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A REVIEW OF COMMUNICATION TECHNOLOGIES FOR NEXT-GENERATION IOT WITH FOCUS ON 5G, LPWAN AND EDGE NETWORKING PARADIGMS

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Abstract: This fast rate of digitalization, the device growth as they are connected, and the changing nature of how they are used are changing the nature of next-generation IoT systems. Flawless communication and low latency, combined with dependable connections, have emerged as essential prerequisites for smart IoT services in various fields, including remote monitoring, healthcare, industrial automation, and smart cities. At the forefront of this shift are the new communication technologies 5G, edge computing, and Low-Power Wide Area Networks (LPWAN). Regarding data speed, energy consumption, wide-area coverage, and real-time responsiveness, each offers special advantages. This paper presents a systematic survey of these enabling technologies, with an emphasis on their synergistic combination and complementary nature in providing scalable and survivable IoT infrastructures. The analysis identifies the factors through which the combination of 5G, LPWAN, and edge networking can address major issues in IoT rollouts, such as network overload, device heterogeneity, and the provision of distributed real-time analytics. Furthermore, the paper highlights some of the most significant implementation issues, including spectrum allocation, power limitations, security loopholes, and the lack of standardization. Through this review, an in-depth overview of the communication systems that will fuel the next generation of IoT is provided, with references made to existing capabilities, integration approaches, and research directions. Future research directions include the creation of harmonized architectures, secure-by-design communication models, and adaptive management of heterogeneous and dynamic IoT environments.

Keywords: 5G Communication Systems, Low Power Wide Area Networks (LPWAN), Edge Computing, Next-Generation IOT, Real-Time Analytics, Mobile Edge Computing (MEC).

1 INTRODUCTION

The Internet of Things (IoT), as a developing process, is quickly changing the paradigm of the digital world, uniting physical items and facilitating real-time data transfer and automated processes in various industries[1]. Such massive interest in the use of IoT has necessitated the development of the next-generation communication technologies to cater to the various and high-volume applications like environmental monitoring, driverless cars, smart agriculture, and industrial automation.

In many of their conventional wireless technologies, such as Wi-Fi and 3G/4G, there are often limitations in terms of their scalability, latency, energy efficiency, and range, which makes them inapplicable in next-generation IoT-based demands[2]. To overcome these difficulties, three major paradigms for Five-Generation (5G) communication, the enabling paradigm for next-generation IoT infrastructures, have been identified as edge computing and Low-Power Wide Area Networks (LPWAN).

5G technology offers extremely low latency, high throughput, and connection for large devices, making it suitable for handling real-time performance-sensitive mission-critical IoT applications[3]. LPWAN technologies simultaneously provide long-range communication of at least 10 km with low power consumption and great scalability[4]. These characteristics make LPWAN suitable for applications that don't need frequent data transfer[5]. But its advantages are offset by other features like small message capacity coupled with lower transmission frequency, which can limit the volume of data and the effectiveness of the security policy.

The edge computing paradigm can improve IoT systems in order to lessen reliance on centralized cloud resources, by decentralizing data processing to the edge devices or as close to the edge devices where data is generated as is practical[6]. This reduces latency, increases bandwidth efficiency, and improves decision-making. Innovations in mobile computing, wireless sensors, and communication technologies have also hastened the process of edge computing in IoT[7]. Fog computing and mobile edge computing (MEC), as well as lightweight cloudlets are edge networking architectures that support local processing and analytics[8]. Such a model assists in reducing the load of the network and improving the responsiveness in real-time. There is now active consideration of combining 5G, LPWAN, and edge computing to develop IoT systems that are effective, scalable, and safe.

This review paper provides an in-depth analysis of these three paradigms of communication, describing their technical bases, deployment structures, areas of implementation and challenges that have been encountered. It discusses hybrid systems, such as the 5G-LPWAN combination with smart city applications, non-terrestrial FWA, the use and security of SDN/NFV-based slicing, and so forth. It also brings into focus new research on the energy efficiency of LPWAN, standards work, and open research questions concerning fields such as environmental monitoring, logistics, and healthcare.

