) [41]. For Massive MIMO, there are three main linear detectors/decoders which are: Maximum ratio combining (MRC), zero-forcing (ZF) and Minimum mean squared error (MMSE) combining that are capable of dealing with interference and ensuring good reliability of data.

It is well known that Massive MIMO technology can provide an enhanced spectral and energy efficiency, also it can ensure maximum achievable capacity owing to both array gains and diversity effects which in turn is the main requirement of 5G technology to accommodate various applications including IoT .

By using simple linear detectors and receivers in Massive MIMO, it can be observed that as the number of BS antennas M grows without bound, the transmitted power of each user is reduced proportionally to $1/M$ if the BS has perfect channel state information (CSI), and proportionally to $1/\sqrt{M}$ if CSI is estimated from uplink pilots, also for low transmit power spectral-efficiency and energy-efficiency can be increased simultaneously under imperfect CSI and this is one of the major requirement of 5G to support IoT.

Consider the system that includes one BS equipped with an array of M antennas that receives data from K single-antenna users. The $M \times 1$ received vector at the BS is [42]:

$$y = \sqrt{\rho_U}\, Gx + n$$

Where G represents the $M \times K$ channel matrix between the BS and the K users, i.e $g_{mk} \triangleq G_{mk}$ the channel coefficient between the mth antenna of the BS and the kth user; $\sqrt{\rho_u}\, x$ is the $K \times 1$ vector of symbols concurrently transmitted by the K users (the average transmitted power of each user is ρ_u); and n is a vector of additive white, zero-mean Gaussian noise.

The channel matrix G models independent fast fading, geometric attenuation, and log-normal shadow fading. The coefficient g_{mk} can be written as:

$$g_{mk} = h_{mk}\sqrt{\beta_k}$$
$$m = 1, 2, \dots, M$$

h_{mk} is a fading factor from the kth user to the mth antenna of the BS, $\sqrt{\beta_k}$ models geometric attenuation and shadow fading which is assumed to be independent over m and to be constant over many coherence time intervals and known a priori.

Assuming that the distance between the users and the BS is much larger than the distance between the antennas, and the value of β_k changes very slowly with time then,

$$G = HD^{1/2}$$

Where H is the $Mx\ K$ matrix of fast fading coefficients between the K users and the BS, i.e., $[H]_{mk} = h_{mk}$ and D is a $Kx\ K$ diagonal matrix, where $[D]_{mk} = \beta_k$. Therefore equation $y = \sqrt{\rho_U}\, Gx + n$ can be written as:

$$y = \sqrt{\rho_U}\, HD^{1/2}x + n$$

Assuming there is no path loss and shadowing factors in D. This channel can offer a sum-rate of

$$R = \sum_{k=1}^{K} \log_2(1 + \rho_u \lambda_k^2)$$

International Journal of Academic Multidisciplinary Research (IJAMR)
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Vol. 2 Issue 11, November – 2018, Pages: 65-78

where ρu is the power spent per terminal and $\{\lambda_k\}_{k=1}^{K}$ are the singular values of H, see [13]. If the channel matrix is normalized such that $|H_{ij}| \sim 1$ (where $\sim$ means equality of the order of magnitude), then

$$\sum_{k=1}^{K} \lambda_k^2 = \|H\|^2 \approx M.$$

Under this constraint the rate R is bounded as
$log2\ (1 + MKpu) \le R \le K\ log2\ (1 + Mpu)$
Which means that the capacity or sum rate of Massive MIMO increases as the number of base stations antennas or users increases.
By considering the case when the BS has perfect CSI, i.e. it knows G. Let A be an $M \times K$ linear detector matrix which depends on the channel G. By using the linear detector, the received signal is separated into streams by multiplying it with A^H as follows

$r = A^H y$ but $y = \sqrt{\rho_U} G x + n$
We consider three conventional linear detectors MRC, ZF, and MMSE, i.e.

$$A = \begin{cases} G & for \quad MRC \\ G(G^H G)^{-1} & for \quad ZF \\ G\left(G^H G + \frac{1}{p_u} I_k\right)^{-1} & for \quad MMSE \end{cases}$$

$$r = \sqrt{p_u} A^H G x + A^H n.$$

Let r_k and x_k be the kth elements of the $K \times 1$ vectors r and x, respectively. Then,

$$r_k = \sqrt{\rho_U} a_k^H G x + a_k^H n = \sqrt{\rho_U} a_k^H g_k x_k + \sqrt{\rho_U} \sum_{i=1, i \ne k}^{K} a_k^H g_i x_i + a_k^H n$$

where a_k and g_k are the k_{th} columns of the matrices A and G, respectively. For a fixed channel realization G, the noise-plus-interference term is a random variable with zero mean and variance

$$\rho_U \sum_{i=1, i \ne k}^{K} |a_k^H g_i|^2 + \|a_k\|^2$$

For an ergodic channel with a large number of realizations of the fast fading factor of G, the achievable capacity or rate is given by

$$C = \log_2\left(1 + \frac{Received\ signal\ power}{(Interference\ power + Noise\ power)}\right)$$

$$C = \log_2\left(1 + \frac{\rho_U |a_k^H g_k|^2}{\left(\rho_U \sum_{i=1, i \ne k}^{K} |a_k^H g_i|^2 + \|a_k\|^2\right)}\right)$$

