# Applications and Future Challenges of IoT Communication in 5G Network

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**Abstract:** This paper delves into the transformative impact of 5G technology, which extends beyond traditional mobile broadband, offering faster communication and expanded capacity. It explores the integration of the Internet of Things (IoT) with 5G, highlighting its potential to redefine human-machine interactions and revolutionize various sectors. By enabling seamless device integration, 5G and IoT together open up possibilities in home automation, smart transportation, farming, and urban development. The research investigates the evolving landscape of IoT deployments, examining challenges and opportunities in their integration with 5G networks. Through exploring IoT applications, the paper aims to showcase how these technologies enhance utilization and processing across different domains, elucidating their transformative potential for future applications.

**Keywords:** Internet of things (IoT), 5G networks, IOT applications, Quality of Service (QoS), Enhanced Mobile Broadband (eMBB), Machine Type Communication (mMTC), Industrial IoT (IIoT), Device-to-Device (D2D) communication.

## 1. Introduction

The advent of 5G technology holds promise for addressing the evolving needs of future IoT (Internet of Things) applications. The integration of 5G and IoT is expected to present novel research challenges and unparalleled opportunities. The Internet of Things (IoT) is a concept that aims to connect various everyday physical objects, ranging from household appliances like microwaves to infrastructure elements like doors and lighting systems. These objects are equipped with sensors that collect data about their environment or usage. This data is then transmitted to a central server or cloud platform for analysis. Once the data reaches the server, it undergoes analysis to extract meaningful insights and patterns. This analysis can lead to the generation of actionable information, which is used to trigger specific behaviors or actions. For example, in a smart home setting, IoT devices can adjust lighting levels based on occupancy patterns or regulate temperature settings based on weather forecasts. The evolution of IoT has resulted in billions of connected devices being able to access the internet, leading to significant impacts on various aspects of daily life. This connectivity enables enhanced automation, efficiency, and convenience in both residential and commercial settings. Table 1 illustrates that 5G networks aim to rectify the limitations of previous generations (2G/3G/4G) while introducing new features [1]. These features encompass various Quality of Service (QoS) specifications, support for high data traffic volumes, and the facilitation of multiple wireless links, all of which are crucial for 5G-IoT applications. However, the convergence of these technologies brings both advantages and disadvantages, not only in terms of implementation costs but also in solution development. The primary objective of 5G is to enhance communication speed and security. Therefore, the amalgamation of speed, protection, and low-cost deployment, coupled with the allure of innovative 5G technologies and applications, is poised to empower new businesses and foster a plethora of smart applications. Nonetheless, the integration of 5G with IoT holds the promise of broadening the potential scope of IoT by making it faster, safer, and more secure. With future 5G access extending to wearable devices such as smartwatches and health trackers equipped with artificial intelligence (AI) and machine learning (ML) capabilities, the applicability of 5G technology becomes evident. In this article, we will delve into discussions surrounding 5G smart applications, and various challenges.

The existing wireless technologies like 3G and 4G are insufficient for the requirements of 5G, especially for low-power wide-area (LPWA) technology and long-distance communication. 5G is expected to utilize unlicensed or unused spectrum bands and be accessed through LPWANs like SigFox, LoRa, WiFi, ZigBee, and NB-IoT. Narrowband IoT (NB-IoT) operates in standalone, in-band, and guard band modes, each with specific applications. [2, 3].

Table :1-Outcomes of telecom generations.

| Generation | Latency | Objectives |
|---|---|---|
| 1G | ~1s | Voice communication |
| 2G | >100ms | Voice and Data communication |
| 3G | <100ms | Mobile Broadband |
| 4G | ~50ms | Advanced LTE |
| 5G | <10ms | Real-time application , Massive IoT |

## 2. Classification of 5G-IoT

Broadband IoT, Critical IoT, and Massive IoT are three classifications used to categorize Internet of Things (IoT) applications based on their specific requirements and characteristics [4, 5].