1.1 Structure of the paper

The structure of this paper is as follows: Section II outlines the fundamentals of next-generation IoT communication. Section III discusses advancements in 5G, LPWAN technologies. Section IV presents edge computing paradigms. Section V analyzes a literature summary of the study. Section VI concludes with insights and future research directions.

2 5G COMMUNICATION AND IOT INTEGRATION

The IoT explosive growth necessitates reliable communication solutions that guarantee scalability, low latency, energy efficiency, and seamless connectivity. This paper investigates how 5G, LPWAN, and edge networking may be integrated as the fundamental building blocks of next-generation IoT systems[9]. 5G provides high-speed, low-latency communication through EMBB, MMTC, and URLLC, allowing real-time applications in smart cities, transportation, healthcare, and agriculture. LPWAN offers energy-efficient long-range connectivity for low-data devices, while edge computing enhances real-time processing at the network edge. Together, these paradigms form an interconnected framework for scalable, intelligent, and secure IoT ecosystems.

2.1 Features and Architecture of 5G Network in IOT

5G is anticipated to outperform ultrabroadband networks and integrate current technologies like blockchain, Using the IoT, cloud, artificial intelligence, and big data to help create new services. Within the context of 5G, three distinct categories of 5G characteristics for IoT include:

- **Enhanced-Mobile-Broadband (eMBB):** The eMBB is a rather simple development of the improved mobile broadband customer experience, which includes encouraging even greater consumer efficiency.
- **Massive-Machine-type Connectivity (mMTC):** The term "mMTC" refers to establishments that stand out for having a variety of gadgets. These systems use very little computer power and have incredibly cheap system costs.
- **Ultra-Reliable and Low-Latency Connectivity (URLLC):** This technology provides latency-reactive tools for a variety of applications, including virtual surgery, autonomous driving, and industrial automation. Sub-millisecond latency is required for this system, which is less than one packet loss in 105 packets[10].

The IoT in the context of 5G comprises a primary four-layer architecture that relates to the following aspects of data collection, processing, analysis, and information sharing across devices and communication networks:

- **Thin layer:** Actuators, devices, sensors, and other physical systems are included in this layer, which also connects to the network layer.
- **Network layer: The** two sublayers of the network layer are (1) 5G backhaul-based connections and (2) low-power wide area technologies (LPWANs), which include SigFox, LoRa, ZigBee, and NB-IoT.
- **Middleware layer:** This layer is regarded as the network's core. The IoT framework emphasizes cutting-edge technologies and solutions like edge computing and fog computing.
- **Application layer:** This layer displays IoT applications that are utilized across several industries, including traffic systems, agriculture, factories and buildings, and IoT ecosystems[11].

2.2 Real-World Applications

The correct operation of business processes depends on dependable and effective connections for IoT devices, which can only be achieved by optimizing 5G networks for IoT services. The IoT and 5G's conceptual operation is depicted in Figure 1 to make a variety of applications possible in a number of fields, including:

- Smart cities and IoT devices allow for the collection of data on energy use, air quality, and traffic patterns in real time[12].
- In healthcare, IoT devices can be used for real-time physician-to-physician communication and remote patient monitoring.
- In transportation, IoT devices may provide users with real-time information on vehicle performance and traffic patterns, it can then be used to improve traffic flow and security.
- Agricultural production may be streamlined and waste can be reduced by using IoT devices to provide real-time data on crops and livestock.
- Retail IoT installations may be made to record real-time information about inventory levels and consumer behavior, which can then be utilized to optimize shop operations and improve the customer experience[13].

