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Internet of Things (IoT) for Next-Generation Smart Systems: A Review of Current Challenges, Future Trends and Prospects for Emerging 5G-IoT Scenarios

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ABSTRACT The Internet of Things (IoT)-centric concepts like augmented reality, high-resolution video streaming, self-driven cars, smart environment, e-health care, etc. have a ubiquitous presence now. These applications require higher data-rates, large bandwidth, increased capacity, low latency and high throughput. In light of these emerging concepts, IoT has revolutionized the world by providing seamless connectivity between heterogeneous networks (HetNets). The eventual aim of IoT is to introduce the plug and play technology providing the end-user, ease of operation, remotely access control and configurability. This paper presents the IoT technology from a bird's eye view covering its statistical/architectural trends, use cases, challenges and future prospects. The paper also presents a detailed and extensive overview of the emerging 5G-IoT scenario. Fifth Generation (5G) cellular networks provide key enabling technologies for ubiquitous deployment of the IoT technology. These include carrier aggregation, multiple-input multiple-output (MIMO), massive-MIMO (M-MIMO), coordinated multipoint processing (CoMP), device-to-device (D2D) communications, centralized radio access network (CRAN), software-defined wireless sensor networking (SD-WSN), network function virtualization (NFV) and cognitive radios (CRs). This paper presents an exhaustive review for these key enabling technologies and also discusses the new emerging use cases of 5G-IoT driven by the advances in artificial intelligence, machine and deep learning, ongoing 5G initiatives, quality of service (QoS) requirements in 5G and its standardization issues. Finally, the paper discusses challenges in the implementation of 5G-IoT due to high data-rates requiring both cloud-based platforms and IoT devices based edge computing.

INDEX TERMS Internet of Things (IoT), 5G, carrier aggregation, CoMP, CRAN, CRs, HetNets, MIMO, M-MIMO, NFV, SD-WSN, QoS.

I. INTRODUCTION

Momentous developments in wireless sensor networks, telecommunications and informatics have paved the realization of pervasive intelligence [1], [2] which envisions the future Internet of things (IoT). The genesis of IoT goes back to the 1980s with the idea of ubiquitous computing whose objective was to embed technology in every day's life [3]. Currently, the IoT is envisaged both at the individual and professional level. For an individual, IoT plays a pivotal role in enhancing living standards in the form of e-health, smart home and smart learning. For a professional, IoT finds its application in automation, smart supply chain and transportation, remote monitoring and logistics.

According to the reports from Ericsson [4], about 28 billion smart devices will be connected across the world by 2021.

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Furthermore, machine-to-machine (M2M) communication is employed in more than 15 billion devices [4]. Further research envisaged that around 6-7 devices will be carried per person by 2020 [5].

A vision of the all-communicating world is stated as the system that provides per area data volume to be increased by 1000 times, the number of connected devices and the user data-rate is to be increased by 10 to 100 times. Furthermore, the extended battery life up to 10 times for massive machine communication devices and end-to-end latency to be reduced by 5 times [6]. Hence, recent trends show researchers huge interests towards the amalgam of various technologies such as integration of sensors and embedded systems with cyber-physical systems (CPS), device-to-device communications (D2D) and 5G wireless systems with IoT as a centre.

Currently, new business models set for IoT implementation requires massive connectivity, high privacy and security, complete coverage, ultra-high reliability and ultra-low latency. The trending 5G enabled IoT encompasses increased data-rates, better coverage and high throughput hence providing solutions to business models and enabling IoT to robots, actuators and drones [7].

So, in this paper, the author's present a comparative analysis and detailed review of the IoT technology covering its statistical/architectural trends, use cases, challenges and future prospects. The paper also presents a detailed and extensive overview of emerging 5G-IoT scenarios, ongoing 5G initiatives all over the globe, QoS requirements in 5G and its standardization issues and the impact of the integration of 5G with IoT and artificial intelligence (AI).

The rest of the article is organized as follows: Section II presents a detailed background and overview on IoT – its vision, architectural trends and objectives, opportunities and prospects, projects and research trends. Section III, gives a detailed overview of 5G enabled IoT where its features, architectural trends, quality of service and standardization issues are discussed in detail. Section IV presents the emerging concept of 5G Intelligent IoT with reference to the AI-based systems. Section V gives an overview of challenging prospects of 5G-IoT, and finally, Section VI concludes the paper.

II. BACKGROUND, MOTIVATION AND OVERVIEW

It is estimated that by 2025, the internet nodes may reside in every single object hence causing the number of devices connected to the internet to rise [8]. According to Cisco, there will be 500 billion devices connected to the internet by the year 2030. Similarly, Telefonica predicted in 2013 that 90% of the cars will be connected to the internet by 2020 [9]. However, the survey in 2015 suggests that more than 250 million vehicles will be connected globally by 2020, which will be an increase of 67% [10]. IoT is one of the emerging trends of the current decade. Also, as per Gartner's IT Hype cycle [11], it is forecasted in 2011 that IoT will take 5-10 years for market adoption. Hence, the US $1.7 trillion is also expected as expenditure on IoT by 2020 as per International Data Corporation (IDC) [9].

A. IoT VISION – ANYTIME, ANYWHERE, ANYTHING

The term IoT was first coined by Kevin Ashton in 1999 with reference to the supply chain management [12]. The concept of IoT revolves around the word ‘‘smartness’’ – ‘‘an ability to independently obtain and apply knowledge’’ [13]. Therefore, IoT refers to the ‘‘things or devices and sensors’’ that are smart, uniquely addressable based on their communication protocols, and are adaptable and autonomous with inherent security [14]. Atzori *et al.* [3] have characterized IoT in three visions. Internet Oriented–the vision focusses on connectivity between the objects; Things Oriented- the vision focusses on generic objects; and Knowledge Oriented – the vision focusses on how to represent, store and organize information. These visions paved towards International Telecommunication Union (ITU) vision of IoT, which defines it as ‘‘*from anytime, anyplace connectivity for anyone; we will now have the connectivity for anything*’’ [15]. In a nutshell, the ultimate objective is ‘‘to plug and play smart objects’’.

B. ARCHITECTURAL TRENDS AND OBJECTIVES

There are three components that form the basis of IoT architecture:

(1) Hardware: It comprises of sensor nodes, its embedded communication and interfacing circuitry.

(2) Middleware: It comprises of data storage, analysis and handling resources.

(3) Presentation layer: It comprises of efficient visualization tools that are compatible with various platforms for different applications and present the data to end-user in an understandable form.

The parameters affecting the architecture of IoT are manifold. Hence, current research efforts have been made to devise the most optimized architecture that handles network issues such as scalability, security, addressability, and efficient energy utilization.

As for the future, the number of devices connected to the network will rise. Hence, the architecture of IoT must cater to it. Scalability, energy consumption, and addressing issues are all considered as challenges for successful deployment of IoT.

Research is carried out in solving the scalability issues by developing various multi-hop routing protocols covering a larger area and are self-adapting. These fall into three domains: 1) Data-centric, 2) Location-based and 3) hierarchical [16].

The energy consumption issues are addressed by using energy harvesting techniques [17], [18], devising energy-efficient MAC protocols [19] and cross-layer protocols [20]. On a large scale, the authors in [3] have suggested the deployment of a combination of internet protocol (IPv6) and low-power wireless personal area networks (6LoWPAN) [21]. The 6LoWPAN technology targets at integrating the low power sensor nodes working at IEEE 802.15.4 protocol into IPv6 networks comprising of 10^{128} addresses. The concept of Mobile IP was presented in [22] rather than the use of home location register (HLR) and visitor location register (VLR) as it does not require any centralized server. On a smaller scale, European Coordinated Action aimed at redefining the RFID standards, so that RFID applications can be shifted to IoT [23].

Handling a huge amount of big IoT data from all the nodes of a network is a tedious task. Also, the energy efficiency of the data centres must be considered. Hence, to cater for these issues, artificial intelligence techniques, novel fusion algorithms, state-of-the-art temporal machine learning methods, and neural networks must be deployed for automated decision making and energy efficiency [16].

Security and privacy are one of the major open issues in IoT architecture as end-user data should be protected from eavesdropping and interference. Data should be authenticated, and its integrity must be maintained at the user end. Various cryptographic algorithms are proposed for data authentication, but it possesses serious energy and bandwidth consumption issues. Hence, key cryptographic schemes are proposed and presented [24], [25]. The security and privacy of an IoT network are also challenged whenever a node enters in or whenever the applications running on nodes are needed to be installed or updated. In this context, remote wireless reprogramming protocol is proposed [3]. This protocol allows the node to look for any malicious attack during installation and to verify each code. These are mostly based on a standard protocol called Deluge [26].

