2021 International Conference on Computational Performance Evaluation (ComPE)
North-Eastern Hill University, Shillong, Meghalaya, India. Dec1-3, 2021

A Study on 5G Technology and Its Applications in Telecommunications

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2021 International Conference on Computational Performance Evaluation (ComPE) | 978-1-6654-3656-4/21/$31.00 ©2021 IEEE | DOI: 10.1109/ComPE53109.2021.9752402

Abstract—***As the fifth generation of mobile networks climbs above the horizon, this technology's transformational impact and is set to have on the world is commendable. The 5G network is a promising technology that revolutionizes and connects the global world through seamless connectivity. This paper presents a survey on 5G networks on how, in particular, it to address the drawbacks of foregoing cellular standards and be a potential key facilitator for the future as well as the extant technologies such as IoT, V2X, etc. and a comprehensive review related to developing and facilitating technologies with the main focus on 5G mobile networks and technologies incorporated with the network for its enhancement. The challenges and open directions of research pertaining to making 5G applications more reliable for future use are also presented with effective context-specific congestion control tools. Hence, the lessons learned, unsolved challenges, and a consolidated review of 5G are presented.***

Keywords- 5G cellular network · 5G services · 5G key technologies · 5G architectures · 5G challenges

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I. INTRODUCTION

The first wireless phone technology was 1G, which was updated further to 2G in the early 1990s, enabling the customers to share text messages between two cellular handsets, which enthralled the sphere. In the fullness of time, the world moved on to 3G, which provided access to making phone calls, sending text messages, and browsing the internet. It could also download and upload big video files without any issues or dilatory. Then, to provide 4G connectivity, LTE, which stands for long-term evolution, was introduced. LTE became the swift and most reliable type of 4G, and it began to compete in the market with technologies such as WiMax. Both approaches produced similar results, but it was crucial to maintain a standard for the coming years. LTE attained all this by making 4G technologies markedly faster, laying a strong foundation for5G [1]. 5G networks have drawn enormous recognition from distinct vertical businesses varying from the manufacturing industry, smart cities, automotive, tourism, public utilities, etc. These vertical markets are made up of a vendors, ecosystem of operators, verticals, and SMEs, each with their own set of preferences and abilities to stimulate the adoption of 5G technology. [2]. The G represents a generation in 5G, and the number 5 denote the evolution. As 5G came into action, it can be summarized that the pace of life has escalated high. Supporting a variety of new applications/platforms, such as the Internet of Things (IoT) [3][4] [5], Augmented Reality (AR) [6],Virtual Reality (VR), , autonomous vehicles,Machine-to-Machine (M2M) communications [7][8], Tactile Internet (TI) [9], Multi- Access Edge Computing [10], and Software-defined networking [11] [12]. The Fifth Generation of the network (5G) and exceeding systems are presumed to deliver particular performance goals, including 20 Gbps peak data rate, 100 Mbps data rates at the cell edges, and 1ms round- trip latency [9]. 5G will push innovation over numerous industries and provide a platform facilitating emergent technologies such as the IoT and Cloud Computing to become an integral part of our economy and lifestyle.

Nonetheless, the integration of a ton of technologies to deliver numerous services end up creating several challenges for security and privacy [13], robustness, network resiliency, data integrity, and in the case of 5G, our environment too. Like every other technology, 5G has its pros and cons [5]. It is being necessary to automate and manage the increase either by further developments or by deploying other technologies like machine learning [4][14], blockchain [15][16][17], cryptography [18] to enhance a more complex 5G network just to undertake the difficulties and to satisfy the requirement of the 5G network.

As a result, the chief contribution of this paper is to serve as a reference work. The goal of this paper is to capture the essence of 5G and the application of various other technologies from a different perspective that can be applied to 5G networks. As AI, whose algorithms would then be utilized to discover accessible frequencies by enabling intelligent awareness of RF activity that was

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previously not practicable for its enhancement, and as machine learning (ML) to tackle security issues, such as intruder detection.

II. Literature Review

In Table 1, some of the recently published surveys and reviews on the 5G network, along with a brief description of the objective and key conclusions. Previous surveys addressed important problems in the 5G network, its potential solutions. Some suggest integrating several technologies with 5G networks like blockchain for security, machine learning to detect network intrusion and cloud computing to enhance and make the network more reliable. At the same time, some include the existing technologies that got augmented by the 5G network.