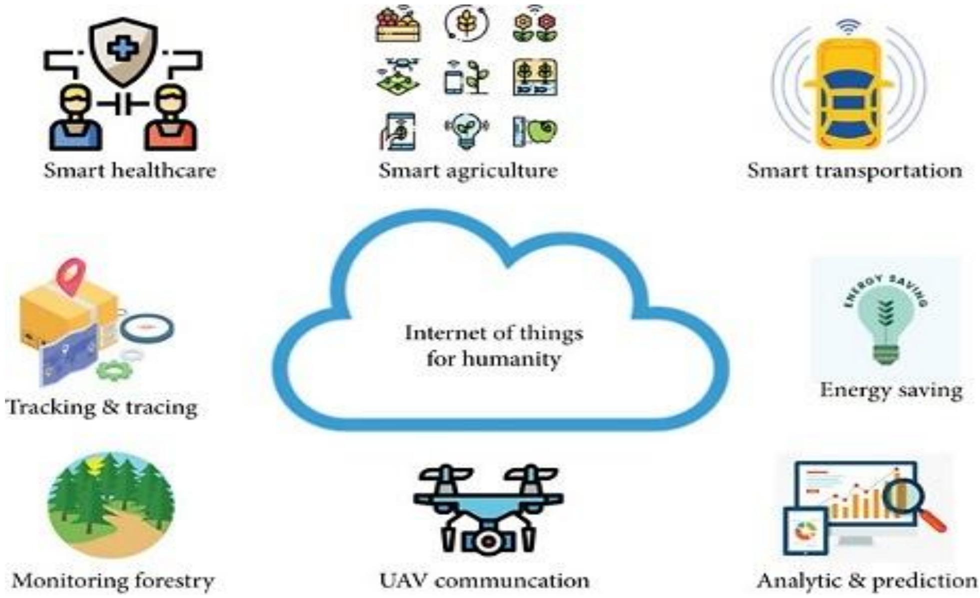

Figure 1: An illustration of IoT applications for humanity.

2.3 Implementation Barriers and Research Directions

Implementing 5G-enhanced IoT on a large scale presents substantial challenges, with infrastructure development being one of the most pressing issues. Unlike previous generations, 5G networks are dependent on a dense small-cell network, compact antennas and transmitters placed much closer together than traditional cell towers to deliver the fast, low-latency connectivity needed for IoT applications. Furthermore, the deployment of IoT devices itself must occur concurrently with the implementation of 5G infrastructure in order to effectively benefit from 5G for IoT[14]. If 5G coverage does not align with IoT demand, devices may suffer from inconsistent connectivity, undermining possible uses for 5G, including remote surgery, driverless cars, and smart agriculture.

Future Prospects of 5G-Enhanced IoT drive a significant transformation across various industries, enabling the widespread adoption of IoT technologies. As industries like agriculture and transportation increasingly adopt 5G-enhanced IoT technologies, they generate innovation that can result in sustainable practices and improved services, in addition to increasing operational efficiency. The ability to harness real-time data and automate processes empower these sectors to respond more effectively to changing conditions, ultimately driving growth and competitiveness in an ever-evolving global market[15].

3 LPWAN TECHNOLOGIES FOR ENERGY-EFFICIENT IOT

Low-Power Wide Area Networks (LPWANs) have become a cornerstone in supporting energy-efficient, large-scale IoT deployments, especially where devices require long-range connectivity with minimal power consumption. Protocols like LTE-M, Sigfox, NB-IoT, and LoRa provide affordable and scalable solutions for low-bandwidth applications in sectors like smart agriculture, logistics, and asset tracking. Their strengths lie in long coverage range, battery longevity, and simplified infrastructure[16]. However, deployment challenges persist, including limited mobility support, interoperability gaps between licensed and unlicensed bands, and security vulnerabilities. Addressing these issues is essential for ensuring LPWAN's full potential in next-generation IoT frameworks.

3.1 LPWAN Protocols Key

As 5G has just been introduced in IoT and the wireless telecommunications sector are expanding quickly in many facets of daily life. IoT devices must be able to function both when moving and at vast distances. It is true that using a wireless medium makes it simpler to link several of these devices under a single network. The higher performance of LPWAN-based protocols makes them superior than cellular IoT protocols. Examining the five protocols from an application standpoint, the most widely used physical layer communication protocols for IoT deployment standards are:

- Sigfox
- LoRa
- Z-Wave
- NB-IoT
- LTE-M

According to comparative analysis, future internet applications are most suited for LPWAN-based protocols because to their ideal energy efficiency, cost, and capacity[17], thereby proving that LPWAN protocols have provided the best application viewpoint for the industrial IoT and are The future protocols for the upcoming industrial revolution.