Another challenge facing IoT successful deployment is the lack of a universal platform, protocol, and a programming language. Today, all connected devices follow a different set of protocols and platforms. The need of the time is to have collaboration among the connecting devices. For this, large enterprises such as LG, Samsung and Philips etc. should join hands and make a consortium for the development of universal coding language and platform. The proposed solution can solve the compatibility issues of IoT up to a significant extent [13].

The IoT must be suitable for all the applications having elastic traffic and in-elastic traffic [16]. The former (elastic traffic) focusses on applications that are delay tolerant, which includes monitoring applications; network scheduling etc. While the latter (in-elastic) requires a prompt response from the network, such as video streaming. Hence, IoT must satisfy both the traffics having different key performance indicators with the high QoS.

Keeping in mind the above open issues, a set of starting guidelines are provided in the IoT architecture reference model (ARM) [3].

Similarly, various IoT architectures have been proposed in the literature addressing various issues. Kaur and Sood [27], address the energy limitation issue by devising the hierarchal architecture which comprises of three layers: Sensing and control layer (SCL), information processing layer (IPL) and application layer (AL). This not only defines the energy efficiency but also increases the hardware resource utilization of both the SCL and the IPL layers. The main feature of the architecture is based on exchanging the energy-related information between the SCL and the IPL, hence controlling the sleep time interval of the sensing nodes. The SCL comprises of sensor nodes (SNs) which are controlled by gateway nodes (eGNs) which in turn is controlled by a base station (eNode). The SNs work in two modes: periodic mode and trigger mode suitable for periodic and critical events, respectively.

On the other hand, the eGNs control the sleep time interval of the SNs depending upon the previous usage history of the SNs and the quality of information available at the nodes. Another important factor in this regard is the conflict factor, which is a measure of duplicate information by different sensors, battery level and coefficient of variation. The coefficient of variation is a measure of variation between current and previously sensed values. If there is no variation in the information received in the past and present, then the sleep interval of sensors is prolonged, and otherwise, it is reduced. The eNodes setups the communication between the SNs and the cloud resources, which to be allocated as per requirement. The eNodes also assign the SNs to the generator nodes depending upon their battery level and distance. The information processing layer stores, processes, and analyzes the extracted data using a cloud-computing platform through energy-efficient resource allocator. The resource allocator is used for processing data in an efficient manner by allocating the hardware resources according to the needs of Sensing and Control Layer and the information analyzer. The information analyzer calculates the level of information extracted from the data and decides the sleep interval of the SNs. The application-dependent information converter then translates the information in the human-readable form and store it in the storage media. The AL provides services to the end-users by using visualization tools. Hence, energy efficiency is achieved by controlling the sleep time interval of the SNs using the eGNs and the BS in sensing and control layer. It is possible by allocating the hardware resources accordingly using the energy-efficient resource allocator in the IPL. The hierarchal architecture is also compared with other architectures such as self-organized things (SoT) [28], energy-efficient index tree (EGF-tree) [29], energy-efficiency hierarchical clustering index tree (ECH-tree) [30] and object group localization (OGL) [31]. After a thorough comparison, itis then concluded that the proposed architecture shows a functionality edge over others.

For efficient data handling, a cloud-based architecture is presented by Gubbi *et al.* [16] and Zhou *et al.* [32], respectively.

Another architecture combining the third-generation (3G) networks and power line communications (PLC), also referred to as 3G-PLC, is presented in [33] to address the scalability issues. Similarly, for large scale networks, self-configuring peer-to-peer based architecture is also presented [34].

C. IoT OPPORTUNITIES AND PROSPECTS

IoT offers many business opportunities, which allow companies to build new business strategies and models to implement

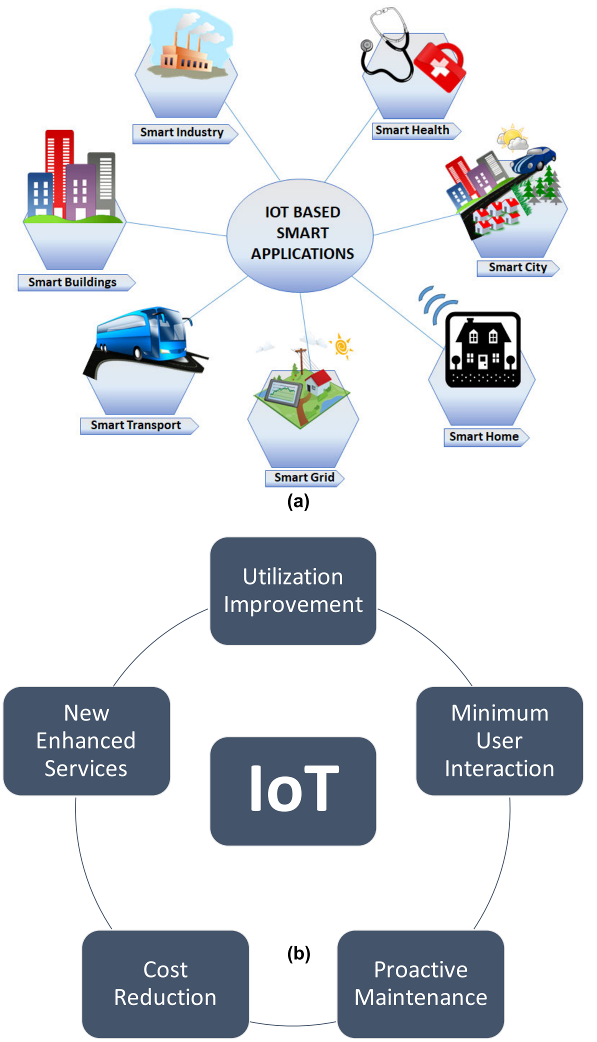

FIGURE 1. **Block diagram showing (a) IoT based smart applications and (b) IoT benefits as the cutting edge technology.**

the concept. Not only business opportunities, but also the realization of efficient and resourceful research opportunities to scholars and investigators of multi-disciplinary fields. Hence, it combines business studies, engineering skills, science and humanities all under one umbrella. Also, IoT transforms the world into a smart world, where everything is easily accessible in less time and effort, as depicted in Fig. 1 (a-b), respectively.

In general, companies are going to take an immediate investment or a wait-and-see approach to investment based on the maturity level of the specific IoT technologies [35]. During the initial deployment phase, the margin should be kept for adapting to changes. For this, open software and hardware-based IoT solutions should be proposed [12]. In this regards, one approach of cost-cutting is to use smartphones serving as IoT nodes [16].

D. IoT PROJECTS

Due to the extensive research and interest in the IoT domain since the concept was first introduced in the 1980s, various countries such as Canada, China, Brazil and UAE have implemented the concept of the smart-cities, smart cranes, smart flood warning system and smart-grid, respectively [12]. These projects are successfully implemented and are running at the Rio Operations Centre, SK Solution, Yellow River Conservancy Commission and BC Hydro, respectively [12]. China had also invested \$100 million in studying the IoT industrial standards and technologies in Shanghai as a part of its 12th 5-year plan [16], [35]. Substantial efforts are underway to merge cross-domain research activities spanning machine-to-machine (M2M) communication, wireless sensor network (WSN) and RFID into unified IoT framework [16]. The European Research Cluster on IoT [3], [16], [36], an organization of the European Union, is currently funding 33 IoT projects [36]. The focus of the organization is to develop IoT architectures, technological and knowledge interoperability with security, reliability and scalability [3], [16], [36], [37]. The reason behind the interest of the first world countries in IoT trends and developments is its prevailed benefits, as shown in Fig. 1(b). The outlined benefits hence proved advantageous for the country's economic sustainability, growth, urbanization, infrastructure, employment rate, citizens' health and services.

E. IoT - A CORPORATE SECTOR VISION

The IoT deployments also enabled the enterprises to meet their business needs [9]. Microsoft proposed a cloud-based architecture in which the nodes send their data to the cloud gateway for processing. Similarly, the IoT based video solution is implemented by Banco de Cordoba [9]. With this implementation, the trainers are not required to visit fields; hence, increased their productivity level. The designed solution also enables security and marketing efficiency. Also, Daimler employed IoT architecture and used IBM services to launch their smart cars concept, which is popularly referred to as Car2go [38].

F. IoT - RECENT TRENDS

Weiser [26] and weiser *et al.* [39], introduced the concept of ubiquitous computing, which later evolved the vision of the smart environment. In the current decade, the 'smart environment' concept has become a booming technology.