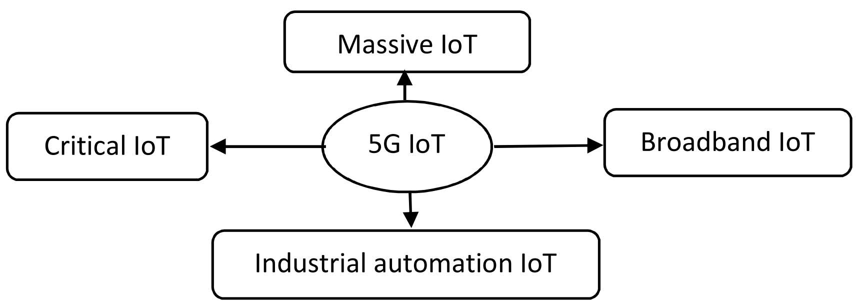


**Fig. 1**. Classification of 5G-IoT.

### 2.1 Broadband IoT

Broadband IoT, also known as enhanced Mobile Broadband (eMBB), refers to IoT applications that require high throughput and capacity.
Focuses on delivering high-speed data transmission for applications with significant bandwidth requirements. Typically, it involves applications that prioritize data transfer rates and high-quality media streaming.
**Examples:**

Augmented Reality (AR) and Virtual Reality (VR) applications.
Ultra High Definition (UHD) video streaming.
Cloud gaming services.
High-resolution surveillance systems.

### 2.2 Critical IoT:

Critical IoT, also known as Ultra-Reliable Low Latency Communication (URLLC), encompasses IoT applications that demand high reliability and very low latency [6]. Prioritizes real-time communication and requires minimal latency to ensure a timely response. Typically used in applications where reliability and instantaneous data transmission are crucial, often involving safety-critical operations.

**Examples:**

- Industrial automation (Industry 4.0) for real-time control of manufacturing processes.
- Tactile Internet applications, which require haptic feedback for remote control systems.
- Medical applications such as robotic surgery and remote patient monitoring where any delay could be life-threatening.

### 2.3 Massive IoT:

Massive IoT, also known as massive Machine Type Communication (mMTC), refers to IoT applications that require scalability to accommodate a massive number of devices [7]. It involves connecting many IoT devices to the network simultaneously. Emphasizes efficient resource utilization and scalability to support massive device deployments.

**Examples:**

- Smart city deployments involve thousands or millions of connected sensors for monitoring and managing urban infrastructure.
- Environmental monitoring systems include the widespread deployment of sensors for collecting data on air quality, temperature, and pollution levels.
- Supply chain management, with extensive tracking of goods and assets throughout the logistics process.
- Real-time tracking of assets (such as containers, vehicles, or tools) ensures efficient utilization and prevents loss.
- Smart bins equipped with sensors monitor fill levels. Waste collection routes are optimized, reducing operational costs and environmental impacts.
- IoT sensors collect real-time data on traffic flow, congestion, and accidents. This information helps optimize traffic management and reduce congestion.

## 3. Applications of 5G IoT

These days, applications are used in two categories: those related to personal use and those related to business use. Each of these categories requires a unique set of requirements in order to function at its best, and in this section, we will examine these two categories and attempt to explain the necessity of 5G as well as its implications [8, 9].

### 3.1 Non – Industrial applications / User applications

Applications used by regular users on a daily basis are known as user applications, and they vary depending on the user. These applications are less sensitive to network delay and require fewer data rates than industrial applications [10]. We might arrange this application in the following order based on the most common uses:

**Smart Cities:** 5G IoT enables the development of smart city infrastructure, including applications such as smart lighting, intelligent transportation systems, waste management, environmental monitoring, public safety, and urban planning. Sensors and devices connected to 5G networks provide real-time data for efficient city management and improved quality of life for residents [11].

**Healthcare:** In healthcare, 5G IoT supports various applications such as remote patient monitoring, telemedicine, medical wearables, smart hospital systems, and surgical robotics. High-speed and low-latency connectivity provided by 5G networks enable healthcare professionals to deliver timely and efficient care, regardless of the location of patients or medical facilities [12]. Examples-

*Telemedicine:* Real-time video consultations between patients and healthcare providers. Remote diagnosis and treatment planning.

*Wearable Health Monitors:* IoT-enabled wearables (such as smartwatches) track vital signs (heart rate, blood pressure, etc.). Alerts for abnormal readings or emergencies.