3.2 Use Cases in Low-Bandwidth Applications

The deployment of a large-scale IoT paradigm now heavily relies on LPWAN. Examples of LPWANs that function effectively in long-range, low-bandwidth networks are LoRaWAN, NB-IoT, and Sigfox, battery-constrained IoT applications, which are discussed below:

- **LoRaWAN:** LoRaWAN technology offers reliable coverage even at lower spreading factors, particularly in challenging environments with poor radio wave propagation conditions. Its robust modulation scheme enables effective communication in non-line-of-sight and obstructed areas, making it suitable for remote and urban deployments alike. Additionally, network performance is optimized via its adaptive data rate (ADR) system by balancing communication range and energy efficiency.
- **NB-IoT:** NB-IoT is gaining significant traction due to its low deployment complexity, extended battery life, wide coverage range, and its capability to support a high device density, which makes it perfect for extensive IoT applications. Compared to unlicensed LPWAN alternatives, operating inside licensed spectrum guarantees greater dependability and less interference. Its seamless integration with existing cellular infrastructure further accelerates adoption across sectors like smart metering, logistics, and environmental monitoring.
- **Sigfox:** Sigfox uses tracking sensor nodes within a cloud-based architecture for network allocation and execution. LPWAN, especially with Sigfox, is effective for short-range platform tracking due to its low power and lightweight communication. The cloud system aids in device coordination and data handling, making it suitable for low-data, energy-constrained IoT applications.
- **Weightless, LTE-M, and Others:** Other LPWAN variants include Weightless (W, N, P), which support both licensed and unlicensed spectrum and flexible topologies. LTE-M (LTE Cat-M1), another 3GPP cellular IoT standard, provides reduced power profiles and greater data speeds and mobility support than NB-IoT. These alternatives broaden the LPWAN landscape by catering to diverse QoS requirements and deployment conditions.

These networks are ideal for use cases that value cost-effectiveness, energy efficiency, and wide-area coverage over real-time streaming or high-throughput data, since they are built for sporadic, small-payload transmissions, usually ranging from a few bytes to a few hundred bytes[18].

3.3 Deployment Challenges of LPWAN in IoT

Deploying LPWAN in large-scale IoT environments poses several operational and technological issues that need to be carefully resolved in order to guarantee reliable and expandable performance[19]. These challenges arise due to the limitations in bandwidth, interference in unlicensed spectrum, network scalability, and device mobility, and further complicating real-world deployment are below:

- **Scalability & Network Management:** LPWAN protocols are constructed to support massive device densities; the deployment in urban and rural environments frequently results in network overload, packet collisions, and bandwidth contention[4].
- **Mobility Support:** The majority of LPWAN protocols were defined with stationary or low-mobility nodes in mind, and handover and tracking of moving assets such as vehicles or drones were not kept particularly simple.
- **Interoperability & Integration:** With varying designs and management systems, LPWAN ecosystems are divided between cellular (NB-IoT, LTE-M) and unlicensed (LoRaWAN, Sigfox) standards.
- **Security & Reliability:** LPWAN standards simplify security measures in order to save money and energy, such as by employing weak symmetric encryption and minimum authentication, which leaves them vulnerable to replay, DoS, and eavesdropping attacks[20].
- **Quality of Service (QoS) Limitations:** Most LPWAN technologies are designed for delay-tolerant, low-throughput applications and thus offer limited QoS guarantees. This makes them unsuitable for time-sensitive or bandwidth-intensive IoT use cases, in situations when latency and dependability are crucial, such emergency response systems or real-time video surveillance.

4 EDGE COMPUTING AND NETWORKING PARADIGMS FOR IOT

Edge networking has emerged as a decentralizing computing and, putting processing closer to data sources, making it a vital enabler for next-generation IoT systems. For uses like smart cities, smart transportation, and healthcare, this change minimizes latency, lessens reliance on the cloud, and facilitates real-time decision-making. Multi-access Edge Computing (MEC), cloudlets, and fog computing are examples of architectures that offer adaptable frameworks for localized data processing[21]. However, managing distributed, heterogeneous infrastructures introduces challenges in security and orchestration. Innovative approaches like SDN, NFV, federated learning, and blockchain are being explored to enhance security, scalability, and automation, positioning edge computing as a key pillar in integrated 5G and LPWAN-enabled IoT ecosystems.