Table 1: A concise description of previous surveys on the 5G network

Author, Year, Ref	Title	Objective	Key Conclusion
S. K. Sharma et. al., 2020, [**9**]	Toward Tactile Internet in Beyond 5G Era: Recent Advances, Current Issues, and Future Directions	Comprehensive survey on5G-enabled TI along with the technical challenges and potential solutions.	Employing ML/deep learning techniques, predictive ML modules can help enhancing the stability of tactual communications.
Quoc-Viet Pham et. al., 2020, [**10**]	A Survey of Multi-Access Edge Computing in 5G and Beyond	Integration of MEC with new technologies.	MEC in 5G enabled VR/AR, autonomous vehicles by providing cloud-computing capabilities within RAN.
HasnaFourati et. al., 2021, [**4**]	A survey of 5G network systems: Challenges and machine learning approaches	Use of ML to subdue the challenges faced by 5G.	ML proved to be effective for reducing network costs by making predictions on catching decisions and 5G applications (IoT, TI).
LubnaNadeem et. al., 2021, [**7**]	Integration of D2D, NS and MEC in 5G Cellular Networks	To deal with the challenges which arise when the network gets inundated with users/ devices.	Integrating D2D helped to use the spectrum without dilation; MEC reduces complexity and NS to improve scalability.
M. Tahir et. al., 2020, [**17**]	A Review on Application of Blockchain in 5G and Beyond Networks	Use of Blockchain in 5G network to deal with the security and privacy issues..	Blockchain has the potential to enhance 5G by providing secure, cost-efficient and productive communication.
ShwethaVittal et. al., 2020, [**19**]	Adaptive Network Slicing with Multi-Site Deployment in 5G Core Networks	End-to-end network slice life cycle management of network slices on different sites.	Proposed algorithms for efficiently activating, deactivating, and decommissioning the network slices.
L. Chettri et. al., 2020, [**3**]	A Comprehensive Survey on Internet of Things (IoT) Toward 5G Wireless Systems	Review on emerging and enabling technologies related to 5G system that enables the internet of things.	Highlighted the enablling technologies in each layer of 5G-IoT as Low Power Wide Area Networks (LPWAN) in Network, Smart Society in Application.

III. 5G Architecture

5G networks have been directed to fulfil the needs of extremely mobile and thoroughly associated humankind. The accordance of humanistic and machine type applications represent distinct capabilities and working specifications that 5G networks need to support. In the 5G System (5GS), end-to-end (E2E), Software-Defined Networking (SDN), Network Functions Virtualization (NFV) [0], andnetwork slicing, service-based architecture is considered as the primary guiders to maintain the distinct complex key performance indicators (KPIs). KPIs need to be managed by economically using the latest use cases to increase network functionality.

In 5G, the network functions are split up by their service, and they communicate with each other via a service-based interface. That's the reason why the architecture of 5G networks is also termed as 5G core Service-Based Architecture (SBA). The topology diagram of 5G is illustrated in figure 1, demonstrating the crucial elements of a 5G core network.

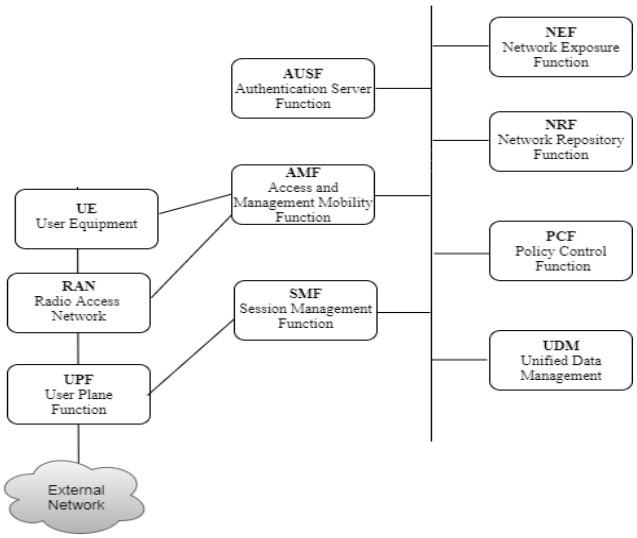

Figure 1: Topology Diagram of 5G Architecture

- User Equipment (UE) are the pieces of equipment

used to connect to the network like 5G smartphones or 5G devices. They link over 5G Radio Access Network (RAN) to the 5G core and then to Data Networks (DN), like the Internet.