Ergodic rate is then given by: $R_k = E\{C\}$ where E[43] means expectation or mean of something.

$$R_k = E\left\{\log_2\left(1 + \frac{\rho_U |a_k^H g_k|^2}{\left(\rho_U \sum_{i=1, i \ne k}^{K} |a_k^H g_i|^2 + \|a_k\|^2\right)}\right)\right\},$$

this equation indicates the ergodic rate which can be also taken as the average of the capacity obtained after transmission in the uplink and hence in one way or another massive MIMO can enhance the applications of IoT in 5G.
The performance of 5G or quality of services can be clearly explained in terms of spectral efficiency and sometimes throughput and it has been observed that the improved spectral efficiency of 5G networks can be achieved by using non-orthogonal access methods in radio access networks and by using non-orthogonal signals [44].

$$S.E^{UL} = \partial^{UL}\left(1 - \frac{B}{S}\right) E\{log_2(1 + SINR^{UL})$$

$S.E^{DL} = \partial^{DL}\left(1 - \frac{B}{S}\right) E\{log_2(1 + SINR^{DL})$ For single user in the cell
Where B is the number of symbols in a data frame, S is the coherence block length respectively, ∂^{UL} is the fractional of uplink transmission and ∂^{DL} is the fraction for downlink transmission, $S.E^{UL}$ is the spectral efficiency in the uplink and $S.E^{DL}$ is the spectral efficiency in the downlink, For K users in the same cell, the $S.E$ is given by

$$S.E^{UL} = \partial^{UL} K\left(1 - \frac{B}{S}\right) E\{log_2(1 + SINR^{UL})$$

$$S.E^{DL} = \partial^{DL} K\left(1 - \frac{B}{S}\right) E\{log_2(1 + SINR^{DL})$$

The total spectral efficiencies is given by $S.E = S.E^{UL} + S.E^{DL}$ but $\partial^{UL} + \partial^{DL} = 1$

$$S.E = \partial^{UL} K\left(1 - \frac{B}{S}\right) E\{log_2(1 + SINR^{UL}) + \partial^{DL} K\left(1 - \frac{B}{S}\right) E\{log_2(1 + SINR^{DL})$$

$S.E \approx K\left(1 - \frac{B}{S}\right) E\{log_2(1 + SINR)\}$ for finite and asymptotic analysis approximations.

$$S.E \approx K\left(1 - \frac{B}{S}\right) E\{\log_2\left(1 + \frac{\rho_U |a_k^H g_k|^2}{\left(\rho_U \sum_{i=1, i \ne k}^{K} |a_k^H g_i|^2 + \|a_k\|^2\right)}\right)\}$$

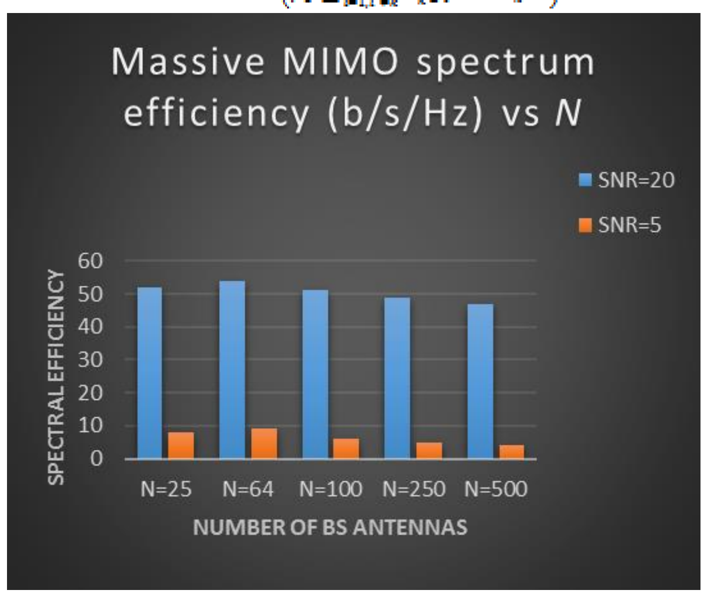

Figure 9: Massive MIMO spectral efficiency with the number of BS antennas [45], adopted from [37].

International Journal of Academic Multidisciplinary Research (IJAMR)
ISSN: 2000-006X
Vol. 2 Issue 11, November – 2018, Pages: 65-78

In figure 8, it can be observed that not only increasing the number of BS antennas improves the spectral efficiency but also apart from adding more numbers of antennas, other factors must also be taken into considerations like propagation path loss coefficients, modulation techniques, number of receiving terminals, signal to noise ratio and many other factors.