4.1 Concept and Role of Edge Computing

The term "edge computing," which first surfaced in 2002, describes a framework that allows computation to occur near data sources by placing computer power at the periphery of the network. Any type of networking or computer equipment that sits between data sources and cloud DCs might be considered an edge device[22]. Applications for the IoT perform worse when data is sent to the edge and then waited for a response. Edge-based devices have a wide range of uses in cities, buildings, homes, healthcare, and transportation[23]. IoT applications that are sensitive to delays can be supported by positioning edge cloudlets between IoT infrastructure and the central cloud[24].

The amount of data sent to the cloud and service access latency are reduced when edge computing is used. Figure 2 shows how cloud and edge computing work in tandem inside the IoT This section below discusses a number of important edge computing functions:

- **Data Acquisition:** Sensors and machines are examples of edge devices that may record data in real time for immediate analysis.
- **Inferential Controls:** This inference capability can use GPS and front and rear cameras to provide drivers with extremely sophisticated navigational advice in a smart vehicle.
- **Data Analysis:** Decision makers may now provide actionable insights more quickly because to edge devices' ability to gather and analyses data from nearby devices.
- **Enhanced Data Security:** Edge computing involves local data collection and processing. Since there is no lengthy routing, it is easy to identify any suspicious activity[25].

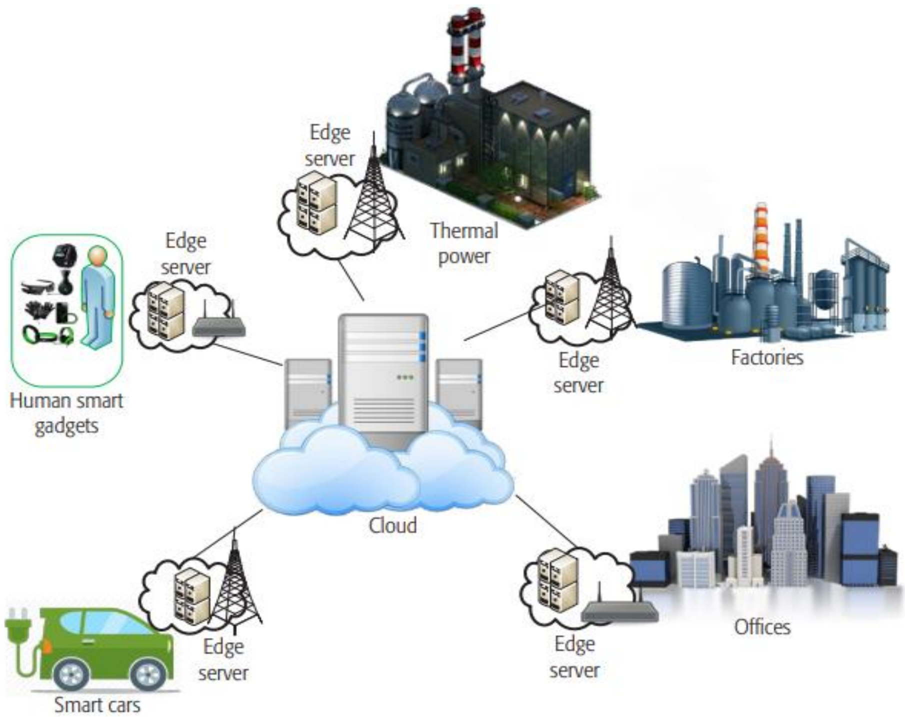

Figure 2: Edge cloud computing's complementary role in IoT

4.2 Architectures and Frameworks Supporting Edge-IoT Integration

A paradigm change is brought about by the decentralization of processing activities and the proximity of computational resources to integrating edge computing with IoT systems to access the data source. As a result of sending less data to centralized cloud servers, this architectural change greatly improves real-time decision-making, lowers latency, and conserves network capacity. Figure 3 shows how edge networking integrates edge computing, cloud computing, and core networks. Users connect via mobile networks (e.g., 5G) to nearby edge devices, which link to cloud data centers through the internet and inter-datacenter networks. This setup enables fast, efficient data processing and delivery.