- The Access and Mobility Management Function (AMF) is the sole entry point for the connection of UE as shown in figure 1.
- Depending on the kind of services demanded by the UE, AMF chooses a particular Session Management Function (SMF) to maintain the user session.
- User Plane Function (UPF) transfers the IP data traffic among the User Equipment (UE) and externally connected networks.
- The Authentication Server Function (AUSF) permits AMF to retrieve the services of 5G core and to authenticate the UE.
- Functions as Policy Control Function (PCF), Application Function (AF), Session Management Function (SMF), and Unified Data Management (UDM) produce and decide control framework for policy and its decisions. They also access the subscription information to control the behavior of the network.

In figure 2, the general network architecture of the 5G is shown.

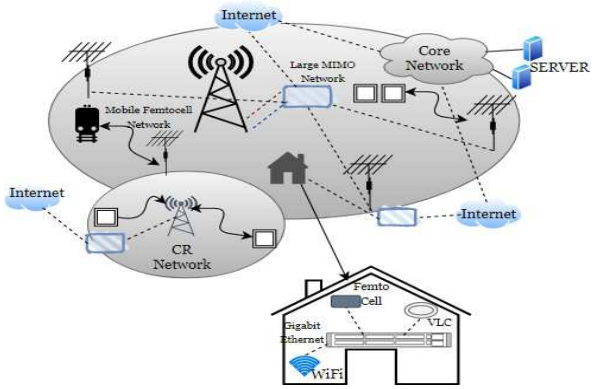

Figure 2: General Network Architecture of 5G

A. *Technology components in 5G Network*

- Radio-links contain the new approaches towards Multiple Access Control (MAC) and radio resources management.
- The spectrum includes the band of the operational frequency spectrum of the network.
- The network dimension includes traffic maintenance considering the demand of the network. It also includes approaches for the effective management of interference in distinct convoluted deployments.
- Multi-node and Multi-antenna transmissions are designing a system of multiple antennas based on a wide range of antenna configurations and modern inter-node coordination and multi-hop technologies.
- Massive Multiple-Input Multiple-Output (MIMO) [19] as shown in Fig2, is a technology that has been derived from conventional MIMO by upgrading it. Massive MIMO uses a set of a few hundred antennas at the same point of time and frequency slot. They then serve many tens of user terminals. The goal of Massive MIMO is to obtain all the advantages of standard MIMO, on a wide scale.

IV. Applications of 5G in the Digital Era

- IoT for various transportation, smart society, crucial infrastructure monitoring, smart grid, and health.

Internet of things (IoT) permits the feasibility to share information beyond various platforms by the interconnection between the internet and objects. An interconnection between intelligent sensing and devices is established to share information and allow a general picture of operation for permitting innovative applications [4]. 5G technology can connect a billion devices without the human interaction between them. The main demands of IoT include a high level of data rate, VR/AR, high definition video streaming, and network scalability [15].

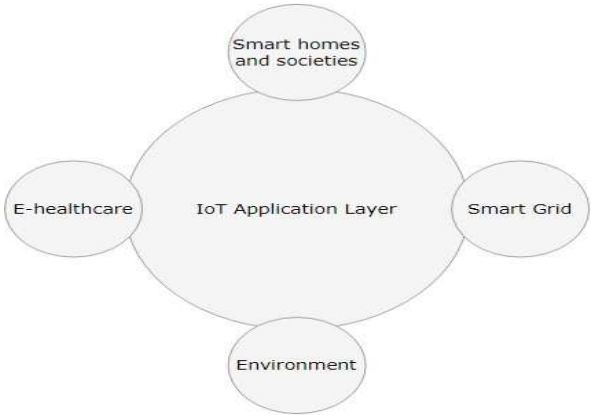

Figure 3: Use cases of IoT

- Vehicle to Everything (V2X) communication

Vehicle-to-vehicle communication (V2V), vehicle-to-network communication (V2N), vehicle-to-infrastructure communication (V2I),vehicle-to-pedestrian communication (V2P), and vehicle-to-network communication (V2N) are all possible with the Intelligent Transport System (V2N). All of these communication setups are part of the vehicle-to-everything communication system (V2X). These wireless activities, in contrast to traditional transportation systems, provide more dependable and pleasant transportation [20] Vehicle to everything (V2X) refers to thoroughly secure communication with great bandwidth and less latency among a wide collection of means of transportation and traffic-related sensors [5]. 5G as technology can have diverse consequences on the V2X ecosystem. In various types of vehicle connectivity incorporating V2X communications are illustrated. Vehicle to Pedestrian (V2P), Vehicle to Network (V2N), Vehicle to Infrastructure

(V2I), and Vehicle to Vehicle (V2N).