*Smart Medical Facilities:* IoT sensors monitor hospital equipment, patient beds, and environmental conditions. Predictive maintenance for medical devices.

*Precision Medicine:* AI-driven analysis of patient data (genomics, medical history) for personalized treatment. Drug discovery and targeted therapies.

*Emergency Response:* 5G enables real-time communication between emergency responders and hospitals. Ambulance telemetry and remote triage.

**Smart Agriculture:** 5G IoT solutions are deployed in agriculture for precision farming, crop monitoring, livestock tracking, environmental sensing, and automated irrigation systems. By collecting and analyzing data from sensors and drones, farmers can optimize resource usage, increase crop yields, and reduce environmental impact [13]. Examples-

*Precision Farming:* Monitor soil conditions, temperature, and humidity using IoT sensors. Optimize irrigation and fertilization based on real-time data.

*Livestock Monitoring:* Track animal health, behavior, and location using wearable devices. Detect anomalies early and improve livestock management.

*Crop Monitoring:* Use drones equipped with cameras and sensors to monitor crop health. Detect pests, diseases, and nutrient deficiencies.

*Automated Machinery:* Deploy autonomous tractors and harvesters for efficient field operations. Optimize routes and reduce fuel consumption.

*Supply Chain Management:* Monitor storage conditions during transportation using IoT-connected containers. Ensure food safety and reduce waste.

**Home Automation:** 5G-IoT enables the development of smart home solutions for home security, energy management, appliance automation, remote monitoring, and assisted living. Connected devices such as smart thermostats, security cameras, smart appliances, and voice-controlled assistants communicate over 5G networks to enhance convenience, comfort, and energy efficiency for homeowners.

**Entertainment and Media:** 5G-IoT technology is poised to revolutionize the entertainment and media industry by enabling various innovative applications and services:

*Enhanced Streaming:* With high-speed and low-latency connections, 5G facilitates seamless streaming of high-definition and ultra-high-definition content, offering viewers an immersive entertainment experience.

*Live Events:* 5G enables real-time broadcasting of live events with enhanced quality and reliability, allowing audiences to participate remotely in concerts, sports events, and more.

*Augmented and Virtual Reality (AR/VR):* 5G's low latency and high bandwidth support AR/VR applications, offering immersive gaming experiences, virtual tours, and interactive storytelling.

*Personalized Content Delivery:* 5G enables personalized content delivery based on user preferences and behavior, enhancing user engagement and satisfaction.

*Remote Production:* 5G facilitates remote production capabilities, allowing media companies to produce and broadcast content from remote locations efficiently.

## 3.2 Industrial IoT (IIoT)

Industrial IoT (IIoT), also known as Industry 4.0, refers to the integration of industrial processes, machinery, and devices with digital technologies and the internet. When combined with 5G networks, IIoT becomes even more powerful, enabling a new era of smart manufacturing, automation, and data-driven decision-making in various industrial sectors [14, 15].

**Transportation and Logistics:** 5G IoT applications in transportation and logistics include asset tracking, fleet management, autonomous vehicles, traffic management, and supply chain optimization. These applications rely on high-speed connectivity and real-time data exchange to enhance efficiency, safety, and sustainability in the transportation industry.

**Industrial Automation (Industry 4.0):** 5G IoT facilitates the implementation of Industry 4.0 initiatives in manufacturing and industrial settings. It enables real-time monitoring and control of production processes, predictive maintenance of machinery, remote operation of equipment, and seamless integration of robotics and automation systems.

**Energy Management:** 5G IoT enables smart grid solutions for efficient energy distribution, renewable energy integration, demand-side management, and grid optimization. IoT devices connected to 5G networks help utilities monitor energy usage, predict demand patterns, and implement demand-response programs to balance supply and demand.

**Real-time monitoring:** By monitoring equipment in real-time, IIoT systems can detect anomalies and predict potential failures, allowing for proactive maintenance. Real-time data monitoring enables industries to optimize their processes by identifying inefficiencies promptly and making adjustments for improved productivity. Industries can ensure product quality by monitoring critical parameters in real-time, allowing for immediate adjustments to manufacturing processes to maintain quality standards.

