5G and Beyond: IoT Support in Next-Generation Networks

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Abstract
The arrival of 5G signals the beginning of a new era of connectivity, one that has the potential to transform many sectors. The promotion of the Internet of Things (IoT), which is a vast network of interconnected devices, is central to this transformation. This article looks at the potential of 5G and its future iterations to facilitate the smooth integration of IoT, addresses the main issues and looks at future developments. It highlights the key characteristics of 5G that make it a perfect platform for the IoT, including Ultra Low Latency (ULT), enhanced Mobile Broadband (eMBB), as well as Massive Machine-to-Machine (mMTC) Communication. The paper further looks at the role of network slicing in customizing network resources to meet the specific needs of various Internet of Things applications. The paper concludes by looking at the possibilities of 6G and other technologies in enhancing the Internet of Things through advanced innovations such as artificial intelligence.

Keywords: *IoT, 5G, URLLC, eMBB, AI, mMTC.*

1. INTRODUCTION

Mobile communication has developed into an essential aspect of today's society, facilitating daily life and contributing to economic development. The technology underpinning mobile networks has made significant progress, from first generation (1G) to the current standards of fourth generation (4G). The main areas of progress are energy efficiency, data transmission speeds, bandwidth use and spectrum management strategies. Each generation is characterised by the dominance of a particular technology: TDMA for 2G, FDMA for 1G, CDMA for 3G, or OFDMA for 4G. The arrival of the 5G generation is expected to transform wireless broadband significantly.

The Internet of Things (IoT), a ground-breaking technological development, has linked billions of devices through the Internet, creating vast sets of data. This data holds significant potential to transform productivity, efficiency, as well as decision-making processes. Nonetheless, the realisation of IoT's full capabilities depends heavily on the availability of stable and dependable connectivity. The deployment of 5G technology, with its sophisticated features, is positioned to furnish the critical infrastructure necessary to foster innovation within the IoT domain. The emergence of 5G signifies a pivotal shift in wireless communication, fundamentally altering the connectivity landscape and facilitating a wide range of applications, especially within the context of IoT (Andrew, 2023). These attributes are essential for accommodating the expanding requirements of IoT, which includes a diverse spectrum of devices and applications, from intelligent home systems to driverless vehicles. The design of 5G networks should support around one million devices per square kilometre, enabling the development of large-scale IoT ecosystems that require not only high data rates but also reliable and stable connectivity (Andrew, 2023). The architecture of 5G includes sophisticated attributes such as network slicing, allowing for customised network configurations to meet specific application requirements, thus increasing the performance of different IoT applications. This flexibility is essential as industries increasingly rely on real-time data exchange and communication between machines and people. In addition, the introduction of ultra-reliable low-latency communication (ULLLC) in 5G networks will ensure that critical applications such as remote surgery and self-driving cars can run smoothly with minimal latency.

The future Internet of Things (IoT) vision has been shaped by major developments in telecommunications, informatics, and wireless sensor networks, all of which have made pervasive intelligence a reality. The idea of IoT began in the 1980s with the idea of ubiquitous computing, which sought to integrate technology into daily life. The current vision for IoT is that it would be used in both personal and business contexts. IoT is essential for raising the quality of life for individuals via applications like e-health, smart homes, and intelligent learning environments. IoT has applications for professionals in remote monitoring, logistics, automation, smart supply chain and transportation (Shafique, et al. 2020).

1.1 Background, Motivation and Overview

By the year 2025, it is anticipated that internet nodes will be integrated into nearly all objects, resulting in a substantial increase in internet-connected devices. Cisco projects that this figure will escalate to approximately 500 billion by 2030. Similarly, in 2013, Telefonica estimated that by 2020, 90% of vehicles would be connected to the internet. However, a 2015 survey indicates that over 250 million vehicles worldwide are expected to be internet-enabled by 2020, representing a growth of 67%. The Internet of Things (IoT) is among the prominent emerging trends of the current decade. Furthermore, according to Gartner's IT Hype Cycle, it was predicted in 2011 that IoT would require five to ten years for widespread market adoption. Consequently, an expenditure of approximately US $1.7 trillion on IoT is projected by 2020, as estimated by the IDC (Shafique et al., 2020).