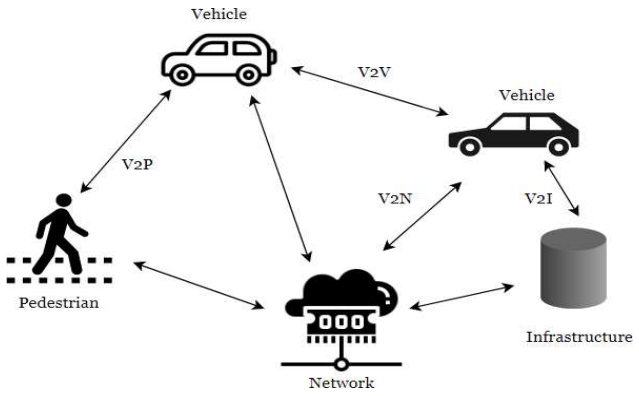

Figure 4: V2X Communications

To allow complicated vehicle operating, sharing their driving aims in fast two-way communications has to be achievable for autonomous vehicles. These interactions will make it feasible for vehicles to act as smart clusters rather than individual units.

- Augmented and Virtual Reality

The institution and commercialization of the 5G network by providing low latency and faster network speeds have impelled the latest developments in the world of AR/VR (augmented and virtual reality) technologies by powering opportunities for live, interactive experiences. The advent of Virtual Reality (VR) and Augmented Reality (AR) technologies has produced a diversity of new applications in various fields such as [6][21] , healthcare, tourism, etc., as listed below.

- Health Care: VR has proven to be a product extension to deplete the operational pain in patients undergoing surgery by its palliative results of decreasing the respiration rate, heartbeat, and blood pressure [9] . It can greatly help in the advancement of the field by connecting ambulances to radiology and high bandwidth. The 5G network can make health care requirements feasible by its collaboration with AR/VR.
- People with disabilities: Systems and assistance produced for disabled or elderly humans frequently find beneficial applications for their able-bodied equivalents– a few examples are subtitles in movies, TV shows which were developed for deaf users in the first place, amplification control for devices was developed for deaf and hard of hearing people but now is effective in a noisy environment, the audio books, podcasts were also originated for blind people, etc. Physically disabled students can benefit from the innovative Virtual Reality.
- Tourism: The evolvement of the 5G Smart Tourism (5GST) project illustrates the immersive experiences which have been never before known or experienced. The arts, culture, heritage, and tourism sectors be interactive and facilitated by 5G [22].

IV. AIM AND REQUIREMENTS OF 5G

The requirements are based on the users and technical system of 5G networks that are set to account for most needs. The golden triangle needs of the 5G network are Latency, Throughput, and Connection Density. Low latency is a basic requirement for use cases that require communications that are rapid and reliable, such as remote surgical procedures and V2V communications. So, a massive reduction in latency which can eventually lead to higher data rates, is expected.Then the Quality of Experience (QoE) i.e. the user's expectations, comes into play. QoE is the individual acceptability of the quality of a telecommunication service perceived by the user. Efforts on QoE in 5G networks continue to come up and focus on extending the work on normalizing the QoE mapping to network enhancement indicators. In Table 1, some of the ITU's IMT-2020 requirements set for the 5G network are listed.

Table 1: IMT-2020 requirements set for 5G

Performance Indicator	Target	Applicability
Connection Density	1 million devices/km2	eMBB
Peak Data Rate	20 Gbps for downlink 10 Gbps for uplink	eMBB
Latency (Control Plane)	10 ms	eMBB and URLLC
Latency (User Plane)	eMBB: 4ms for uplink 4ms for downlink URLLC: 0.5ms for uplink 0.5ms for downlink	eMBB and URLLC
Mobility Interruption Rate	0ms	eMBB and URLLC
Network Energy Efficiency	Efficient data delivery and granular discontinuous reception/discontinuous transmission	eMBB

5G network is designed to have connectivity for many devices to create a huge impact on IoT, V2X communications. Along with the speed and connectivity, there is a need to improve the flexibility and network availability towards signaling-based threats, including maliciously caused overloading for destruction. Various technologies such as machine learning [4], block chain [15][16], cryptography [18], etc., are being researched upon, which can aid to lessen the security threats to the 5G network.