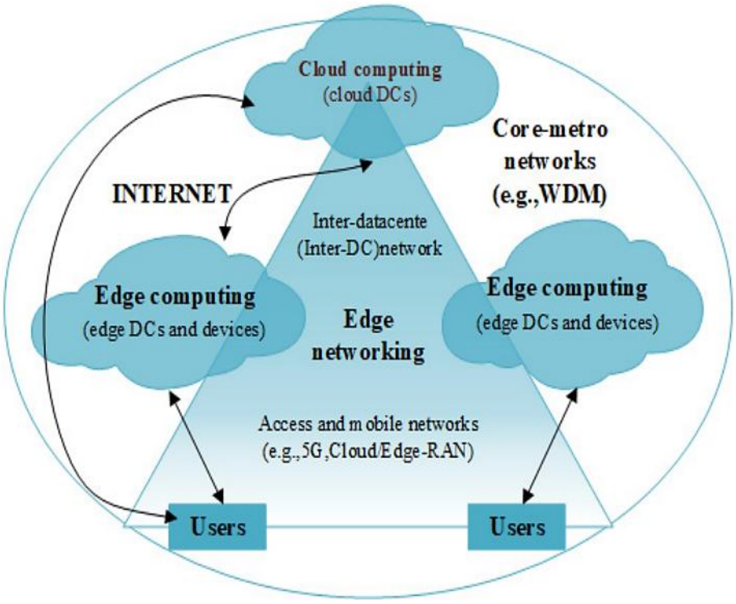

Figure 3: Architecture of Edge networking

Several architectural models have been developed to support this transition, each with distinct capabilities and deployment contexts:

- **Cloudlet Architecture:** Computational nodes called cloudlets serve as a link between the cloud and IoT gadgets. They are designed to handle latency-sensitive and computationally intensive tasks that exceed the capabilities of endpoint devices[26]. Typical use cases include augmented/virtual reality (AR/VR), rapid data aggregation, and local content caching.
- **Fog Computing:** Fog computing brings cloud features to the network's edge, enabling localized data filtering, aggregation, and analytics. By distributing intelligence across multiple fog nodes, this architecture enhances responsiveness and resilience, especially in applications that require quick responses, including smart grids and industrial automation.
- **Multi–Access Edge Computing (MEC):** Standardized by ETSI, MEC directly combines computational resources from base stations to radio controllers under the Radio Access Network (RAN). MEC reduces latency and increases throughput by moving edge servers closer to mobile users. It finds specific application in such use cases as connected cars, video analytics, and mobile AR, where the real-time performance is essential.
- **Hybrid and Dynamic Architectures:** Emerging frameworks are also learning towards a hybrid model, so these systems are a mix between cloudlet, fog, and MEC, which allows them to be more flexible and context-aware. These moving architectures use the distributed workloads and capabilities of adjacent devices and edge nodes to balance the workload and dynamically assign resources in real-time. One such system is Recursive Distributed Node Architecture (RDNA)[27].

4.3 Security and service management in Edge-Enabled IoT Systems

The need to ensure high security and good management has become central to edge networking that is evolving as a key foundation block of next-generation IoT systems[28]. The distributed architecture of edge computing introduces new vulnerabilities that it shares in the process of distributing computation and storage across various nodes. Due to the uncontrollable environment in which edge devices can be deployed often, they tend to be subject to physical attack, unauthorized access, and malicious data leakage[29]. This entails the need for lightweight context-specific security operations such as real-time anomaly detection, AI-based threat response, and zero-trust authentication standards[30].

Furthermore, resource management in environments with heterogeneous edges is difficult. Optimal assignment of computing and storage power demands smart orchestration using ML, Network Function Virtualization (NFV), and Software Defined Networking (SDN). With these technologies, it is possible to do dynamic resource distribution and predictive scaling. The service discovery, deployment and monitoring of any Mware-based solution depends on the usage of middleware platforms and the efficient operation of distributed edge nodes.