The swift evolution to 4G from 1G and subsequent generations has not only enhanced communication capabilities but also facilitated the emergence of a diverse range of services and applications. Mobile phones operating on the 1G standard were prevalent during the 1980s, utilising analogue FM modulation with FDMA in accordance with the AMPS standard in the United States. The advent of 2G technology in the early 1990s marked a transition to digital formats, introducing features such as text messaging. 2G employed digital voice transmission through digital modulation techniques and utilised standards such as GSM, CDMA, and others. The emergence of 3G around the year 2000 represented a significant growth towards digital data access, enabling more sophisticated mobile services (Jain & LF-IAFI, 2013).

1.2 Research Objectives

i. To access the capabilities of 5G and its successors
ii. To study the challenges of IoT and propose solutions using 5G
iii. To examine the main features of 5G for an ideal platform for IoT

1.3 Importance 5G and IoT Support in Next-Generation Networks

The concepts underlying the Internet of Things (IoT) provide numerous services applicable across various sectors, including smart cities, smart grids, smart homes, and a wide range of business opportunities. These enable organisations to develop innovative strategies and models for implementing IoT-based solutions. Beyond commercial prospects, IoT also offers valuable avenues for conducting efficient and resourceful research within multidisciplinary fields. Despite the extensive presence of IoT concepts in academic literature, it is now imperative to devote greater attention to these ideas, as we stand on the cusp of a transformative era driven by IoT. This transformation is shifting our daily experiences from familiar routines to environments characterised by intelligent interactions with millions of devices, facilitated by emerging platforms. Furthermore, IoT is redefining the world into a 'smart' environment, where accessibility is enhanced, and tasks are completed more swiftly and with less effort, as illustrated in Figures 1 (a-b).

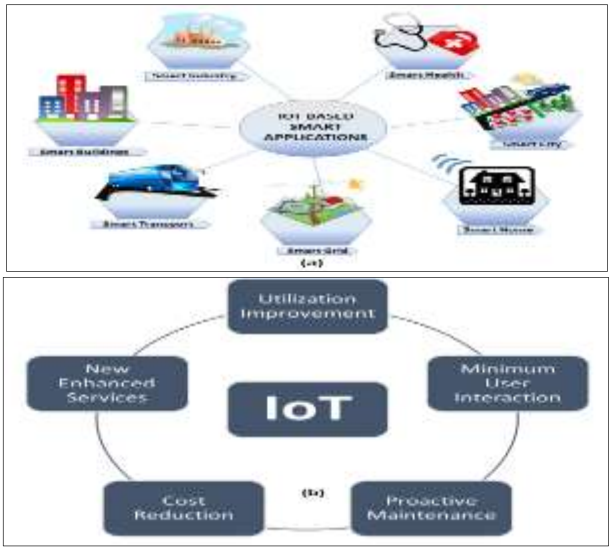

Figure 1: Block diagram of (a) IoT-based smart applications and (b) IoT advantages as a cutting-edge technology (Shafique et al., 2020).

The Internet of Things (IoT) revolutionizes the global environment into a sophisticated, interconnected system where access to information is streamlined, reducing both time and effort, as illustrated in Figures 1 (a) and (b). As noted by Sahinel, et al. (2017), smart homes exemplify an IoT application that generates extensive data streams from various sensors, including temperature sensors, smart meters, security cameras and multimedia devices as well as lighting controllers. Presently, the majority of sensory data collected from these devices are processed locally, thereby minimizing communication challenges. The terminology associated with these technologies—such as augmented reality, virtual reality, real-time pattern recognition, tactile Internet, and semantic recommendations is now widely recognized. A shared characteristic among these applications is their reliance on remote processing; that is, sensory data must be analyzed in computationally advanced remote servers, such as virtualized cloud platforms, with the results subsequently delivered to users. The significance of IoT in supporting the development of next-generation networks can be further understood through these aspects.