After all the requirements that broadly aim to enhance the network's speed, connectivity, and security of the network there comes the need to lessen the energy dissipation by the network to preserve the environment [23].

V. CHALLENGES FACED BY 5G

During the deployment process, every industry has to look at numerous hindrances that can affect the network and identify an optimal solution to escape from that and meet the business demands of the end-user or any

corporation. Figure 3 depicts the major challenges faced by the 5G network [4][24].

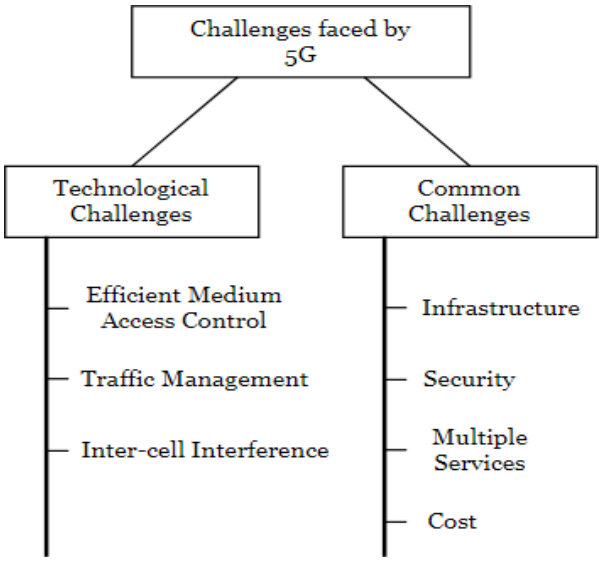

Figure 4: Challenges faced by 5G

- **Security:** Security attacks [13] are unethical or unauthorized attempts to steal, expose or cause damage. These attacks are categorized in two major types, viz, passive and active attacks. In the case of a passive attack, the attackers aim to use the data or information from the authorized users but don't propose to attack the communication. Passive attacks in a network are of two kinds, viz, traffic analysis and eavesdropping. These attacks intend to disrupt the data confidentiality and privacy of the user. Active attacks, on the other hand, include interference of legitimate communications or alteration of data. Common active attacks area man-in-the-middle attack (MITM), distributed denial of service (DDoS) attack, denial of service (DoS) attack, and replay attack [25].
- **Cost:** It's anticipated that the convolution of 5G and further networks will outpace an operator's capability to lead them from the initial to the end-stage. Hence, the resources need to be split among various stakeholders just so that multiple services can be provided to end-users across several areas. [16].
- **Infrastructure:** As the network evolves, it becomes difficult to correctly handle resource allocation among users and maximize the infrastructure's monetization. [26] Includes methods to increase throughput and ML approaches to meet the technological obstacles of normalization and utilization of 5G services [27].
- **Multiple Services:** Multiple services are all those services enabled by 5G for transmission of the signal. These services majorly rely upon the accessibility of the radio spectrum. Even in the presence of well-built computational powers, 5G technology still needs massive infrastructuremaintenance to process the large volume of data incoming from various individual sources.
- **Efficient Medium Control Access:** Medium Access Control i.e the access control methods which deal with collisions and function as a traffic light to allow a seamless flow of traffic over a network. If the heavy deployment of user terminals and access points is needed, the throughput there will be low and latency high. To give out large throughput, the existing hotspots will no longer be fit. It requires to be examined well to optimize the technology.
- **Inter-cell Interference:** One of the significant technical issues that have to be resolved is inter-cell interference. Due to differences in the measurements of conventional small and microcells, eventually, interference arises.

VI. Enhancement of 5G

To enhance the 5G network features, several technologies are being incorporated into it looking at the challenges faced by the network alone.