So in massive MIMO through beamforming it is possible to improve both the data rates and capacity because multiple antenna elements are used to form narrow beams which are directed to the specific receiving antenna also through spatial multiplexing it is possible to improve the capacity because propagation features are exploited to deliver multiple data streams concurrently to one or more terminals [46].

ii. Exploiting the extremely high frequency (EHF) or very high frequency (VHF)

The bandwidth scarcity facing wireless carriers globally due to the rapid growth of mobile data and high-speed communication requirements has driven the exploration of the Extremely high frequency (EHF) frequency spectrum/bandwidth (30 GHz–300 GHz) that lies between the microwaves and the infrared waves [47].

5G networks are anticipated to be motivated by the enlarged wireless capacity and speeds obtainable by high-frequency millimeter waves. To have high-speed wireless broadband communications, the antennas must have short wavelengths that range from 10 millimeters to 1 millimeter and this is obtained when the spectrum/bandwidth is extremely very high. In telecommunication this is known as millimeter wave (mm Wave) and is used for diversity of services on mobile and other wireless network services, as it provides higher data rates up to 10 Gbps.

The two main noticeable features of the millimeter-wave bands are hefty amounts of bandwidth, allowing very high in coverage throughput, and very small wavelengths allowing a large number of tiny antennas in a given device area [48].

In mm Wave higher -bandwidth point-to-point communication links are used and they range from 71 Ghz to 76 Ghz, 81 Ghz to 86 Ghz and 92 Ghz to 95 Ghz [49].

At higher bandwidth with smaller wavelengths, a smaller received power can be anticipated and this is well explained by Friis' equation in which the received power always decreases with the square of frequency and it is given as [50]:

$$P_r = \frac{P_t G_t G_r c^2}{(4\pi)^2 r^2 f^2}$$

Where P_r is the received power, P_t is the power transmitted, G_t is the gain of the transmitter, G_r is the gain of the receiver, r is the distance between the transmitter and the receiver and f is the frequency.

The free space path loss (FSPL) which is the loss in signal strength of a signal as it moves from one transmit antenna to receive antenna through free space, may be experienced on the way.

$$FSPL = 20\log_{10}(r) + 20\log_{10}(f) + 20\log_{10}\left(\frac{4\pi}{c}\right) - G_t - G_r$$

From the Friis' equation, it can be easily seen that the received power may be minimal due to high frequency but since in mm-Wave antenna the number of packed antennas may be extremely large due to the fact that the spacing between one antenna and the other is small so it is possible to accommodate a large number of antennas and thus making the substantial antenna gain to be large.

From $\lambda = \frac{c}{f}$ where λ wavelength, c is speed of light waves and f is the frequency, the spacing between one antenna and the other is given by $spacing = \frac{\lambda}{2}$

So increasing the frequency as in the case of mm-Wave, will decrease the spacing between one antenna and another because $spacing \propto \frac{1}{f}$ and thus allowing more packaging of antennas either in ULA or UCA.

When joined with massive MIMO, mm-Wave transmissions are extremely directional and this brings much higher array again and hence improvements in capacity.

iii. Dense small cells

It is understood that small cells will play a very significant part in 5G to encounter the 5G necessities in traffic volume, frequency efficiency, and energy and cost reduction which then will make the deployment of IoT applications to be easy because IoT needs a lot of data volume[51].

Small cells are low-power wireless access points (AP) that operates in licensed spectrum and provide an enhanced cellular coverage, capacity and applications for households and enterprises, they are usually controlled by an operator of the given spectrum.

Densifying the number of wireless nodes is another way of improving the network density and throughput, because with small cells, the size of the cell is reduced which means that the users are now closer to the network they are being served with (and the coverage are in the range of 10m to 100m).

So the higher number of low-powered transmission allows better use of presented frequency resources and hence improvement of spectral efficiency. In increasing the level of network capacity, 5G networks will be built in heterogeneous networks (HetNets) manner in which the macro and small cells will be located and sometimes they may be connected to one another and this makes small cells to be an important component of Heterogeneous Networks (HetNets), with the purpose of delivering higher capacity and improved spectrum efficiency.

According to Bhushan *et* al [48], spatial densification is obtained by increasing the number of antennas per node (user device and base station), and increasing the density of base stations installed in the given geographic area, while also guaranteeing nearly uniform distribution of users among all base stations.

In order to support current IoT requirements, like very low latency and high reliability that are not certainly supported by current networks, operators are progressively investing to improve network capability and optimize its usage by installing more localized capacity, in the form of small cells (e.g., pico and femto cells and remote radio units, RRUs, that are connected to centralized baseband units by optical fiber) to improve capacity [52].
For the dense small networks the total system capacity is given by the following formula [53]:

$$C_{sum} = \sum_{Small\ cells} \sum_{Channels} (B_i log_2 (1 + \frac{P_i}{N_p}))$$

Where B_i is the bandwidth of the ith channel, P_i is the signal power of the ith channel, and N_p denotes the noise power.
So in order to increase the total capacity of the system, someone can increase the network coverage (via heterogeneous networks with macro-cells, microcells, small cells, relays, MFemto-cell as shown in the equation above [54].