i. **Healthcare IoT:** Certain pathologies have a pronounced impact on society by contributing to widespread healthcare challenges. Furthermore, Souza et al. (2020) introduce an alternative model that leverages IoT systems for the organisation and segmentation of pneumonic CT images, employing machine learning techniques—specifically Parzen's probability distribution—for robust learning strategies. Their model incorporates an application programming interface (API) that utilises the Internet of Medical Things to interpret lung imagery. The methodology demonstrated high efficiency, achieving accuracy rates exceeding 98% in the classification of aspiratory images. Subsequently, the model advances to the segmentation phase, utilizing the Mask R-CNN architecture to generate a lung mask and applying adjustments to delineate pneumonic boundaries within the CT images. This approach outperformed comparable studies in the literature, attaining high segmentation accuracy—up to 98.34%. Notably, the entire process was completed in approximately 5.43 seconds, and the method exhibited improvements over other transfer learning models, establishing itself as a fully automated system that enhances both speed and precision in lung image analysis.

ii. **Industrial IoT:** The advancement of intelligent industries has exerted a significant and lasting influence on the inevitable evolution of global manufacturing. Industry 4.0 has integrated smart industry within cyber-physical systems, facilitating more sophisticated and efficient technological developments, thereby enhancing quality, performance, management, controllability, and equity of industrial processes in the context of IoT-enabled smart industries. The development of more affordable sensing technologies in the next generation is fundamental for effective data collection and the reliable operation of manufacturing sectors and supply chains.

iii. **Next-generation IoT-based smart healthcare:** The integration of Internet of Things (IoT) technology within healthcare is increasingly adopted in commercial sectors. Numerous solutions have been developed to support individual healthcare needs. Nonetheless, there remains significant potential to improve IoT-enabled healthcare systems as vital medical services and to transform hospitals into secondary healthcare facilities. Consequently, it is crucial to identify prospective advancements that can address the challenges and issues associated with achieving these goals. Future developments may include the implementation of real-time location tracking for patients with Alzheimer's disease, utilizing geospatial sensors to monitor their whereabouts continuously. Additional emerging healthcare technologies encompass real-time detection of epileptic seizures and strokes, augmented reality (AR) and virtual reality (VR) applications for telehealth, portable summarised electronic health data, blockchain-based secure data services (Zikria et al., 2021).

iv. **IoT-based smart agriculture as a Next-generation:** Next-generation Internet of Things (IoT)-enabled smart agriculture is anticipated to enhance farming practices and techniques to support sustainable farming communities and resource management. This approach is economically viable, socially stable, and demonstrates effective performance. Its primary objectives include maintaining soil health, mitigating soil degradation and erosion, and conserving water resources. Implementing sustainable smart agriculture systems contributes to increasing land biodiversity and fostering a healthy, environmentally friendly landscape. It is crucial to align these initiatives with the growing focus on food security and environmental change, as well as addressing future ecosystem degradation. Such strategies play a vital role in conserving natural assets, reducing emissions of ozone-depleting gases, preventing biodiversity loss, and preserving valuable landscapes.

2. 5G CAPABILTIES FOR IoT

Mobile phones have become an essential component of contemporary society, facilitating daily activities and contributing significantly to economic development. The evolution of cellular technology has been marked by substantial advancements, progressing from 1G to the current 4G standards, with notable improvements in data transmission rates, energy efficiency, bandwidth utilization, and spectrum management. The main performance metrics for IMT-2020 are:

i. **Data Rate:** his specification enables improved mobile broadband (eMBB) data transfer, achieving peak data rates of up to 10 Gbps for uplink and 20 Gbps for downlink. User experiences based on empirical evidence have indicated uplink data rates of 50 Mbps and downlink rates of 100 Mbps. Additionally, the spectral efficiency obtained is 15 bits per second per Hertz (bps/Hz) for the uplink and 30 bps/Hz for the downlink. The traffic capacity for the designated area is established at 10 Mbps for each square meter.

ii. **Density:** The smallest connectivity density is one million devices for each square kilometer is necessary to support the development of mMTC and guarantee a specific quality of service (QoS).