## 4. Future challenges of 5G-IoT

As 5G IoT applications become more prevalent, the demand for bandwidth will escalate, posing challenges for network infrastructure to handle the surge in data traffic. The seamless integration of 5G IoT with existing digital infrastructure and technologies requires careful planning and coordination, which may pose challenges due to dependencies and interoperability issues. Here are the few challenges of 5G IoT:

### 4.1 Complex-Network-Architecture

The challenges of 5G IoT in reference to complex network architecture are multifaceted and require a comprehensive approach to address. Here are some of the key challenges:

**The challenges of 5G IoT across different layers:** The challenges of 5G IoT across different layers are significant and diverse, impacting various aspects of network architecture and functionality. Here's a breakdown of some of the key challenges at different layers:

*Physical Layer:* The Physical Layer is the lowest layer in the OSI (Open Systems Interconnection) model. This layer faces challenges such as managing the high-frequency spectrum of 5G, including millimeter waves, which have a shorter range and require a denser infrastructure. It deals with the actual transmission and reception of raw data bits over a physical medium (such as cables, fiber optics, or wireless channels). Additionally, ensuring the physical security of the network against tampering and unauthorized access is crucial [16].

*Network Layer:* The Network Layer is responsible for routing, forwarding, and addressing. It ensures efficient data transmission across interconnected networks. Challenges include the development of new routing protocols to handle the increased traffic and the need for network slicing to allocate resources dynamically based on the service requirements. 5G networks handle significantly higher data volumes due to enhanced mobile broadband (eMBB) and massive machine type communication (mMTC). Existing routing protocols may struggle to manage this increased traffic efficiently [16].

*Transport Layer:* The Transport Layer is pivotal in 5G networks, handling the complex task of managing end-to-end communication between devices. In the dynamic landscape of 5G, maintaining seamless connectivity across diverse networks with varying demands is crucial. This layer faces the challenge of ensuring reliable data transfer amidst mobility and fluctuating service requirements, which are inherent characteristics of 5G networks. Achieving consistent and dependable connectivity in such dynamic environments is a significant challenge that the Transport Layer must address for the success of 5G communication [17].

*Session Layer:* The Session Layer in network communication is responsible for managing the sessions between devices. This layer handles the establishment, maintenance, and termination of connections between applications. In the context of 5G networks, which are designed to support a large number of IoT (Internet of Things) devices, each device establishes sessions to exchange data. It is essential to efficiently manage these sessions to ensure seamless communication. One significant challenge in 5G networks is maintaining uninterrupted connectivity during handovers, which happen when a device moves from one cell (coverage area) to another. Handovers must be managed carefully to minimize the risk of dropping connections, ensure a smooth transition between cells, and maintain a consistent communication experience for users [18].

*Presentation Layer:* The Presentation Layer focuses on data representation and translation, ensuring that data exchanged between devices and services can be interpreted correctly. With IoT devices utilizing diverse data formats like JSON, XML, and binary, the Presentation Layer is crucial for handling format conversions to facilitate interoperability. Additionally, it addresses the challenge posed by different devices and services using proprietary or standard protocols, ensuring seamless communication across disparate systems [19].

*Application Layer:* The Application Layer is the topmost layer in the OSI model. It is responsible for managing communication between applications and the underlying network infrastructure. In the context of 5G, the Application Layer plays a crucial role in enabling various services and applications to function seamlessly over the high-speed, low-latency 5G networks. At this layer, challenges encompass crafting applications capable of harnessing the entire spectrum of 5G's speed and latency capabilities while safeguarding user data's privacy and security [20].

**Network Slicing Management:** Network slicing allows a single physical network infrastructure to be partitioned into multiple virtual networks, known as slices, to serve diverse services, including IoT applications [21]. Managing these slices effectively poses several challenges:

*Slice Design and Resource Allocation:* Efficient slice design requires optimizing resource allocation based on IoT use case requirements, including bandwidth, latency, and QoS. Dynamic slice creation and resource optimization algorithms ensure optimal resource utilization.

*Isolation and Security:* To maintain data privacy and prevent interference between slices, robust isolation mechanisms and security protocols, such as virtualized firewalls and access controls, are essential.