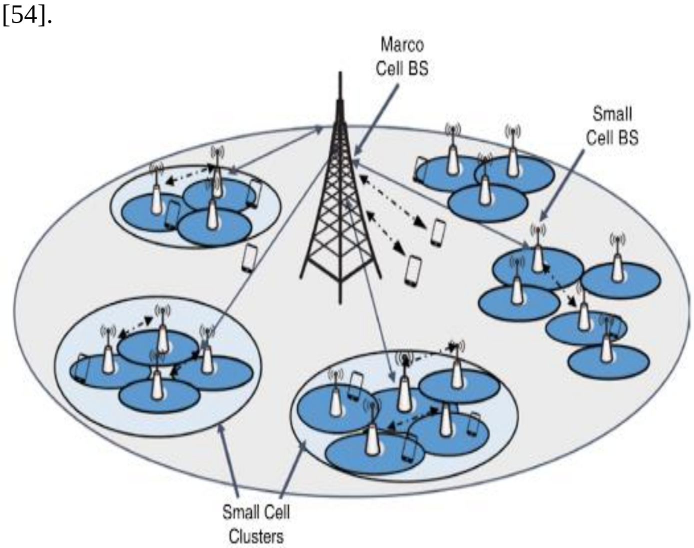

Figure 10: Small cells diagram as seen the macro BS is serving the UE but those UEs which are within the small cell clusters are being served by AP covering the region in which the UE is currently in [40].

V. CHALLENGES FACING THE DEPLOYMENT OF MASSIVE MIMO, MM-WAVE AND DENSE SMALL CELLS FOR 5G

In employing massive MIMO antenna and millimeter-wave communication technologies, the small cells are expected to deliver more than 1 Gb/s throughput in 5G ultra-dense cellular networks but there is the backhaul network capacity that will be a bottleneck making the small cell densification in such kind of cellular network and according to [55], the backhaul network capacity is given by:

$$Backhaul\ network\ capacity = \frac{Y_{(n)} \times W}{K_{(n)}}$$

where $Y_{(n)}$ is the average number of concurrent transmissions in macro cell, W is the transmission rate of a small BS and $K_{(n)}$ is the average hop number of backhaul traffic in the cell, n is the number of small cell BSs in a macro cell.
Not only backhaul network capacity brings bottleneck in small cell densification but also backhaul energy efficiency which is given by:

$$Backhaul\ energy\ efficiency = \frac{Backhaul\ network\ capacity}{n \times (small\ cell\ BS\ backhaul\ energy\ consumptions}$$

So knowing the backhaul network capacity and energy efficiency for 5G will provide a guideline for designing the densification of 5G ultra-dense cellular networks.
Modeling of the locations of the nodes in the network is another challenge facing ultra-dense small networks because it is very difficult to determine the position deterministically.
The major challenges for millimeter-waveband communications comprises large path loss (especially with non-line-of-sight, NLoS, propagation), signal blocking/absorption by various objects in the environment, and low transmission power capability of current millimeter-wave-band amplifiers, the following propagation path loss models were derived by different scholars depending on the propagation environments:
Shu et al [56], proposed two propagation path loss models which are alpha-beta-gamma model and the model that is close to that of the free space path loss model,
In alpha-beta-gamma path loss model the following equation govern the model

$$PL = 10\alpha \log_{10}(\frac{d}{d_0}) + \beta + 10\gamma \log_{10}(\frac{f}{f_0}) + x_\sigma$$

Where: $PL = the\ path\ loss\ in\ dB\ over\ frequency\ and\ distance$
$\alpha =$ coefficient showing the dependence of path loss on distance

$\gamma =$
coefficient showing the dependence of path loss on frequency

$\beta =$ optimized offset value for path loss in dB ,
$d =$ distance separating transmitte and receiver
$f =$ carrier frequency , $f_0 = 1GHz$ reference frequency
$x_\sigma = \log -$ normal random shadowing variable
In model close to that of free space path loss model, is governed by the following equation:
$PL = FSPL + 10n \log_{10}(d) + x_\sigma$ Where
$FSPL = free\ space\ path\ loss\ model$ and
$n = single\ model\ parameter$
The model close to that of free space model showed almost the same results in both LOS and NLOS propagation environments as compared to Alpha-Beta-Gamma model in which their results deviated between LOS and NLOS.
Inomata *et* al [57], proposed a path loss model which covers a large range of frequency and for the case of analysis they used measurements obtained in street micro-cell environments covering the range of frequency between 2GHz up to 37GHz and the propagation model was:

$$P_L = \beta_{constant} + (\alpha_f log_{10}(f) + C_f)(\alpha_d log_{10}(d) + C_d)$$