- **Cloud Computing:** Cloud computing draws notable recognition as it gives ubiquitous access to a shared heap of customizable computing resources with the least maintenance effort. As networks become denser due to multiple devices, the interference scenarios become more complex as the inter-cell interference rises, which cause multitier interference. [28]Cloud computing allows for resource sharing by virtualizing physical infrastructure, which can then be deployed dynamically to meet the demands of diverse complex computer infrastructures and applications. Servers, networks, storage, services, and applications are examples of physical resources that may be shared. The cloud computing ecosystem relies heavily on Service Providers (SPs) and Infrastructure Providers (InPs).[17]. Cloud computing is seen as a solution for smart gadgets that can't handle large volumes of data. It addresses the difficulty of calculating. In 5G, the cloud can help with the complex maintenance of dense networks. In a centralised way, it manages network components, collects data, and composes the needed specifications.

- **Software-defined networking (SDN):** Software-Defined Networking (SDN) is a unique intelligent architecture for networks to diminish hardware restrictions. It seems to be a reliable technology for network virtualization. It has emerged to enable the users to maintain the network equipment using software that can run on stock hardware rather than promptly run on a switch or router. In the 5G network, SDN is liable for regulating and managing the applications in a network-wide manner [28]. It reduces the cost of construction and training the network's intelligence, consequently minimizing the network complexity.

- **Network Function Virtualization (NFV):**[28][29]: NFV architecture virtualizes all network operations such as VPN, firewall, and router, which were previously handled on dedicated hardware and now operate on cloud infrastructure. It allows a network operator to deliver virtual networks with features specific to certain services via a network infrastructure in the 5G Core (5GC). The operator provides these services through network slices that are administered by a comparable network slice and belong to a certain user.

SDN and NFV are incorporated in the same architecture to get access to intelligent and adaptable services. For better resource allocation and load-sharing, both SDN and NFV use data centers. They upgrade the performance of Device-to-Device communication in 5G architecture. NFV can constructively maintain many connections that enhance IoT and Machine-to-Machine communications in the 5G network. Additionally, the SDN controller makes use of ML algorithms to provide intelligent global network control.

- **Network Slicing:** Video streaming, remote surgery, and smart metering all have different necessities regarding the quality of service and Quality of Experience (QoE). Hence, the network has to meet such a broad range of quality of service necessities. Till now, the cellular network's central objective has been to make the network seem resolute, i.e. confined to some particular use cases, by providing high-speed connectivity [17]. SDN and NFV technologies, on the other hand, have enabled the slicing of physical network infrastructure into multiple virtual networks, known as network slices.[30][31] .Network Slicing gives several logical networks the ability to share partial network infrastructure. [32]An independent end-to-end network is denoted by every instance of a network slice which then enables the deployment of different architectural flavors in parallel slices. Network slicing permits the production of logical networks that are under every application's quality of service requirements. Notwithstanding the benefits it delivers to network operators, there are a few challenges as well. In [33] various challenges raised by Network Slicing are demonstrated.

Although the SDN and NFV are proven to be effective for network slicing in a mobile network, efficient end-to-end slice management in the 5G network system is a challenge. So, to facilitate the network's connectivity, latency, and throughput, each proposed service still needs to be looked.[26]

VII. CONCLUSION AND FUTURE DIRECTIONS

In this section, potential succeeding inclinations in the domain of 5G and some specific recommendations to upgrade the quality of the network are described that are to be formed in future research activities.

This paper discussed the architecture, key technologies enabled by 5G as IoT, V2X, and AR/VR. The benefits and challenges such as security, cost, traffic management, etc., are faced by the 5G network. It gives a concise survey on existing and advancing 5G architectures by integrating cloud computing, SDN and NFV architecture, ML for network intrusion etc. The survey distinctly underscores how the 5G network can become a backbone for several technologies like IoT, V2X, AR/VR, etc. As the process and further developments of the 5G network unfurl, global organizations will prove it to be quintessential to allow a cross-industry commitment in organizing and developing the 5G system.

The prevailing expectations and expected development of the 5G are reassuring to present innovative services and quality of experience (QoE) for the users. However, it is highly challenging because of the restrictive nature of the network when it comes to resources. This resource-constrained nature of the network has compelled the researchers to assure that the conditions for the vast deployment of several applications are achieved. It is intelligible that further research needs to be initiated into how to resolve the challenges faced by the network, out of which some are listed in the paper. Some challenges regarding reliability i.e safeguarding the network from attacks, how to make the network completely autonomous, and lastly, how to competently balance the cost and efficiency of the network remain open.

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