The concept is diverse as it covers transportation/logistics, healthcare, utilities, personal home/offices and much more. During this decade, concepts like augmented maps, autonomous car, mobile ticketing, and passenger counting in transportation/logistics domain have been successfully implemented. The continuous improvement in these technologies is also currently in practice. The concept of IoT enabled Robot taxi, which is underway as a futuristic application [40], [41]. Similarly, remote patient monitoring, smart biosensors, smart ambulances, wearable devices, telemedicines in IoT-enabled healthcare domain benefitted the society manifold [42], [43]. Public utility infrastructure has been improved to a large extent, with the concept of smart metering and smart-grid systems [44].

TABLE 1. IoT enabled smart environment.

Applications	Communication Enablers	Network Types	Wireless local area network (WLAN) standards	Modules	References
Smart-Cities	Wi-Fi, 3G, 4G, Satellite	MAN, WRANs	802.11	Architectures, protocols, and enabling technologies for urban IoT. Integrated information centre for the smart-city	[46], [57]
Smart Homes	Wi-Fi	WLAN	802.11	Cloud-based home solution for detection of faulty location using software-defined networks (SDNs)	[58]
Smart-Grid	3G, 4G, Satellite	WLAN, WANs	802.11	Real-time monitoring system for powering transmission-lines to avoid disasters. Smart-grid control	[59]-[60]
Smart Buildings	Wi-Fi	WLAN	802.11	Access control for services inside a typical smart building	[13]
Smart Transport	Wi-Fi, Satellite	WAN, WRANs, MANs	802.11	Smart-ticketing, smart passenger counting	[61]
Smart Health	Wi-Fi, 3G, 4G, Satellite	WLAN, WPANs, WANs	802.15.4	Remote health care	[62]
Smart Industry	Wi-Fi, Satellite	WLAN, WPANs, WANs	802.11	Energy-efficient remote monitoring and optimized decision-making.	[63]

TABLE 2. Comparison of previous wireless technologies from 1G - 4G.

Wireless Technology	Data-Rate	Services	Bandwidth	Reference
1G	2.4Kbps	Voice	30KHz	[63]
2G	10Kbps	Voice, Data	200KHz	[63]-[64]
2.5G	50Kbps/200Kbps	Voice, Data	200KHz	[63]-[64]
3G	384Kbps	Voice, Data, Video Calling	5 MHz	[63]-[64]
3.5G	5-30Mbps	Voice, Data, Video Calling	5MHz	[63]-[64]
3.75G	100-200Mbps	HD video, peer to peer file sharing, composite Web services, online gaming	1.4MHz-20MHz	[63]-[65]
4G	DL 3Gbps UL 1.5Gbps	HD video, multimedia, data services at much higher data-rate	1.4MHz-20MHz	[65]-[66]

Not only the country's infrastructure has been improved, but also the end-users are also benefitted at a personal level with the concept of smart homes [45] and smart-cities [46], [47], which prove cost-effective and convenient. Smart health-care manages the health of the consumer efficiently. The concept of the smart gym [48] allows the end-user to monitor his exercise schedule regularly. Since today's human beings are also socially active; there is a need of time to automatically update their social activities on social media. This concept has already been introduced by Tweetbot [49]. A digital diary application that records personal data and updates it on the Google calendar [3]. Hence, IoT also proved beneficial at the end-user level with the challenges of security and privacy.

In a nutshell, the technical specifications currently become part of published literature on IoT enable smart environment is summarised in Table 1.

G. WIRELESS TECHNOLOGY AND IoT

IoT is a heterogeneous network that will be connecting around 7 billion devices by 2025 using different wireless technologies and standards such as 2G, 3G, 4G, Bluetooth and Wi-Fi etc. as predicted in 2015 by Machina Research [50]. The mobile devices subscriptions as per 2G/3G/4G technologies are shown in Fig. 2 [51], [52]. The specifications of previously used wireless technologies are listed in Table 2 [53]. Currently used IoT networks use these technologies as listed in Table 3 [51].

It is important to realize that the above discussed technologies are not fully optimized for IoT business models and devices which requires low power and less data-rate [51], [54]. Therefore, adrift from various wireless technologies such as 1G, 2G, 2.5G, 3G, 3.5G and 4G towards 5G can be observed. The 5G technology is highlighted as it addresses the major challenges of a cellular network more effectively as

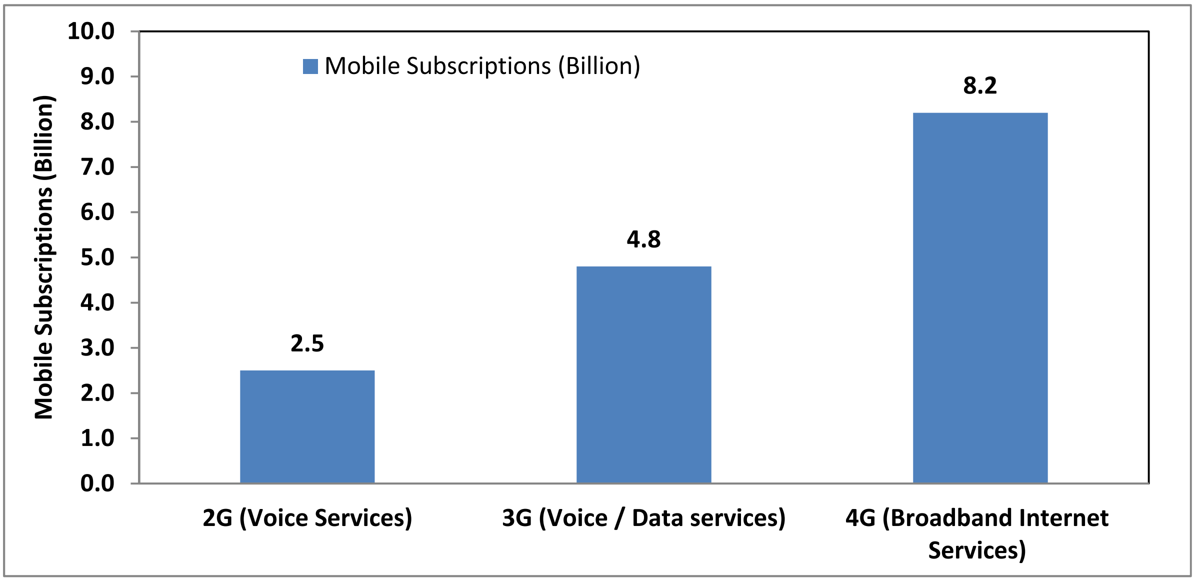

FIGURE 2. Mobile devices subscriptions with respect to different wireless technologies.

TABLE 3. Wireless technology currently employed for IoT.

Type of Technology	Wireless Technology
Personal area network (PAN)	Bluetooth Low Energy, Zigbee
Wireless local area network (WLAN)	Wi-Fi
Cellular communication	3GPP, 4G (LTE)
Wide area network (WAN)	LP-WA

TABLE 4. 5G initiatives in different countries.

Country	Initiative
United States	4G America
China	IMT-2020 (5G)
Japan	2020 and beyond
Korea	5G forum
Europe	5G Private Public Partnership (5GPPP)
UK	5G Innovation Centre (5GIC)

compared to its predecessors [55], [56]. These challenges are appended below:

- Large bandwidth
- Higher data-rate
- Massive connectivity
- Low end to end latency
- Cost-effective
- Consistent Quality of Service
- Device computational capabilities
- Device intelligence services

III. VISION AND DEVELOPMENT OF 5G-ENABLED IoT FROM 5G CELLULAR TECHNOLOGIES

A. 5G ENABLED IoT – GLOBAL INITIATIVES

Various initiatives are taken all around the world for adopting and standardizing 5G enabled IoT, as listed in Table 4 [67]. Different European projects beyond 4G can be found in [68]. Similarly, International Mobile Telecommunications (IMT) also initiated the research and technology practices back in 2013 and the standardization in 2016 [67]. In 2015, it was decided that the Third Generation Partnership Project (3GPP) will formulate a group called technical specification group (TSG), which will be responsible for establishing 5G RAN [69].

During the same era, International Telecommunication Union-Radio Communication (ITU-R) has taken the responsibility of defining and specifying 5G technology by 2020 [70].

B. SPECTRUM REQUIREMENTS OF 5G-IoT

Innovation in wireless domains, next-generation technologies and development of 5G enable IoT requires cutting-edge services and solutions together with the need of broadband spectrum to meet the demands of rapidly growing traffic. Therefore, a combination of low-band, mid-band and high-band spectrum is desirable to manage the use cases of 5G enable IoT successfully as suggested by 5G Americas [71]. Using a combination of different bands help to address certain use cases better than others. The comparison of each band with respect to different use cases presented in Table 5 [71].