Where:

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P_L = path loss
f = frequency of the carrier in MHz
d = distance in metres ,$\beta_{constant}$, α_f , α_d, C_f and C_d are parameters calculated as $\beta_{constant} = 4.15$ $\alpha_f = 1.41$, $\alpha_d = 0.79$, $C_f = -7.82$ and $C_d = 1$
This model was found to cover both in LOS and NLOS micro-cell environment model in the frequency range of 2 – 37GHz.
Sulyman *et* al [58], proposed a simple path loss models for LOS and NLOS derived from Stanford University Interim (SUI) that are suitable for cellular planning within the 28 and 38 GHz bands:
For NLOS propagation environments the path loss equation is given by

$$P_L = \alpha_{NLOS}(P_{L_{SUI}}(d) - P_{L_{SUI}}(d_0)) + FSLP(d_0) + x_\sigma$$

Where
$P_{L_{SUI}}(d) = SUI\ path\ loss\ at\ distance\ d$
$P_{L_{SUI}}(d_0) = SUI\ path\ loss\ at\ reference\ distance\ d_0 = 1m$

For LOS propagation environments the path loss equation is given by

$$P_L = \alpha_{LOS}\left(FSLP(d) - FSLP(d_0)\right) + FSLP(d_0) + x_\sigma$$

Where α_{LOS} and α_{NLOS} are the average slope correction factors taken directly from empirical results. The overall results showed that the results obtained from this model were found to match that from real measurements.
Rangan *et* al [59] pointed the following as the main challenges facing mm-Wave technology:

- Range and directional communication: the reliance on extremely directional transmissions will necessitate certain design changes to current cellular systems.
- Shadowing: materials such as brick can weaken signals by as much as 40 – 80 dB
- Rapid channel fluctuations and intermittent connectivity: From a systems viewpoint, this indicates that connectivity will be extremely intermittent and communication will need to be quickly adaptable.
- Multiuser coordination: for massive spectral efficiency, cellular systems need concurrent transmissions on multiple interfering links, and new mechanisms will be required to coordinate these transmissions in mm-Wave networks.
- Processing power consumption: A/D converters at rates of 100 Ms/s at 12 b and 16 antennas would require more than 250 mW, a substantial drain for current mobile devices.

So challenges like channel characterization, NLOS connectivity conditions and coverage (and mobility) problems needs to be addressed before the effective deployment of mm-Wave in 5G technology.
For massive MIMO, the following challenges will be an obstacle to implement 5G for IoT accommodation:

Propagation Models

There is substantial performance degradation for the case of closely spaced users with a Line of Sight (LOS) path to the BS for various system settings in which instead of achieving 80–90% of the best dirty paper coding (DPC) bound, the performance was found to drop to about 55% [60].

Pilot Contamination

Pilot contamination causes focused inter-cell interference which tends to grow together with the number of BS antennas and considerably damaging the system performance because the antenna receives the signals which was intended to be received from another transmitting equipment.

Hardware Impairments

Hardware impairments can cause the channel estimation error and a capacity ceiling which eventually will impact the spectral efficiency and usually the user impairments is more serious than the BS side.

VI. DISCUSSION AND OBSERVATIONS

In 5G enabling technologies which involves Massive MIMO, mm-Wave and dense small cells, it has been observed that each technology play an important role in order to enable the IoT applications to be effectively integrated in 5G networks in the sense that, Massive MIMO offers interference suppression and spatial multiplexing thus providing high array gain at the same time reducing total transmit power by deploying massive number of antennas which uses very low transmit power, mm-Wave offers underutilized large bandwidths like the bandwidths in the range of 30GHz – 300GHz which were not being used, will start to be used in order to accommodate the growing number of interacting devices, while dense small cells reduce link distances and alleviate coverage holes in the deployment area.

VII. CONCLUSSION AND FUTURE WORK

Integrating IoT applications into 5G networks are now becoming the area of research interest and this requires a wisdom of determination to bring new innovative and inventive new technologies to reality. Mm-Wave technology were perceived provide a lot benefits in terms of high spectrum provision to enable those IoT applications to be easily integrated into 5G but they are now considered not to be capable to handle this alone anymore as it was pointed out in the challenges facing mm-Wave technology above.

A comprehensive review of the schemes used to deploy IoT applications in 5G networks have been described in this article and it come out with an observation that combining all three technologies (massive MIMO, mm-Wave and dense small networks) will ultimately make integration of IoT services in 5G technology to be easy, because mm-Wave technology provides gigantic bandwidth (which can accommodate a large number of applications) and hence high data rates, massive MIMO provides an enhanced capacity and energy efficiency by using an array gain where also spatial multiplexing was found to prevent the path loss, and the deployment of dense small cells in 5G technology were found to improve the SINR together with network capacity (because capacity in dense small is proportional to the number of nodes) and spectral efficiency and by lowering its transmission power, the battery life of the IoT devices will last longer.