Significant technical challenges must be addressed in order to achieve this aim. Dense deployment of wireless cells, Massive MIMO, beamforming, and mmWave are all viable solutions for increasing data rates and cell capacity. Because of its propagation features, mmWave technology is suitable for short-range applications. However, some of the capabilities of the 5G network are described as follows:

i. **Enhanced mobile Broadband:** Dynamic spectrum access enhances spectrum efficiency (SE) by optimising the allocation of radio resources. Accurate performance and quality assessments are crucial for all mobile network operators to ensure the maintenance and monitoring of their existing quality of service (QoS). Consequently, fifth-generation (5G) networks offer improved mobile broadband (MBB) capabilities, supporting high-speed data transmission, video streaming with low latency, and seamless mobility.

ii. **Broadband IoT extends** high-speed enhanced Mobile Broadband (eMBB) services are essential for data-intensive Industrial Internet of Things (IIoT) applications. In contrast to conventional eMBB, these specific use cases necessitate distinct requirements and unique traffic patterns. To mitigate this issue, broadband Internet of Things (IoT) endeavors to deliver supplementary IoT-centric functionalities, encompassing reduced latency, enhanced battery longevity, extended coverage, and improved uplink data rates.

While based on 5G reliability-enhancing features, below are some of the selected once:

- Ultra-reliable low-latency communications (URLLC) necessitate highly robust modulation and coding schemes, in contrast to conventional wireless traffic that typically employs link adaptation strategies with error rate targets ranging from 10% to 30%. To satisfy the stringent reliability demands of URLLC. Since the control channel plays a vital role in configuring communication parameters, enhancing its robustness is critical; nonetheless, grant-free (GF) transmission schemes can alleviate the need for additional redundancy by reducing control signalling overhead.
- Diversity techniques, including multi-antenna configurations, utilisation of multiple carriers, and packet duplication at the physical (PHY) and medium access control (MAC) layers, constitute essential components of the reliability strategies employed in URLLC.
- Network slicing enables mobile network operators (MNOs) to establish multiple virtual networks over a shared physical infrastructure. Each slice comprises a dedicated or shared subset of network functions and resources—such as processing capacity, storage, and bandwidth—to deliver specified quality of service (QoS) levels to individual customers. This approach supports diverse service categories, including enhanced mobile broadband (eMBB) and URLLC, by allowing slices to operate concurrently while maintaining isolation consistent with service level agreements tailored to various vertical industries. Network slicing can extend across all segments of a 5G system, encompassing access, transport, cloud, and core networks, and even span multiple operators. This innovative feature of 5G facilitates the creation of multiple virtual networks atop a single physical infrastructure, which is particularly advantageous for Internet of Things (IoT) applications, as it permits customized allocation of network resources to meet the specific needs of different IoT use cases.

3. Challenges and Solutions

i. **The Challenge of Device Density:** The rapid proliferation of mobile devices mandates the development of scalable and energy-efficient networking infrastructures to facilitate seamless communication. Whereas 4G technology is capable of accommodating approximately 2,000 devices per square mile, 5G technology aspires to connect millions of devices within an equivalent spatial context. This heightened density of devices, however, presents considerable challenges, especially concerning the longevity of battery life.

ii. **Data Rate Compatibility:** One of the foremost challenges within the realm of the Internet of Things (IoT) pertains to the assurance of compatible data transmission rates among devices. In instances where one device produces data at a velocity surpassing the processing capabilities of another, congestion may ensue. To mitigate this issue, sophisticated IoT devices possess the capability to dynamically modulate data transmission rates and buffer dimensions in order to enhance overall performance.

iii. **Heterogeneous Devices:** The amalgamation of a multitude of devices possessing disparate capabilities presents substantial challenges within the realm of the Internet of Things (IoT). In order to remediate this issue, sophisticated platforms have the potential to promote seamless interoperability among heterogeneous devices, thereby facilitating efficient communication and data interchange. By endowing IoT devices with cognitive capabilities, they become adept at adjusting to varying protocols and standards, thus guaranteeing a fluid user experience.

The primary obstacle to the successful deployment of the Internet of Things (IoT) lies in the absence of a universal platform, protocol, and programming language. Currently, each connected device adheres to its own distinct set of protocols and platforms. There is an urgent need for interoperability among these devices to facilitate seamless communication. To achieve this, major corporations such as LG, Samsung, and Philips should collaborate to establish a consortium dedicated to developing a universal coding language and platform. Such an initiative has the potential to substantially address the compatibility challenges faced by IoT systems (Ahmed, Yaqoob, Gani, Imran and Guizani, 2016).