Apart from the generalized spectrum requirements, a new air interface called New Radio (NR) is defined by 3GPP for 5G [72]. Its specification falls into two categories. Firstly, FR1, which refers to spectrum below 6GHz [72]. Here, FCC has provided two licensed spectrums for 5G deployment. 1) Citizens Broadband Radio Service (CBRS) operating at 3.55 – 3.7GHz. 2) C-band operating at 3.70 – 4.2GHz, respectively. Others possible spectrum ranges suggested by FCC are 6-7 GHz band (5.925-6.425 GHz and 6.425-7.125 GHz) which are unused and can support wider bandwidths than its

TABLE 5. Comparison of the spectrum with respect to different 5G use cases.

Spectrum Type	Characteristics	Use Cases
Low-frequency band (below 2GHz)	• Higher Coverage and Mobility • Wider channels availability	1. Massive Machine-Type Communications 2. Indoor applications
Higher frequency millimetre waves (mmWave) bands	• Short-range with low latency. • High capacity due to wider channelization	1. Enhanced mobile broadband Communications 2. Urban and sub-urban applications
Mid-frequency bands	• Short-range with low latency and high capacity transmission for few macro-based stations	1. 5G implementation in uncrowded/open areas 2. Urban deployment.

predecessor (LTE) [71]. Secondly, FR2, which is a higher frequency mmWave band [72] has significant unused spectrum having large bandwidths which is suitable for 5G deployments. Therefore, 24GHz, 28GHz, 37GHz, 39GHz, and 47GHz are also identified for 5G deployment by FCC, and their auction is expected nearly [71]. For instance, in Nov 2018, 28GHz band auction has begun. Other bands to be auctioned in 2019. In addition, bands such as 32 GHz, 42 GHz and 50 GHz are also under consideration [71]. The details of the spectrum allocation of each NRs can be viewed in [72].

After looking at the above-mentioned spectrum characteristics/requirements of 5G technology, there is still a gap between the actual implementation of a 5G technology and the promises made by the next-generation wireless network.

Hence certain technologies must be involved in the implementation of 5G deployment [73]. For instance, transmission/reception at mmWaves have high path-loss, and their rate of absorption by the atmospheric parameters such as rain and greenery are very high. Hence, it is likely that a smaller cellular architecture is needed in a form micro-, pico- or femto-cell to improve the coverage and decrease the path-loss at mmWaves. This paved the way towards the new concept – small, low-power cellular base station (BS). These cells are low power, compact and portable BSs which are placed meters apart. Thousands of these small cells form a dense network acting as a relay and boosting a signal between the end-users and BSs. As these small cells are handling mmWaves, so the antennas attached to these BSs are smaller and lighter as compared to their traditional counterparts. Hence, these BSs can be easily fitted on poles or buildings top. Also, another benefit of using a small cell is spectrum re-usage. To further enhance the advantages of small cells and reduce the complexity of extensive cells and antennas running in an urban environment – a M-MIMO technology is also incorporated.

A 4G BS currently employs dozens of antenna ports to handle its traffic efficiently. However, in case of 5G traffic, these ports must be increased significantly from dozens to hundreds to enhance the capacity by a factor of at least 22. This is solved by incorporating M-MIMO technology, which targets at incorporating many antennas on a single BS. This creates another problem: Interference. To cater for it, a beamforming technology is incorporated [53], [73]. As the 5G technology aimed at integrating various heterogeneous access technologies leading to the implementation of the vision of IoT. The 5G technology employs beam division multiple access (BDMA), an advanced technology in which BS allows an orthogonal beam to each mobile device and BDMA technique will divide the beam as per the position of the mobile devices. This enables the multiple accesses to the devices hence increases the capacity manifold [53] with reduced interference.

Besides using mmWaves for enhanced data-rates, M-MIMO and beamforming for spectrum efficiency, 5G technology also requires high throughput with low latency. This necessity is fulfilled by integrating the full-duplex technology, which targets at antennas' transceiving methodology [73].

A 5G transceiver must be capable of transmitting and receiving the data at the same time and on the same frequency – hence a transceiver must be full-duplex and operate in both Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD) modes. This is achieved by using silicon transistors acting as fast switches allowing it to transmit/receive on the same frequency [73].

Nevertheless, the above mentioned technologies are still in their infancy and are under research to cater for their drawbacks and implement a successful 5G enable the system. Furthermore, other related technologies are also discussed in the later section.

C. FEATURES EMPLOYED IN 5G PHY LAYER TO SUPPORT 5G-IoT

MIMO, CoMP, and the HetNets, etc. are some of the features that have been standardized for LTE/LTE Advanced (LTE-A) technology. These technologies show encouraging results in providing massive connectivity and high data-rate. Therefore, 5G technology employs these concepts. These concepts are discussed at first to get their insight in the next sub-sections.

1) CARRIER AGGREGATION

Carrier aggregation was introduced in 4G LTE– A based on Release 10 of the 3GPP. It aggregates up to 5 component carriers (CCs) of LTE–A having 20 MHz of bandwidth thus enhancing the overall bandwidth to 100 MHz. In carrier aggregation, it is possible that the mobile device may receive more than one CC. Multiple CCs with different bandwidths can be aggregated in the uplink and downlink, where the number of uplink aggregated CC may not be higher than the number of aggregated CC in the downlink. The CC may belong to the same band known as intra-band carrier aggregation or to the different band known as inter-band carrier aggregation. In each type of carrier aggregation, it is also possible to perform contiguous and non-contiguous component carrier aggregation. In uplink and downlink, one of the CC must be selected as a primary component carrier (PCC) while others as a secondary component carrier (SCC). The number of CCs in different 3GPP releases has increased significantly. In rel-10, there was only 2 CC in downlink while no CC in uplink; in rel-11 carrier aggregation is improved drastically with the addition of 2 CC in the uplink, in rel-12 FDD/TDD is added. In rel-13, the number of 20 MHz aggregated CCs are increased from 5 to 32. Even though carrier aggregation is a powerful technique but due to inter- and intra-band carrier aggregation, intermodulation product may interfere with the signal.

2) MASSIVE-MIMO (M-MIMO)

The MIMO technology is considered a necessary part of LTE-A and is based on the concept of spatial multiplexing. Data streams from multiple antennas are multiplexed and are transmitted over a variety of spatially separated channels.

On the other hand, M-MIMO is an integral part of the 5G infrastructure. At mmWave, many antenna elements are needed so that highly directional narrow beam can be produced to counteract the path-loss. This technique becomes feasible to implement the high-order multi-user MIMO (MU-MIMO) to enhance the small cell capacity. In 5G radio access network (RAN), is based on M-MIMO in ''macro-assisted small cells''. The control-plane traffic is provided in the macro cell at lower band frequencies using omni-directional antenna while user-data traffic is delivered using highly directional M-MIMO beam at mmWave band frequencies. M-MIMO allows the possibility of distributed MIMO, where multiple narrow beams simultaneously get transmitted to the same mobile station from the BS at a different location to improve throughput and reduce the correlation among the antenna elements. A subsequent of MIMO technology, which targets at the spectrum efficiency by using the arrays of a few hundred antennas having one time and frequency slot to serve tens of user equipment. Hence, leveraging the MIMO technology on a larger scale. As compared to conventional MIMO technology, instead of using pilot waveforms for channel estimation, M-MIMO employs TDD mode and rely on the reciprocity mechanism between the uplink and the downlink channels [53]. M-MIMO has proved to be beneficial in providing improved radiation efficiency up to 100 times, increased capacity by order of 10, increased protection against interference and intended jamming, a significant decrease in latency and have low power and low-cost setup [74].

3) COORDINATED MULTIPOINT PROCESSING (CoMP)

Coordinated Multipoint (CoMP) was first introduced and standardized by 3GPP in Rel-10 and employed in LTE-A. CoMP transmission in downlink and reception in uplink is a very effective way to enhance the cell-edge user throughput. CoMP utilizes distributed MIMO for transmission and reception from different antennas, which may not belong to the same cell to reduce, received spatial interference and enhanced the received signal quality. CoMP is a very effective technique if deployed using MU-MIMO to increase cell edge coverage and reduce the outages caused by blocking and channel conditions. There were several studies conducted using CoMP with MIMO by NTT Docomo and Ericsson in Stockholm, Sweden to see the effectiveness in terms of coordination between distributed MIMO and how the combination of both technologies will improve user data-rates at mmWave frequency bands. At mmWave, the study was carried out at 73GHz in an urban micro-cell environment for BS diversity in CoMP style manner. The CoMP is a transceiver technique, by which the interference issues can be lessened. This is done by coordinating the transmission and reception between the spatially distributed BSs using the channel state information. The technique includes coordinated scheduling and joint transmission [67].