Despite all the benefits of deploying the above technologies in 5G networks in order to house the IoT applications there are some challenges as depicted in this paper which needs to be overcame before the official launching of 5G in the year 2020, so the authors recommends those challenges to be an area of future research in these technologies.

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REFERENCES

[1] S. Li, L. Da Xu, and S. Zhao, "5G internet of things: A survey," *Journal of Industrial Information Integration,* 2018.
[2] C. X. Mavromoustakis, G. Mastorakis, and J. M. Batalla, *Internet of Things (IoT) in 5G mobile technologies* vol. 8: Springer, 2016.
[3] M. Chiang, B. Balasubramanian, and F. Bonomi, *Fog for 5G and IoT*: John Wiley & Sons, 2017.
[4] Wikipedia. (2018). *Internet of things*. Available: https://en.wikipedia.org/wiki/Internet_of_things
[5] G. A. Akpakwu, B. J. Silva, G. P. Hancke, and A. M. Abu-Mahfouz, "A survey on 5G networks for the internet of things: communication technologies and challenges," *IEEE Access,* vol. 6, pp. 3619-3647, 2018.
[6] S. Madakam, R. Ramaswamy, and S. Tripathi, "Internet of Things (IoT): A literature review," *Journal of Computer and Communications,* vol. 3, p. 164, 2015.
[7] V. Sharma, F. Song, I. You, and M. Atiquzzaman, "Energy efficient device discovery for reliable communication in 5G-based IoT and BSNs using unmanned aerial vehicles," *Journal of Network and Computer Applications,* vol. 97, pp. 79-95, 2017.
[8] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, "Internet of Things (IoT): A vision, architectural elements, and future directions," *Future generation computer systems,* vol. 29, pp. 1645-1660, 2013.
[9] P. Moby, K. Athira Krishna, C. Axamol Charly, and P. Sreeshma, "Enhancement of Channel Potential and Spectral Efficiency using Hyper-MIMO In 5G."
[10] C. V. N. Index, "Cisco visual networking index: global mobile data traffic forecast update, 2014–2019," *Tech. Rep,* 2015.
[11] N. Saxena, A. Roy, B. J. Sahu, and H. Kim, "Efficient IoT gateway over 5G wireless: A new design with prototype and implementation results," *IEEE Communications Magazine,* vol. 55, pp. 97-105, 2017.
[12] S. K. Goudos, P. I. Dallas, S. Chatziefthymiou, and S. Kyriazakos, "A Survey of IoT Key Enabling and Future Technologies: 5G, Mobile IoT, Sematic Web and Applications," *Wireless Personal Communications,* vol. 97, pp. 1645-1675, 2017.
[13] A. Markhasin, V. Belenky, V. Drozdova, A. Loshkarev, and I. Svinarev, "Cost-effective ubiquitous IoT/M2M/H2H 5G communications for rural and remote areas," in *Information Science and Communications Technologies (ICISCT), International Conference on*, 2016, pp. 1-8.
[14] R. Muñoz, R. Vilalta, R. Casellas, A. Mayoral, and R. Martínez, "Integrating optical transport network testbeds and cloud platforms to enable end-to-end 5G and IoT services," in *Transparent Optical Networks (ICTON), 2017 19th International Conference on*, 2017, pp. 1-4.
[15] R. T. Tiburski, L. A. Amaral, and F. Hessel, "Security Challenges in 5G-Based IoT Middleware Systems," in *Internet of Things (IoT) in 5G Mobile Technologies*, ed: Springer, 2016, pp. 399-418.
[16] A. Ö. Ercan, O. Sunay, and I. F. Akyildiz, "RF energy harvesting and transfer for spectrum sharing cellular IoT communications in 5G systems," *IEEE Transactions on Mobile Computing,* 2017.
[17] J. Cheng, L. Da Xu, W. Chen, F. Tao, and C.-L. Lin, "Industrial IoT in 5G Environment towards Smart Manufacturing," *Journal of Industrial Information Integration,* 2018.

[18] M. Series, "IMT Vision–Framework and overall objectives of the future development of IMT for 2020 and beyond," 2015.

[19] Y.-H. Lee, A.-S. Wang, Y.-D. Liao, T.-W. Lin, Y.-J. Chi, C.-C. Wong, *et al.*, "Wireless power IoT system using polarization switch antenna as polling protocol for 5G mobile network," in *Wireless Power Transfer Conference (WPTC), 2017 IEEE*, 2017, pp. 1-3.

[20] S. Mathur, S. S. Sagari, S. O. Amin, R. Ravindran, D. Saha, I. Seskar, *et al.*, "Demo abstract: CDMA-based IoT services with shared band operation of LTE in 5G," *arXiv preprint arXiv:1705.06968,* 2017.