4. IoT USE CASES ENABLED BY 5G

The advanced capabilities of 5G open up a wide range of innovative applications of the IoT in different sectors. These applications will benefit from the high speed, low latency and massive connectivity characteristics of 5G, delivering unprecedented value and performance.

Table 1: IoT Use Cases Enabled by 5G

Sector	Use Case	5G Benefit
Smart Cities	Intelligent Traffic Management	Real-time data processing for optimal traffic flow
Healthcare	Remote Surgery	Ultra-low latency for precise control
Manufacturing	Industrial Automation	Massive device connectivity for smart factories
Agriculture	Precision Farming	Wide coverage for remote field monitoring
Automotive	Autonomous Vehicles	High reliability for safety-critical communications

5. Conclusion

As we embark upon a novel epoch characterized by enhanced connectivity, the synergistic interplay among 5G technology, forthcoming iterations of network architectures, and the Internet of Things (IoT) is set to profoundly revolutionize our societal framework. The augmented functionalities of these networks will enable a degree of device interconnectivity and data transmission that was once relegated to the domain of speculative fiction. The range of applications, which includes advanced urban environments that optimize resource allocation and elevate quality of life, as well as healthcare systems that provide customized, immediate treatment, is extensive and possesses considerable transformative capacity. As continuous innovation perpetuates the expansion of achievable possibilities, it is projected that the IoT, supported by sophisticated network infrastructure, will evolve into an indispensable and seamlessly integrated component of quotidian existence, promoting enhanced efficiency, sustainability, and the creation of new opportunities across various sectors.

References

Ahmed, A. I. A., Gani, A., Ab Hamid, S. H., Abdelmaboud, A., Syed, H. J., Mohamed, R. A. A. H., & Ali, I. (2019). Service management for IoT: requirements, taxonomy, recent advances and open research challenges. *IEEE Access*, *7*, 155472-155488.

E. Ahmed, I. Yaqoob, A. Gani, M. Imran and M. Guizani, "Internet-of-Things-based smart environments: State of the art taxonomy and open research challenges", *IEEE Wireless Commun.*, vol. 23, no. 5, pp. 10-16, Oct. 2016

El-Saleh, A. A., Alhammadi, A., Shayea, I., Hassan, W. H., Honnurvali, M. S., & Daradkeh, Y. I. (2023). Measurement analysis and performance evaluation of mobile broadband cellular networks in a populated city. *Alexandria Engineering Journal*, *66*, 927-946.

Javaid, N., Sher, A., Nasir, H., & Guizani, N. (2018). Intelligence in IoT-based 5G networks: Opportunities and challenges. *IEEE Communications Magazine*, *56*(10), 94-100.

Jain, P. C. Recent Trends in Next Generation Cellular Mobile Network-5G and beyond (6G).

K. I. Pedersen, et al.,(2018) "Preemptive scheduling of latency critical traffic and its impact on mobile broadband performance," in IEEE VTC Spring, pp. 1–6

Li, Q. C., Niu, H., Papathanassiou, A. T., & Wu, G. (2014). *5G Network Capacity: Key Elements and Technologies. IEEE Vehicular Technology Magazine, 9(1), 71–78.* doi:10.1109/mvt.2013.2295070

Mahmood, A., Beltramelli, L., Abedin, S. F., Zeb, S., Mowla, N. I., Hassan, S. A., ... & Gidlund, M. (2021). Industrial IoT in 5G-and-beyond networks: Vision, architecture, and design trends. *IEEE Transactions on Industrial Informatics*, *18*(6), 4122-4137.

N. Kaur and S. K. Sood (jun. 2017) "An energy-efficient architecture for the Internet of Things (IoT)", *IEEE Syst. J.*, vol. 11, no. 2, pp. 796-805

Shafique, K., Khawaja, B. A., Sabir, F., Qazi, S., & Mustaqim, M. (2020). Internet of things (IoT) for next-generation smart systems: A review of current challenges, future trends and prospects for emerging 5G-IoT scenarios. *Ieee Access*, *8*, 23022-23040.

Zikria, Y. B., Ali, R., Afzal, M. K., & Kim, S. W. (2021). Next-generation internet of things (iot): Opportunities, challenges, and solutions. *Sensors*, *21*(4), 1174.