4) HETEROGENEOUS NETWORKS (HetNets)

A network comprising of different types of cell layers (femto-cells, pico-cell, micro-cell and macro-cell) and different RATs. These networks consist of low power nodes needed for data offloading [75]. The HetNets supports the ''green'' aspect of 5G by maximizing the spectral efficiency through reusing the spectrum tightly and with low uplink and down-link power transmission [67] making it spectrum and energy-efficient. Sharing the spectrum by the massive number of user equipment – an ultra-dense network (UDN) requires an intelligent interference mitigation technique. In order to cater for the interference, the HetNets uses enhanced inter-cell interference coordination (e-ICIC) and further enhanced ICIC (feICIC) [67]. These features allow it to handle massive traffic and large node density; hence; making it suitable for satisfying the requirements of service-driven 5G enabled IoT. The HetNet enabled 5G-IoT based solutions are provided in [51].

5) D2D COMMUNICATIONS

The HetNet realizes the coordination between macro-cell BS and the low power BS. However, for short-range communication, it does not prove to be efficient. Hence, the D2D communication is evolved that allows low power consumption, better QoS and load balancing between the devices for short-range communication (< 200m). In light of this, the BS will either have the full control over allocating the resources among source, destination and relaying nodes or have partial control. Hence, keeping in view this scenario, in [53], the authors [53] classified D2D communication into four main categories.

TABLE 6. Enhancements proposed for 5G on cellular IoT.

Open Standards	Enhancements Proposed
Machine type communications (MTC) or M2M Communications	• Reduced complexity • Increased transport block size to improve the data-rate • Ensure Voice over LTE • Ensure multi-cast transmission • Ensure enhanced coverage area • Enhance MTC related to reception and transmission in case of time difference measurements
Narrowband Internet of things (NB-IoT)	• Multicast support for downlink transmission • Mobility and enhanced service continuity • Lowering the maximum transmit power which enables reduced form-factor of wearable devices • Increased transport block size with 1352 bits for downlink and 1800 bits for uplink to support high data-rate, low latency and reduced power consumption • Co-existence of NB-IoT User equipment with CDMA to lower the adjacent channel leakage ratio (ACLR) up to 49dB • New band supports for NB-IoT for effective utilization • D2D communication is employed as an extension to NB-IoT to provide routing cellular links

- Device relaying with BS controlled link information.
- Direct D2D communication with BS controlled link information.
- Device relaying with device-controlled link information.
- Direct D2D communication with device-controlled link information.

However, D2D communication offers, significant security and interference management issues [76] which must cater before its deployment. Hence, research efforts [53] are underway to provide a solution to these issues.

6) CENTRALIZED RADIO ACCESS NETWORK (CRAN)

The CRAN is another concept towards greener and cleaner communication by reallocating the functions of BSs. It only allocates the radio functions to the BS that is remote radio unit or remote radio head. Other unit like baseband unit (BBU) is distributed to the cloud-based central processor. This enables centralized intelligence, cooperative communication among cells, improved cell utilization and reduces complexity and cost at the BS end [67].

To support the massive connectivity of devices, different 5G standards are developed for Cellular IoT. In the first phase, M2M communication, narrowband IoT (NB-IoT), a low power wide area technology aiming to ease the massive deployment of IoT [77] are specified in the 3GPP Release 14. Nowadays, the 3GPP standardization is working on the enhancements, so that it can cater to the growing demand. These enhancements are summarized in Table 6 [77].

Also, the New Services and Markets Technology Enablers (SMARTERs) by 3GPP are currently reviewing over 70 use cases for 5G service requirements. These use cases as per there service requirements are categorized in Table 7 [77], [78].

Other than the above mentioned standards, there are other network enablers to support 5G enabled IoT. It is evident that the conventional features of a network are becoming obsolete

TABLE 7. SMARTER use cases.

Services	Use Cases
Massive MTC (mMTC)	Smart buildings, smart-cities, smart wearables, etc.
Enhanced Mobile Broadband (eMBB)	User movement from urban to rural areas or urban to sub-urban areas
Critical Communications	Industrial control applications (drone or robots), Tactile internet
Network Operations	Network related functions such as slicing, routing, internetworking, enhancements, security and optimizations
Enhancement of Vehicle to everything (eV2x)	Self-driven cars, autonomous flights, etc.

with the increasing demands and requirements needed to support massive connectivity of devices and providing them with the high QoS in case of massive and critical IoT.

D. FEATURES EMPLOYED IN 5G NETWORKING LAYER TO SUPPORT 5G-IoT

These network architectures previously hardware-based, will now have to manage the exponentially growing traffic, deployment/induction of new nodes, efficient network forwarding infrastructures and the network expansion flexibility. To achieve these objectives, different network-enabling technologies are developed which are now emerging. Some of them are discussed below.

1) SOFTWARE-DEFINED WIRELESS SENSOR NETWORKING (SD-WSN)

Conventional methods to deploy cellular technology are generally hardware-based. The hardware-based deployment limits the flexibility of network expansion. Hence, SD-WSN, a promising paradigm, is developed to overcome this limitation [77], [79], [80]. The SD-WSN is a blend of SDN inside the

WSNs. The SDN found its applications in data centers (wired communication networks) and for Internet connectivity [81]. Currently, it is envisaged as 5G technology enabler [82], [83]. The primary purpose of using this model for deployment of 5G networks is to decentralize the control logic plane from the network device [77] and providing the centralized mechanism to program the entire network.

Due to the increasing demands of the massive connected devices, a centralized software-based paradigm like SDN is necessary to fulfil the requirements of maintaining consistent QoS. The SDN will simplify the network management issues such as link/node down issues, allocation of resources, and deployment of new links/nodes by manifold. Different proposed SDN solutions are Soft Air [51], Cloud RAN [84] and CONTENT [51]. Hence, it is seen as a pivotal enabler of future next-generation 5G technology.

2) NETWORK FUNCTION VIRTUALIZATION (NFV)

The NFV virtualizes the network functions. These functions can then be implemented into software packages which can later be used for providing network service requirements [85]. The NFV and SDN are mutually exclusive. The NFV concept is originated from the perception of virtual machines, which can be installed on different operating systems on the same server. Some foreseen use cases related to NFV are core virtualization and centralized baseband processing within RANs [84]. The NFV is a promising candidate for the successful deployment of 5G enabled IoT. Since, the network virtualization concept supports the network scalability mechanism, network slicing over the distributed cloud, real-time processing capability (optimizing speed and capacity in sliced networks) and maintains its heterogeneity – one of the significant features and requirements of 5G over IoT [51], [77]. Not only this, the NFV is also energy and cost-efficient, thereby reducing the capital and operational expenditure. Therefore, a lot of research is going on this technology as recently (2019) Intel and Ericsson have developed the 5G platform that incorporates the software and hardware management, NFV and cloud services for 5G [74].

3) COGNITIVE RADIOS (CRs)

The current IoT applications from massive to critical IoT represents massive connectivity and overloading of the network resources resulting in the scarcity of spectrum.

Hence, there is a dire need to use the spectrum efficiently and intelligently to satisfy the growing demand. The CR handles this issue perceptively, by using/sharing the spectrum resources in an opportunistic manner [77].

A CR can be defined by [76] ''a radio that can change its transmitter parameters based on the interaction with the environment in which it operates''. Hence, this leads to the concept of cognitive capability and reconfigurability.

The former refers to capturing the spatial and temporal variations with reduced interference in a radio environment. Subsequently, an optimized spectrum can be captured for transmission. This is usually an unused spectrum called spectrum hole or white space. If it is being used by any licensed user, then interference is reduced by three ways. Firstly, hopping towards the other spectrum hole. Secondly, by keeping its power level low and thirdly by changing the used modulation scheme [86]. Furthermore, the CR also manages the spectrum by selecting the best available channel and allows spectrum sharing. Another striking property of the CR is the spectrum mobility that is to vacate the allocated channel when a primary user arrives [77].

The latter refers to the dynamic programmability with respect to the radio environment. Hence, a CR can transmit and receive using different frequencies, modulation schemes, transmission powers, communication technologies, protocol parameters and transmission access technologies depending on its hardware [87]. This scalability is not only possible at the beginning but also during the transmission.

A generic architecture of a cognitive radio consists of RF front-end and a baseband processor [86]. To adapt to a time-changing RF environment, a control bus is attached to each component. A cognitive radio differs from its traditional peers by its RF front end, which comprises of a wideband antenna, power amplifier and an adaptive filter. These characteristics of an RF front end enables its wideband sensing capability. Also, a CR should be capable of detecting weak signals in a wide spectrum [88], [89].

As the CR aims at adapting to the needs of a radio environment, it follows a cognitive radio cycle [86]. The cycle comprises of three basic steps: 1) Spectrum Sensing 2) Spectrum Analysis 3) Spectrum Decision.