[21] B. Khalfi, B. Hamdaoui, and M. Guizani, "Extracting and exploiting inherent sparsity for efficient IoT support in 5G: Challenges and potential solutions," *IEEE Wireless Communications,* vol. 24, pp. 68-73, 2017.

[22] K. Lei, S. Zhong, F. Zhu, K. Xu, and H. Zhang, "A NDN IoT Content Distribution Model with Network Coding Enhanced Forwarding Strategy for 5G," *IEEE Transactions on Industrial Informatics,* 2017.

[23] M. Condoluci, G. Araniti, T. Mahmoodi, and M. Dohler, "Enabling the IoT machine age with 5G: Machine-type multicast services for innovative real-time applications," *IEEE Access,* vol. 4, pp. 5555-5569, 2016.

[24] A. Ijaz, L. Zhang, M. Grau, A. Mohamed, S. Vural, A. U. Quddus, *et al.*, "Enabling massive IoT in 5G and beyond systems: PHY radio frame design considerations," *IEEE Access*, vol. 4, pp. 3322-3339, 2016.

[25] P. Duan, Y. Jia, L. Liang, J. Rodriguez, K. M. S. Huq, and G. Li, "Space-Reserved Cooperative Caching in 5G Heterogeneous Networks for Industrial IoT," *IEEE Transactions on Industrial Informatics,* 2018.

[26] S. S. Sagari, S. Mathur, D. Saha, S. O. Amin, R. Ravindran, I. Seskar, *et al.*, "Realization of CDMA-based IoT Services with Shared Band Operation of LTE in 5G," in *Proceedings of the Workshop on Mobile Edge Communications*, 2017, pp. 37-42.

[27] F. Conceicao, N. Oualha, and D. Zeghlache, "Security establishment for IoT environments in 5G: Direct MTC-UE communications," in *Personal, Indoor, and Mobile Radio Communications (PIMRC), 2017 IEEE 28th Annual International Symposium on*, 2017, pp. 1-5.

[28] D. Zhang, Z. Zhou, S. Mumtaz, J. Rodriguez, and T. Sato, "One integrated energy efficiency proposal for 5G IoT communications," *IEEE Internet of Things Journal,* vol. 3, pp. 1346-1354, 2016.

[29] N. ul Hasan, W. Ejaz, I. Baig, M. Zghaibeh, and A. Anpalagan, "QoS-aware channel assignment for IoT-enabled smart building in 5G systems," in *Ubiquitous and Future Networks (ICUFN), 2016 Eighth International Conference on*, 2016, pp. 924-928.

[30] M. Klymash, H. Beshley, O. Panchenko, and M. Beshley, "Method for optimal use of 4G/5G heterogeneous network resourses under M2M/IoT traffic growth conditions," in *Information and Telecommunication Technologies and Radio Electronics (UkrMiCo), 2017 International Conference on*, 2017, pp. 1-5.

[31] M. Shirvanimoghaddam, M. Dohler, and S. J. Johnson, "Massive non-orthogonal multiple access for cellular IoT: Potentials and limitations," *IEEE Communications Magazine,* vol. 55, pp. 55-61, 2017.

[32] A. K. Yerrapragada and B. Kelley, "An IoT self organizing network for 5G dense network interference alignment," in *System of Systems Engineering Conference (SoSE), 2017 12th*, 2017, pp. 1-6.

[33] M. 2020. (2015). *Mobile and wireless communications Enablers for the Twenty-twenty Information Society*. Available: https://www.metis2020.com/metis-deliverables-d1-3-d1-5-d5-4-d6-6-and-d8-4-were-completed-in-april-2015/index.html

[34] S. Borkar and H. Pande, "Application of 5G next generation network to Internet of Things," in *Internet of Things and Applications (IOTA), International Conference on*, 2016, pp. 443-447.

[35] Q. Zhang and F. H. Fitzek, "Mission critical iot communication in 5g," in *Future Access Enablers of Ubiquitous and Intelligent Infrastructures*, 2015, pp. 35-41.

[36] F. B. Saghezchi, J. Rodriguez, S. Mumtaz, A. Radwan, W. C. Lee, B. Ai, *et al.*, "Drivers for 5G," *Fundamentals of 5G Mobile Networks,* pp. 1-27, 2015.

[37] J. Rodriguez, *Fundamentals of 5G mobile networks*: John Wiley & Sons, 2015.

[38] V. Tikhvinskiy and G. Bochechka, "Prospects and QoS requirements in 5G networks," *Journal of Telecommunications and Information Technology,* p. 23, 2015.

[39] MIMOInfo-point. (2018). *Massive (Very Large) MIMO Systems*. Available: https://massivemimo.eu/

[40] V. G. Nguyen, A. Brunstrom, K. J. Grinnemo, and J. Taheri, "5G Mobile Networks–Requirements, Enabling Technologies, and Research Activities," 2017.