4.4 Future Directions and Emerging Technologies

In the future, a number of revolutionary technologies completely change the edge-IoT scenery. Blockchain is also being considered as a means of secure, verifiable, and unmodifiable communication between edge nodes. Federated learning makes it possible to train AI models in a decentralized way, with the raw data being stored locally. Further, edge-native AI is creeping up, with a view to carrying out real-time analytics and Network edge decision-making reduces reliance on centralized processing[31]. The advances are a harbinger of a smart, self-governing, and safe IoT world. In this moving landscape, 5G, LPWAN, and edge computing integrated to result in scalable, low-latency, and reliable IoT applications.

5 LITERATURE OF REVIEW

The literature review section focuses on next-generation IoT communication technologies, with a focus on the development of 5G architecture, LPWAN consolidation, and the edge networking paradigm. It discusses issues such as encryption policies, data collection architecture, hybrid network infrastructure, and IoT scaling challenges.

Ravi et al. (2025) paper focuses on the discussion of data encryption algorithms and authentication procedures specifically developed to work with 5G networks, as these networks are designed for use in the next generation of mobile communication. Begin by conducting an analysis of the vulnerabilities inherent in existing wireless communication systems. This discussion highlights the importance of having strong encryption protocols in place to secure against unauthorized access and data loss. Some of the advanced algorithms that are discussed in research paper are elliptic curve cryptography (ECC), homomorphic encryption, and quantum key distribution (QKD). There is also the discussion of a range of encryption methods that is made to suit the 5G architecture[32].

Jain (2025) According to this study, the fifth-generation (5G) standard has revolutionised wireless technology. Massive Machine-Type Communication (mMTC) enables trillions of Enhanced Mobile Broadband (eMBB) devices, which support extremely fast speeds and massive data transmission, as well as Ultra-Reliable Low-Latency Communication (uRLLC), allowing for near-real-time responsiveness with high reliability. This combination facilitates smooth communication between IoT devices. 5G is based on requirements that use the mmWave frequency spectrum to deliver downlink data speeds of 20 Gbps with a low latency of 1 ms. Making the IoT a reality and the Internet of Everything (IoE), a concept that envisions unrestricted connection of people, devices, and smart environments, requires it. The 6G network have higher speeds, efficient use of spectrum, and high reliability[33].

Reddy et al. (2024) present a work that proposes an IoT data aggregation system for LPWANs, which fundamentally addresses the issues of security, scalability, data distortion, and energy consumption. The proposed framework maximizes energy efficiency and ensures accurate and timely data transmission by combining advanced aggregation techniques with intelligent time division and data compression. Through online simulations and real-life testing, the potential benefits have been observed to be up to 40% efficiency increment over the conventional aggregation techniques, 99% data dependability and excellent network efficiency in large-scale applications. Because the encryption method used doesn't demand a lot of processing power, the obtained aggregated data is still safe, hence ensuring maximum level of security with minimal incorporation of additional power [34].

Bhatia et al. (2023) present the current state of the IoT, along with potential scenarios and challenges that may impact IoT adoption. Examined is the current use of 5G edge network architecture with IoT-enabled equipment. 6G and 7G technologies are needed for hybrid and multi-cloud deployments. This research compares a number of communication methods within the framework of the IoT. The study's conclusion discusses the effects of 5G, 6G, and beyond 7G technologies in the IoT era. Embedded objects are another name for the IoT, which uses 5G, 6G, and 7G cellular networking technologies to link people and send data over the Internet. A wide variety of items and communication techniques are combined in the IoT[35].

Chen et al. (2022) Present an LPWAN-5G integration survey that highlights the main integration problems and potential solutions in order to compare popular licensed and unlicensed LPWA technologies. Next, the 5G architecture and auxiliary technologies for LPWAN-5 G integration must be introduced. Lastly, discuss the difficulties and possible solutions of integrating LPWAN-5G in depth, addressing all the crucial points, including mobility, security, hybrid architecture, LPWAN coexistence and compatibility with other wireless technologies. Research indicates that LPWAN-5G integration tends to move from the access network to the core network. Because of their affordability and performance advantages, Low Power Wide Area (LPWA) technologies are becoming more popular for both commercial and private applications as a result of the IoT widespread adoption[36].