At first, the radio environment is sensed for white holes, primary user appearance, variations in traffic and user movements, etc. This is performed by various techniques such as transmitter detection, cooperative detection and interference-based detection for cognitive radio networks (XG network) [86]. Then the estimations/analysis on characteristics of spectrum holes is performed. This analyzes the parameters which define the quality of spectrum such as interference, path-loss, wireless link errors, link-layer delay, and holding time [86]. Finally, depending on the above-mentioned steps, CR decides the suitable data-rate, bandwidth and transmission mode of any transmission. This transmission is in full consent with QoS, user requirements and features of the spectrum. In [86], different spectrum decision rules are discussed depending upon the QoS of each use case.

All these features make the CR an efficient candidate for the successful deployment in 5G.

Other than these technologies, the domain of cloud computing is also putting up efforts in recognizing a 5G enabled IoT [53]. The efforts put forward under this domain are summarized in Table 8.

E. ARCHITECTURAL VIEW OF 5G-IoT

As discussed in the previous section, the IoT technology has immense demands. Hence, a 5G architecture should be capable of proving a scalable network, network virtualization facility, cloud services, network densification capability,

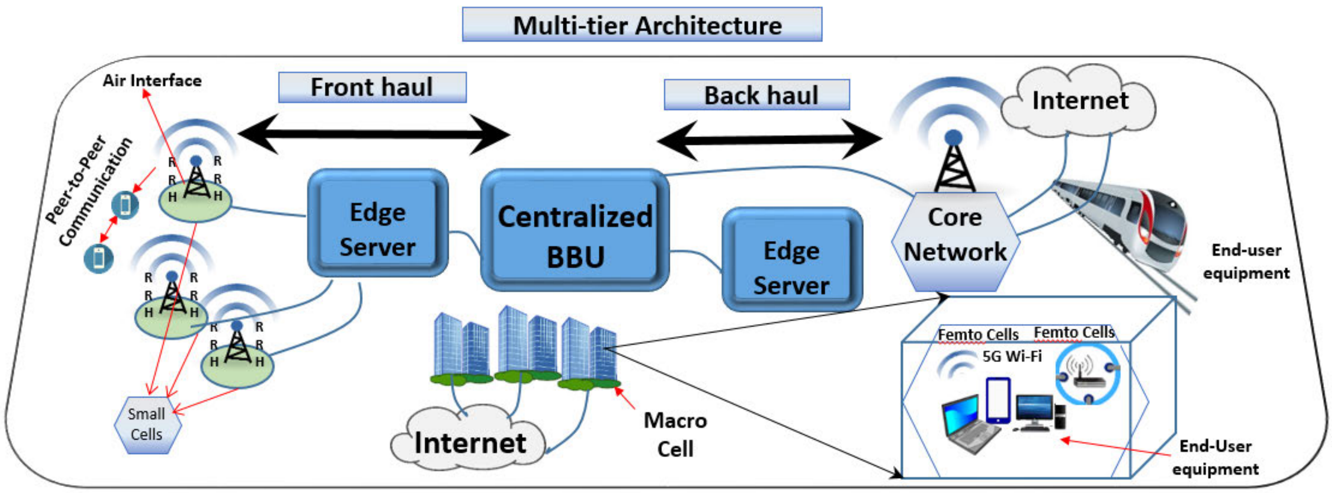

FIGURE 3. Multi-tier architecture showing the front-haul, back-haul and core network highlighting the peer-to-peer communication, macro- and femto-cells.

TABLE 8. Cloud computing technology for 5G networks.

Cloud Computing technology for 5G RANs	Key Aspects
Mobile cloud computing	Targets at fulfilling the resources (computational power, memory, energy, storage) of mobile devices [91]
RAN as a service	Targets at centralizing the RANs functionalities as service on the cloud [53]
Joint RAN Backhaul Operation	Flexible centralized dynamic adjustment of network routes

TABLE 9. Cell spectral efficiency for 5G technology.

Cell Spectral Efficiency	5G Technology	4G Technology
Uplink (bps/Hz)	05	1.8
Downlink (bps/Hz)	10	2.6

mobility control services, radio access control, efficient resource allocation mechanism, and big IoT data analysis tools. In a nutshell, a 5G-IoT based architecture should provide an independent HetNet, that is self-configurable as per the application requirement. A cellular 5G architecture mainly consists of a front-haul, mid-haul, and back-haul networks.

The front-haul network connects the remote radio-head (RRH) to the BBU, as shown in Fig. 3. Back-haul refers to the connection between the BBU to the core wired network often made from coaxial cable and/or optical fibre. Mid-haul refers to the connection between RRH and the next link [67].

The two logical layers existing in the 5G cellular network architecture are radio network and network cloud. The 5G cellular network architecture is explained in detail in [67], [91], [92].

In [53], the authors provide a mmWave solution for implementing a 5G cellular network. The authors explained that by using steerable antennas at the BS and the mobile station with state-of-the-art CMOS technology and the mmWave's spectrum, high data-rate can be achieved. Not only this, but this will also support mobile communication and the back-haul network. Furthermore, the lower wavelength of the mmWaves makes it an excellent candidate for the polarization and various spatial processing techniques such as MIMO, M-MIMO and antenna beamforming, hence key architecture enabler of the 5G-IoT.

As far as a prototype building is concerned, realizing a 28GHz antenna array directly on the printed circuit board (PCB) also reduces the insertion-loss between the antenna and radio frequency integrated circuit (RFIC) [93], [94]. A comparison in the configuration of the antenna array at 28GHz for 4G and 5G technology is shown in [53].

The mmWave spectrum was underutilized since the past decade due to its inappropriateness for mobile communications, particularly because of propagation issues such as path-loss, blocking, atmospheric and rain absorption etc. These issues are resolved now up to a great extent by using large antenna arrays and then steering up the beam energy and collecting it coherently.

F. QoS IN 5G-IoT

The QoS in a 5G cellular network can be comprehended by its spectral efficiency and latency [53]. The spectral efficiency in a 5G network can be achieved by using non-orthogonal signals and radio access methods, whereas latency demands vary in case of a user and control plane traffic.

A typical 4G and 5G network cell spectral efficiency in the uplink and downlink is shown in Table 9, and the latency in the control and user plane is shown in Table 10 [95], respectively.

TABLE 10. Latency in 5G network.

Latency	5G Technology	4G Technology
User plane (msec)	1	10
Control plane (msec)	50	100

It can be seen from Table 9 and Table 10, that about 50% decrease in latency can be seen in the control plane in case of 5G network with significant improvement in the cell spectral efficiency.

G. STANDARDIZATION IN 5G-IoT

The standardization process in the 5G-IoT involves mainly two types of standards. One is the technology standards that deal with network technology, protocols, and wireless communication and data aggregation standards. Second is a regulatory standard that comprises of security and privacy of data.

IV. ARTIFICIAL INTELLIGENCE DRIVEN USE CASES FOR 5G-IoT NETWORKS

The higher data-rates possible in 5G-IoT makes it possible for the implementation of data-hungry and computation intensive Artificial Intelligence (AI) algorithms for various user applications. With high data transmission capacity of the network comes a possibility of the use of efficient deep learning algorithms such as virtual speech recognition and video classification [97] over wireless 5G-IoT nodes. The combination of 5G, IoT and AI has a higher potential of changing the landscape of businesses by making intelligent decisions in real-time. With the availability of powerful hardware for IoT nodes, the inclusion of intelligence on IoT nodes or a fog node closer to end devices decreases latency, improves link capacity, and upgrades the network security.

Interestingly, AI based techniques could also be employed over 5G-IoT networks to further optimize its own performance at application, physical and network layers to further enhance data rates by predicting traffic patterns on the network, thus facilitating the provisioning of AI based user applications. For example, at the application layer, AI techniques could be utilized for studying network traffic and capacity trend analysis to make the network self-configurable, self-organized and self-adaptive [96]. On physical and network layers, AI based optimization algorithms could facilitate dynamic spectrum management, structuring of huge data, integration of heterogeneous devices, ultra-densification of devices, IoT nodes interoperability, and improved battery life [96].

Some current and futuristic AI based applications that could be supported over 5G-IoT are summarized below:

A. BIG DATA PROCESSING ENHANCEMENT

The 5G Intelligent IoT has the potential to tackle problems related to communication channel congestion and enormous data processing. The amalgamation of AI algorithms and 5G tech, the objective of the 5G Intelligent IoT is to process huge amount of data intelligently, optimizing the communication channels and upgrading the utilization of channels effectively [98]. Moreover, the inclusion of AI in the main components of firmware will give safe environment running applications which in return will help in making intelligent decisions completely uninterrupted [96].