[41] K. Davaslioglu and R. D. Gitlin, "5G green networking: Enabling technologies, potentials, and challenges," in *Wireless and Microwave*

Technology Conference (WAMICON), 2016 IEEE 17th Annual, 2016, pp. 1-6.

[42] H. Q. Ngo, E. G. Larsson, and T. L. Marzetta, "Energy and spectral efficiency of very large multiuser MIMO systems," *IEEE Transactions on Communications*, vol. 61, pp. 1436-1449, 2013.

[43] T. M. C. Chu, T. Q. Duong, and H. J. Zepernick, "Outage Probability and Ergodic Capacity for MIMO-MRT Systems under Co-Channel Interference and Imperfect CSI," in *Proc. of IEEE Swedish Communications Technology Workshop (Swe-CTW'11)*, ed, 2011.

[44] G. Wunder, "5th generation non-orthogonal waveforms for asynchronous signalling," in *COST Meeting 2014*, 2014.

[45] H. Q. Ngo, T. L. Marzetta, and E. G. Larsson, "Analysis of the pilot contamination effect in very large multicell multiuser MIMO systems for physical channel models," in *Acoustics, Speech and Signal Processing (ICASSP), 2011 IEEE International Conference on*, 2011, pp. 3464-3467.

[46] E. Dahlman, G. Mildh, S. Parkvall, J. Peisa, J. Sachs, Y. Selén, *et al.*, "5G wireless access: requirements and realization," *IEEE Communications Magazine*, vol. 52, pp. 42-47, 2014.

[47] S. Garg. (2018). *Is millimeter wave technology future of wireless communications?* Available: http://www.microwavejournal.com/blogs/25-5g/post/28775-is-millimeter-wave-technology-future-of-wireless-communications

[48] N. Bhushan, J. Li, D. Malladi, R. Gilmore, D. Brenner, A. Damnjanovic, *et al.*, "Network densification: the dominant theme for wireless evolution into 5G," *IEEE Communications Magazine*, vol. 52, pp. 82-89, 2014.

[49] C. Networks. (2018). *millimeter wave (MM wave)*. Available: https://searchtelecom.techtarget.com/definition/millimeter-wave-MM-wave

[50] Antenna-Theory. (2018). *The Friis Equation*. Available: http://www.antenna-theory.com/basics/friis.php

[51] S. Chen and J. Zhao, "The requirements, challenges, and technologies for 5G of terrestrial mobile telecommunication," *IEEE Communications Magazine*, vol. 52, pp. 36-43, 2014.

[52] P. K. Agyapong, M. Iwamura, D. Staehle, W. Kiess, and A. Benjebbour, "Design considerations for a 5G network architecture," *IEEE Communications Magazine*, vol. 52, pp. 65-75, 2014.

[53] C.-X. Wang, F. Haider, X. Gao, X.-H. You, Y. Yang, D. Yuan, *et al.*, "Cellular architecture and key technologies for 5G wireless communication networks," *IEEE Communications Magazine*, vol. 52, pp. 122-130, 2014.

[54] F. Haider, C.-X. Wang, H. Haas, D. Yuan, H. Wang, X. Gao, *et al.*, "Spectral efficiency analysis of mobile femtocell based cellular systems," in *Communication Technology (ICCT), 2011 IEEE 13th International Conference on*, 2011, pp. 347-351.

[55] X. Ge, S. Tu, G. Mao, C.-X. Wang, and T. Han, "5G ultra-dense cellular networks," *IEEE Wireless Communications*, vol. 23, pp. 72-79, 2016.

[56] S. Sun, T. S. Rappaport, S. Rangan, T. A. Thomas, A. Ghosh, I. Z. Kovacs, *et al.*, "Propagation path loss models for 5G urban micro-and macro-cellular scenarios," in *Vehicular Technology Conference (VTC Spring), 2016 IEEE 83rd*, 2016, pp. 1-6.

[57] M. Inomata, W. Yamada, M. Sasaki, M. Mizoguchi, K. Kitao, and T. Imai, "Path loss model for the 2 to 37 GHz band in street microcell environments," *IEICE Communications Express*, vol. 4, pp. 149-154, 2015.

[58] A. I. Sulyman, A. T. Nassar, M. K. Samimi, G. R. MacCartney, T. S. Rappaport, and A. Alsanie, "Radio propagation path loss models for 5G cellular networks in the 28 GHz and 38 GHz millimeter-wave bands," *IEEE Communications Magazine*, vol. 52, pp. 78-86, 2014.

[59] S. Rangan, T. S. Rappaport, and E. Erkip, "Millimeter-wave cellular wireless networks: Potentials and challenges," *Proceedings of the IEEE*, vol. 102, pp. 366-385, 2014.

[60] X. Gao, F. Tufvesson, O. Edfors, and F. Rusek, "Measured propagation characteristics for very-large MIMO at 2.6 GHz," in *Signals, Systems and Computers (ASILOMAR), 2012 Conference Record of the Forty Sixth Asilomar Conference on*, 2012, pp. 295-299.