*Inter-Slice Interference:* The coexistence of multiple slices can lead to interference, impacting performance. Techniques like frequency planning and dynamic spectrum sharing mitigate interference issues.

*Slice Mobility and Handovers:* Seamless handovers between different slices, considering their specific requirements (e.g., latency or throughput), are complex. Intelligent handover mechanisms need to be developed for a smooth transition.

*Scalability and Slice Density:* Managing a large number of slices as IoT device deployments increase requires scalable management architectures and efficient slice allocation algorithms.
Effectively addressing these challenges is crucial for enabling network slicing to meet the diverse requirements of IoT applications and ensure efficient and reliable network operation.

**Security and Privacy:** Protecting the network from cyber threats and ensuring the privacy of the data being transmitted over 5G networks is a major concern. This includes securing the network architecture from potential breaches.

*Privacy Challenges:*

Location Tracking: 5G networks rely on a multitude of smaller antennas and base stations, both indoors and outdoors. While this enhances coverage, it also enables precise location tracking. Each time a user connects to a 5G antenna, their location can be pinpointed, even down to the specific building they are in.
Semantic Information Attacks: These attacks exploit location data, potentially revealing sensitive information about users.
Access Point Selection Algorithms: These algorithms can inadvertently leak location data.
Identity Concerns: Attacks like International Mobile Subscriber Identity (IMSI) catching can expose user identities [22].

*Security Solutions:*

Comprehensive Measures: Security must span various operations, including radio transport, telco cloud, IoT devices, security operations, and slicing security.
Encryption and Authentication: Robust encryption and authentication mechanisms are essential to safeguarding user data.
Threat Detection: Real-time monitoring and detection of security threats.
Edge-Based Security: As 5G enables edge computing, securing distributed resources becomes critical.
IoT Device Security: Protecting IoT devices from vulnerabilities and ensuring confidentiality [22].

*5G Impact on Networks:*

Speed and Capacity: 5G promises faster speeds and greater capacity.
Reduced Latency: Ultra-low latency benefits real-time applications.
Flexible Service Delivery: 5G enables dynamic service provisioning.
Complex Security Landscape: The interconnection of distributed resources and edge-based computing introduces new security challenges. [23].

*IoT Device Security:* IoT devices on 5G networks will need robust security to prevent loss of confidentiality and protect against vulnerabilities. This includes addressing both technical and human-centric issues [24].

User Awareness: Educate users (including employees and consumers) about security best practices. Users should understand the risks associated with IoT devices and follow guidelines.
Privacy Settings: Provide clear privacy settings for users. Allow them to control data sharing and permissions.
Default Credentials: Avoid using default credentials for IoT devices. Change the default passwords during setup.
Physical Security: Protect physical access to devices. Unauthorized physical access can compromise security.
Network Segmentation: Separate IoT devices into different network segments. Critical devices should be isolated from less critical ones.
Network Monitoring: Continuously monitor network traffic for anomalies. Detect and respond to suspicious behavior promptly.
Firewalls and Intrusion Detection: Deploy firewalls and intrusion detection systems to safeguard against attacks.

**Quality of Service (QoS):** Quality of Service (QoS) in 5G IoT is a crucial aspect that ensures the network can meet the specific performance requirements of various IoT applications. Here are some key points about QoS in 5G IoT:

*High Data Rate and Low Latency:*

High Data Rate: Applications like autonomous vehicles, smart cities, and healthcare demand large bandwidth and high data rates.
Low Latency: Real-time responsiveness is critical for applications such as remote surgery or industrial automation [25].

*Reliability:*

QoS ensures reliable data delivery. For critical IoT applications, timely and accurate data transmission is vital.

Imagine a medical device sending patient data—reliable delivery is crucial to prevent life-threatening situations [25].

*Resource Management:* Efficient management of network resources is necessary to handle the massive number of IoT devices, ensuring that each device receives the necessary bandwidth and connectivity. Challenges addressed by resource management are as follows [26].

Massive Device Deployment: The proliferation of IoT devices demands efficient resource allocation. 5G networks are expected to connect billions of devices, making resource management critical.