The latest techniques practised in IoT and the reliable and fast speed of 5G network incubates the environment of creating applications which utilize big data to its maximum potential, such as natural language processing, face recognition, etc, which can run in the terminal. Ever-present connectivity provided by 5G leads to the creation of an enormous amount of data. This data set can also be utilized as a mean of exchange in 5G IoT-based networks for making intelligent decisions. AI algorithms can extrapolate and come up with more accurate decisions after finding patterns from a data set based on the currently stored and processed data. For defining the importance and potential of Artificial Intelligence in new techs, there is a need for integration of Artificial Intelligence with 5G IoT-based networks. Furthermore, it will also help in incorporating immense IoT devices and manage the enormous volume of data, which is likely in TB's [96].

B. EXPANDING THE HORIZON OF HEALTHCARE

The combination of 5G and AI in the field of healthcare can improve the lives of millions of people by upgrading the existing system. Chen *et al.* [99] designed a personalized emotion-aware healthcare system using 5G that emphasizes on the emotional care, especially for children, and mentally ill and elderly people.

In [100], Genetic algorithm and simulated annealing were utilized to find the best position for 5G drone base stations within the constraints of coverage, energy and cost.

C. INTELLIGENT NETWORKING

One of the applications of AI is the implementation of 5G networks, which is shown in the CogNet project [101] in which an architecture of an autonomic self-managing network extending NFV management with the machine learning-based decision-making mechanism is discussed. The reason behind deploying a more adaptive controlling mechanism next to base NFV functionalities is the pursuit to reduce the costs of the system, whilst keeping QoS on a competitively high level.

D. SMART TRANSPORTATION SYSTEMS

Vehicles with continuous connectivity, are becoming a reality with the integration of 5G with IoT. This integration has given the ability to access the internet in a more efficient way. Now, car manufacturers have developed their interest and are exploring different markets to bring this technology in the field of transportation systems. Researches have been performed regarding a self-driven vehicle with the use of connecting to the internet. A smart transportation system can

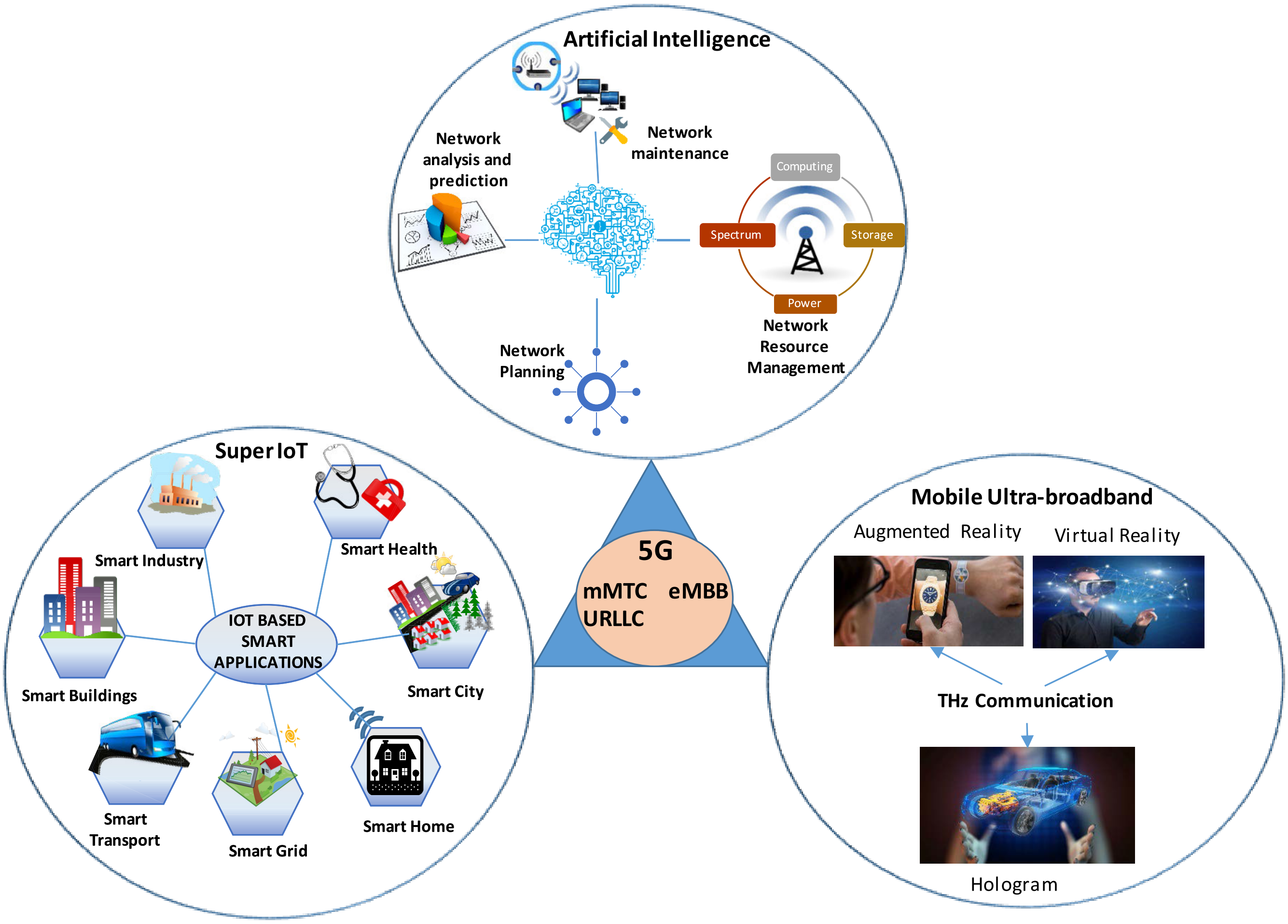

FIGURE 4. Architectural scenario where 5G meets artificial intelligence.

provide communication between the smartphone of passengers and the vehicle itself. Just like other IoT devices, a smart transportation system can also provide new features for more control [103].

The installation of sensors in traffic lights provide the data which helps in making decisions for efficient traffic routes reducing the propagation time of vehicles. The integration of IoT with 5G has improved the overall traffic system. IoT has helped with reducing manual labor in areas such as managing traffic; this can help to reduce costs.

E. UTILIZING ABUNDANT DATA OF INTER-CONNECTED IoT DEVICES

The huge data generated from continuous connectivity of IoT based devices with 5G, can be used in the prediction of accidents and crimes by correlating the available huge data [102]. Hence, it helps in innovating new ideas that might become projects for big companies, generating huge data (huge data set can be further used to find similarities, connections and patterns) and providing various ways of communicating, as depicted in Fig. 4. The extraction of real-time data is possible with the help of IoT. This has allowed devices to be controlled in various ways without much human interaction. IoT devices have provided the new infrastructure for managing traffic daily. Wireless network technology has been used to detect surroundings. This also indicates that IoT has been introduced as a way of providing surveillance. Generating big data from IoT devices has played a role in making plans and improvements to the environment within a city [103].

Moreover, IoT big data analytics have proven to bring value to the society. For example, it is reported that, by detecting damaged pipes and fixing them, the Department of Park Management in Miami, USA, has saved about one million USD on their water bills [104]. Previous wireless technologies did not support effective means of communication among machines. The increased data-rate, reduced end-to-end latency, improved coverage, and the support for large amounts of devices hold the potential to satisfy the most demanding IoT applications in terms of communication requirements. Its support for large amounts of devices enables the vision of a truly global IoT. In addition, for its focus on the integration of heterogeneous access technologies, 5G may play the role of a unified

TABLE 11. Trending research on challenges of 5G-IoT.