Lanka, Aung Win and Eshan (2021) This review paper's goal is to investigate how the 5G network can be deployed in this more rapid and localised edge infrastructure. The edge computing architecture is explained, along with some of its well-known applications and 5G constraints. In order to facilitate communication between IOT applications, edge computing performs a number of fundamental tasks, encompassing data sources—places where information is captured and kept from clients or other data sources —data processing procedures—where the gathered data is retrieved and used to uncover patterns-based machine learning mechanisms—and using visualisation tools to display the outcomes of the preceding stage. Recent developments in edge computing technology are promoting creativity and expansion in both business and society. Simply described, edge computing is a newly developed technique for handling gathered data[37].

Table 1 summarizes key studies on IoT communication technologies, highlighting their approaches, main findings, challenges, and future directions across 5G, LPWAN, and edge networking paradigms.

Table 1: Comparative Analysis of Recent Studies on Enabling Next-Gen IoT: 5G, LPWAN, and Edge Networking Paradigms

Reference	Study On	Approach	Key Findings	Challenges	Future Direction
Ravi et al. (2025)	Data encryption and authentication protocols for 5G	Analytical review of 5G	Highlights ECC, QKD, and homomorphic	Current wireless protocols have	Development of lightweight, 5G-specific

		security mechanisms	encryption as secure techniques for 5G	vulnerabilities; need stronger encryption	cryptographic algorithms
Jain (2025)	5G enhancements for IoT and IoE	Descriptive study of 5G architecture	Defines eMBB, mMTC, and uRLLC; 20 Gbps speed and 1ms latency enable IoT/IoE	Ensuring uniform QoS across massive connections	6G promises higher efficiency, reliability, and smarter connectivity
Reddy et al. (2024)	LPWAN energy optimization and data aggregation	Proposed framework with simulations	Up to 40% more energy efficiency, 99% data reliability	Scalability and accuracy in large LPWAN deployments	Integrating AI and ML for adaptive energy-efficient protocols
Bhatia et al. (2023)	Comparison of 5G/6G/7G in IoT infrastructure	Comparative study	Outlines edge-enabled IoT and connectivity evolution from 5G to 7G	Lack of maturity in beyond-5G standards and interoperability	Calls for unified architecture for hybrid IoT environments
Chen et al. (2022)	LPWAN-5G integration challenges	Survey and comparative analysis	Covers architecture, hybrid models, mobility, and security in LPWAN-5G	Difficulty in seamless interoperability and hybrid integration	Trends towards core-network-level LPWAN integration and coexistence
Lanka, et.al. (2021)	Edge computing in 5G-IoT	Application-focused analysis	Describes edge-layer tasks like local ML, data visualization, and caching	Data orchestration and security in decentralized environments	Advancing intelligent, autonomous edge systems through edge-native AI

6 CONCLUSION AND FUTURE WORK

Emerging innovations in communication technologies are redefining intelligent systems and smart environments. By integrating high-speed connectivity, low-power transmission, and localized intelligence, next-generation IoT ecosystems are becoming more adaptive, autonomous, and scalable. The convergence of 5G, LPWAN, and edge computing introduces a new paradigm in data generation, processing, and utilization. Each technology contributes uniquely: 5G ensures fast, ultra-reliable transmission; LPWAN enables energy-efficient, long-range communication; and edge computing enables real-time data processing close to the source. This collaboration lays the groundwork for IoT infrastructures that are scalable, low-latency, and energy-efficient, enabling industrial automation, smart cities, and healthcare. However, this convergence faces challenges, including limited infrastructure, interoperability gaps, and security concerns.

Future research should focus on developing unified communication frameworks, lightweight security models, and adaptive orchestration mechanisms. The focus should naturally shift toward interoperable, secure, and energy-aware systems that integrate 5G, LPWAN, and edge computing. Additionally, flexible AI-based orchestration is crucial for optimizing resource allocation, managing dynamic workloads, and informed decision-making in IoT environments. Developing robust architectures capable of supporting large-scale implementations in areas such as smart infrastructure and connected healthcare is crucial. This technological fusion is crucial for achieving a connected, intelligent, and sustainable digital future through cross-domain collaboration and overcoming current technical limitations.

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