Diverse IoT Applications: IoT applications vary widely, from smart cities to industrial automation. Each application has unique resource requirements (e.g., latency, data rate and reliability).

Dynamic Network Conditions: 5G networks are dynamic, with varying traffic loads, mobility, and interference. Resource management must adapt to changing conditions.

*Future Research:* Challenges in 5G-IoT are as follows [27].

Ensuring that IoT applications receive the required QoS while leveraging the capabilities of 5G networks.

Developing QoS-aware solutions that work across different IoT platforms and technologies.

Designing QoS mechanisms that scale efficiently with the increasing number of connected devices.

Allocating resources dynamically based on real-time demands. Ensuring consistent QoS across edge nodes.

Enhancing security without compromising QoS.

QoS mechanisms must adapt in real time.

**Device-to-Device Communication:** Device-to-Device (D2D) communication in 5G IoT devices is a transformative feature that enables direct communication between devices without the need for intermediary network infrastructure. Here's how D2D communication impacts 5G-IoT [28, 29]:

*Enhanced Efficiency:*

D2D allows IoT devices to transmit data directly to each other.

This improves energy efficiency by avoiding unnecessary hops through the network infrastructure.

It also reduces latency, benefiting real-time applications.

Support for V2X (Vehicle-to-Everything):

D2D is crucial for V2X communications.

V2X includes Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), and more.

It enables safer driving, traffic management, and autonomous vehicles.

*Increased Capacity:*

By offloading traffic from the cellular network, D2D increases overall system capacity.

Devices communicate directly, freeing up network resources.

*Security Considerations:* Security in D2D communication is paramount, as it involves direct links that could be susceptible to eavesdropping or interference. Solutions include encryption, authentication, and secure key distribution mechanisms.

*Challenges:*

Interference Management: Coexistence with existing cellular networks requires interference mitigation.

Seamless Integration: Ensuring smooth integration of D2D with cellular infrastructure.

Reliability Enhancement: Ongoing research aims to enhance D2D reliability.

### 4.2 Ultra-High Frequencies

UHF refers to radio frequencies in the range of 30 GHz to 300 GHz. 5G uses ultra-high frequencies, which face challenges through passing obstructions and have short propagation distances [30].

*Challenges with UHF in 5G:*

Obstruction Penetration: UHF signals struggle to penetrate solid objects (walls, buildings, and trees). This limitation affects indoor coverage and connectivity.

Short Propagation Distances: UHF waves travel shorter distances compared to lower-frequency bands. To provide coverage, 5G networks need more base stations, especially in densely populated areas.

Energy Efficiency: Balancing high-speed data transfer with energy efficiency is crucial.

Harmonization and Spectrum Availability: Ensuring harmonized spectrum allocation globally. Managing spectrum availability for optimal network performance.

Security and Device Availability: Addressing security concerns in UHF communication. Ensuring a wide range of compatible devices.

Ultra High Definition (UHD) apps and other advancements in video quality have led to this issue. 5G addresses 4G's shortcomings. Real-time UHD audio and video activities will be possible with 5G. 5G will work with all earlier versions of technology. 5G will function at a minimum of 1 Gbps and even faster. significant obstacle 5G will make use of UHF, which cannot pass through obstructions. There will be short propagation distances. Future difficulties could relate to UHF, low frequency, automation requirements for installations, energy efficiency, harmonization and availability of the spectrum, security, and device availability.

## 5. Conclusion

The fusion of 5G technology with the Internet of Things (IoT) presents a transformative opportunity to revolutionize connectivity across industries. 5G's rapid communication, expanded capacity, and reduced latency mark a significant leap forward in wireless technology, enabling innovative solutions globally. Integrating IoT with 5G networks enhances device connectivity and communication, paving the way for advancements in home automation, smart cities, and industrial processes. Despite its vast potential, challenges such as device compatibility and security must be addressed for seamless integration and scalability. Looking ahead, 5G-enabled IoT applications promise to reshape user experiences and drive innovation. Collaboration among stakeholders is crucial to navigate complexities and realize the full potential of these technologies, fostering a more connected and efficient world. Thus, proactive efforts are essential to harnessing the transformative power of 5G-IoT for the benefit of society.

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