Article	Challenges	Solution	Reference
Enabling Massive IoT in 5G and beyond Systems: PHY radio frame design considerations	Flexibility in the physical layer radio framework? of 5G technology to satisfy the diverse requirements of IoT	Suitable radio numerology is designed with a random-access channel to support massive connection density and is capable of dealing with channel impairment and imperfections in the transceiver	[114]
A Survey of Client-controlled HetNets for 5G	Huge signalling overhead in network control schemes for network edge devices and leveraging Radio access technologies (RATs)	A review on client-controlledHetNets for 5G networks is provided in-depth with distributed and hybrid control approaches	[115]
The next-generation of IoT	Different companies such as Tata communications, DellIoT Services, Sierra Wireless are presented which are developing IoT technology all around the globe		[116]
Long-Range IoT Technologies: The Dawn of LoRa™	Efficient low power WAN (LPWAN) enabling technologies for IoT	LoRa is presented as the latest and most promising technology	[117]
Extracting and exploiting inherent sparsity for efficient IoT Support in 5G: Challenges and potential solutions	Scarcity in spectrum resources to provide support for IoT devices to enable 5G technology. Also, the radio access channel has many limitations to handle IoT enabled 5G devices	Wide-spectrum management techniques, D2D communications, and the concept of edge cloud solutions are presented	[106]
Energizing 5G	Keeping in mind the 5G-IoT scenarios, the efficient recharging of ubiquitous IoT devices is a tedious task	Solutions for the wireless powering of IoT devices using near and far-field techniques is provided. Furthermore, a new networking model called Wireless power communication network is introduced that integrates wireless power transmission and communication.	[2]
A Survey of 5G Network: Architecture and Emerging Technologies	To cope up with the needs of 5G enable IoT such as better data-rate, reduced latency, consistent quality of service and huge spectrum resources	5G cellular network architecture is presented with its enabling technologies such as M-MIMO, D2D communication. Other associated emerging technologies are also presented, such as ultra-dense networks, cognitive radios, millimetre-wave (mm-wave) solutions for 5G networks and cloud technologies, etc.	[53]
5G Backhaul Challenges and Emerging Research Directions: A Survey	The requirements for maintaining the high quality of service in a 5G paradigm present a bottleneck: backhaul. The requirements of backhaul must be addressed as it is responsible for connecting the highly dense and heavy traffic cells to the core	A joint radio access and backhaul framework is presented which addresses the QoS issues efficiently. The framework called Backhaul as a Service (BHaaS) which is a part of SDN with Radio access network (RAN) intelligence, Self-optimizing network (SON) and caching capabilities has a complete vision of end-to-end network and also enables optimization.	[68]
A Heuristic Offloading Method for Deep Learning Edge Services in 5G Networks	The limited computing resource and battery consumption of mobile devices (MDs), mobile tasks are often offloaded to the remote infrastructure, like cloud platforms, which leads to the unavoidable offloading transmission delay.	Computation offloading is a key technique for the deep learning edge services in 5G networks. In order to shorten the transmission delay of deep learning tasks, a heuristic offloading method is devised and shown	[97]

interconnection framework, facilitating a seamless connectivity of "things" with the Internet. [105]. The integration of 5G with IoT and AI has a huge impact on business by making predictions using available data and taking control decisions for enhancing the technology to improve quality-of-life.

V. CHALLENGES AND ISSUES

Current trends show that the future 5G-IoT network should be capable of supporting the massive connectivity of devices by providing high and consistent QoS. A 5G network has to cater for *massive* as well as *critical* IoT.

A. CAN 5G FIND THE BALANCE BETWEEN EASE OF CONNECTIVITY AND SECURITY?

The arbitrary connection of cellular phone devices, to the network, gives rise to security related issues such as interception of data flowing in a network and incorporation of unauthorized codes to unofficially control the network services. Thus, this exchange of data among devices, with the assistance of coexisting technologies, requires security at almost each relay node or a BS in order to sustain the security of the network services. Thus, it opens the window of opportunity for manufacturers to develop the systems which incorporate the intelligence in order to recognize, validate, and assign a session and authority with definite features. This makes it easy for end-users to fulfill and finish their task without any constraint and interruption in connectivity. With the evolution of software only, it is not possible to assure the security and protection of interconnected IoT-based 5G networks. There should be an association, joint effort, and coordination to strengthen the security. The implementation of secure boot and reliable execution environment contributes to the security of intelligent devices which protects them from illegal involvement of other devices. An amalgamation of intelligent system and security of software will not only strengthen the safe communication of interconnected IoT devices, but also motivates the novel approaches for upcoming wireless communication networks [96].

B. IS 5G FLEXIBLE ENOUGH TO FACILITATE DIFFERENT TYPES OF NETWORK CONFIGURATION?

The traffic generated by such IoTs is different from that generated by cellular systems in many aspects. First, unlike the case of broadband access, most IoT traffic is in the uplink. Moreover, IoT networks' messages are typically small in size and sparse in time. Furthermore, IoT devices are limited in energy and computation resources. These IoT devices' characteristics make their access to 5G systems different from classical cellular devices [106]. Identifying the right system parameter configuration for the specific IoT use case is a big challenge [107].

C. HOW WILL 5G CATER HIGHER DENSITY OF CONNECTED DEVICES?

Aggressive development of the cellular devices demands expandable and power-efficient foundation for communication without any hindrances. In 5G technology, one million devices could be connected over 0.38 mi^2, whereas in 4G, only two thousand devices can be connected [96]. This extensive coverage would significantly drain the battery of devices. The intelligent 5G-IoT network constitutes narrowband IoT (NB-IoT) that is required for effective energy utilization and it contributes to considerably lower-power communication. Thus, an intelligent 5G-IoT environment will assure the capability to process huge volume of data with minimal latency, reliability, and sustained accessibility of the network services. For effective management and handling of devices, the requirement of intelligence for IoT-based devices is essential especially when huge traffic is formed by all connected elements via Internet [96].

D. WILL 5G BE FUTURE-PROOF?

Among many challenges discussed for IoT access technology, coverage enhancement (CE) is one of the primary and challenging physical layer objectives to improve the *maximum coupling* required to support tactile internet and multimedia applications [108]. Security/privacy, energy efficiency and massive connectivity are other major concerns. Hence, research efforts are being actively pursued by researchers in each domain. The extensive research efforts are due to the high demands, and requirements of 5G enabled IoT networks driven by previously never thought-of use cases [108].

Apart from these initiatives, researchers are also putting efforts in providing solutions to the challenges related to the architecture, physical layer, channel access; energy efficiency and spectrum efficiency of 5G enabled IoT technology. Some of these researches and their solutions to the proposed challenges are listed in Table 11.

These requirements include high data-rate for high definition video streaming, augmented reality (AR) and virtual reality (VR) applications; The applications typically require very high data-rates, up to 25Mbps [51]. The 5G-IoT based network can totally be disintegrated due to the deficiency in exchange of information or data among systems. Thus, it encourages the research for new intelligent, publicly accessible standards for unseamed communication of interconnected and attached IoT devices. It is possible by ensuring the compatibility of the operating system for every object [109]. These standards can be widely implemented at the cloud platform to connect and enable interoperability [96].

Nowadays, deep learning is applied to IoT and mobile applications for implementing real-time or near real-time data processing tasks. Considering the limited performance of data transfer networks, transmitting massive data to Cloud for deep learning will consume much energy and produce much transmission delay, which reduces the efficiency of deep learning tasks [97]. The challenge of the cloud-centric system was considered, and an autonomous and incremental computing framework and architecture for deep learning-based IoT applications was proposed to tackle it [110].

Future intelligent systems require such IoT nodes to work under varying operating conditions, and with the network and cloud maximizing system intelligence while minimizing energy/information [111]. The method to maximize the overall performance of the network is to incorporate intelligence and self-adaptation into a self-organizing network (SON). The main goal of the SON is to improve service quality and reduce the costs associated with network operations by reducing human involvement while enhancing network performance [112].

The primary motives for using AI related technologies in the 5G-IoT infrastructures is to enable the network to intelligently adjust its configurations as the requirements or parameters of the environment change [101]. The new 5G network should be able to provide efficient solutions for radio resource management (RRM), mobility management (MM), management and orchestration (MANO), and service provisioning management (SPM), making dedicated purpose networks no longer necessary instead dynamic reconfigurations of networks [113].

VI. CONCLUSION

This paper presented an exhaustive review of the 5G wireless technologies that have become key enablers for the ubiquitous deployment of the IoT technology. The survey presented a review of the evolution of cellular wireless technologies making a case how 5G wireless technology improved upon its predecessor technologies, making ubiquitous deployment of IoT possible. The various architectural components of the 5G networks are also discussed, with special emphasis to the key improvements to the physical and network layer of 5G networks over its predecessors.

The paper also discusses in great depth the challenges of QoS requirements in modern day 5G-IoT whose traffic characteristics differs significantly from other legacy 5G network applications, being predominantly in the uplink direction instead of the downlink. High data transmission rates with low latency from the 5G-IoT nodes are vital for the cloud-based application layer programs running state of the art artificial intelligence, machine and deep learning algorithms for efficient real-time data processing and prediction. Such modern day applications running on top of 5G-IoT, e.g. smart transport, smart healthcare etc are also discussed, and benchmarks for acceptable performance, key performance indicators (KPIs) are also presented. Another challenge discussed in this paper is that of the standardization issues due to the several heterogeneous nodes participating in the 5G-IoT network (HetNets).

The comprehensive review presented in this paper will help in more coordinated efforts from both industry and academia for bringing about improvements in the 5G-IoT technologies.

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