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Review on LoRa Communication Technology, Its Issues, Challenges and Applications in Healthcare System

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Abstract: *The Internet of Things (IoT) has transformed various industries by enabling interconnected devices to collect, share, and analyze data in real-time. A crucial component of this transformation is Long Range (LoRa) technology, designed for low-power, wide-area networks (LPWAN). LoRa enables long-distance communication with minimal energy consumption, making it ideal for IoT applications in sectors like healthcare, agriculture, and smart cities. Specifically, in healthcare, LoRa facilitates remote monitoring through the Internet of Medical Things (IoMT), where patient data, such as vital signs, can be transmitted efficiently over vast distances. This paper discusses the significance of LoRa in medical applications, its advantages, challenges, and solutions, and reviews existing literature on its implementation. Key challenges include low data rates, packet loss, and latency issues, while solutions such as adaptive data rate mechanisms and multi-hop networks offer potential improvements for medical IoT systems. Also based on the given comparison among communication technologies, the consumer can make his decision on chosen the right technology for his application.*

Keywords: lora, spreading factor, internet of things

INTRODUCTION

The Internet of Things (IoT) represents a transformative paradigm that integrates physical devices with the internet, enabling them to collect, share, and analyze data autonomously. This interconnectedness facilitates a myriad of applications across various sectors, including healthcare, agriculture, transportation, and smart cities. The significance of IoT in contemporary life cannot be overstated, as it enhances operational efficiencies, fosters innovation, and improves the quality of life for individuals. The IoT ecosystem comprises sensors, software, and other technologies that communicate over the internet, allowing for real-time data exchange and decision-making processes that were previously unattainable. For instance, in higher education, IoT technologies have been shown to enhance the educational experience by providing real-time feedback on student performance, thereby enriching the learning process [1].

Moreover, the IoT's impact extends to critical global challenges, such as food security and sustainable development. In agriculture, IoT technologies optimize productivity and resource management, which are essential for addressing the growing demands of a burgeoning population [2]. The integration of IoT into various industries signifies a shift towards more intelligent systems that can adapt to changing conditions and user needs. This adaptability is particularly relevant in the context of Industry 4.0, where the convergence of IoT with cyber-physical systems is revolutionizing manufacturing processes and operational efficiencies [3].

As the IoT continues to evolve, it is essential to explore specific technologies that facilitate its implementation. One such technology is the Long Range (LoRa) network, which is designed for low-power, wide-area network (LPWAN) applications. LoRa technology enables devices to communicate over long distances while consuming minimal power, making it an ideal solution for IoT deployments that require extensive coverage and battery longevity.

The architecture of LoRa networks supports a star topology, where multiple devices connect to a central gateway, allowing for efficient data transmission over large geographical areas. This capability is particularly advantageous in scenarios where traditional cellular networks may be cost-prohibitive or insufficient [4].

LoRa networks have found extensive applications in various fields, particularly in the healthcare sector, where they are instrumental in the development of the Internet of Medical Things (IoMT). The IoMT encompasses a range of medical devices and applications that connect to healthcare IT systems through online networks. The integration of LoRa technology within the IoMT framework enhances the ability to monitor patient health remotely, ensuring timely interventions and personalized care. For example, wearable health monitors can transmit vital signs to healthcare providers in real-time, facilitating proactive management of chronic conditions [5]. The benefits of using LoRa in medical applications are manifold. Firstly, the low power consumption of LoRa devices allows for prolonged usage without the need for frequent battery replacements, which is crucial in medical settings where device reliability is paramount [6]. Secondly, the long-range capabilities of LoRa enable healthcare providers to monitor patients in remote or underserved areas, thus expanding access to essential health services [7]. Furthermore, the scalability of LoRa networks allows for the integration of numerous devices, accommodating the growing demand for connected health solutions as the IoMT landscape evolves [6].

In addition to enhancing patient monitoring, LoRa networks can also facilitate the management of medical assets within healthcare facilities. By deploying LoRa-enabled sensors, hospitals can track the location and status of medical equipment, ensuring that critical devices are readily available when needed. This capability not only improves operational efficiency but also enhances patient safety by minimizing delays in care delivery. Moreover, the data collected through LoRa networks can be analyzed to identify trends and optimize resource allocation, further contributing to improved healthcare outcomes [8].

Despite the numerous advantages of LoRa technology in the medical field, it is essential to address the security challenges associated with the IoMT. The proliferation of connected medical devices increases the potential attack surface for cyber threats, necessitating robust security measures to protect patient data and ensure device integrity [9]. As such, the development of secure communication protocols and intrusion detection systems tailored for IoMT environments is critical to safeguarding sensitive health information [8].

LITERATURE REVIEW

Dimitrievski et al. propose a rural healthcare IoT architecture based on LoRa technology, emphasizing the integration of fog computing to enhance data collection and processing capabilities. Their study illustrates how LoRa can facilitate remote healthcare services in rural areas, addressing the challenges of limited access to medical facilities. This architecture not only improves healthcare delivery but also empowers healthcare providers to make informed decisions based on real-time data [10].

Sánchez-Iborra et al. evaluate the performance of LoRa in various scenarios, including its reliability under different conditions. Their findings indicate that while vehicle motion can negatively impact transmission reliability, LoRa remains a viable option for healthcare applications that require consistent data transmission. This adaptability is crucial for developing robust medical monitoring systems that can operate effectively in dynamic environments [11].

Lousado and Antunes focus on the use of LoRa communication technologies for monitoring and supporting elderly individuals. Their research highlights the potential of LoRa to facilitate remote health monitoring, enabling caregivers to track the health status of elderly patients in real-time. This application is particularly relevant as the aging population increases the demand for innovative healthcare solutions that promote independence and safety [12].

Sultana et al. discuss the maximization of user utility in narrowband IoT for prioritized healthcare applications. They emphasize the importance of integrating various wireless technologies, including LoRa, to enhance service quality for patients. This study underscores the potential of LoRa to support critical healthcare applications that require reliable and efficient communication [13].

Kalokidou et al. investigate the resilience of LoRaWAN under jamming attacks, highlighting its robustness in healthcare applications. Their findings suggest that LoRa can maintain communication integrity even in challenging conditions, making it suitable for critical medical monitoring systems. This resilience is essential for ensuring uninterrupted healthcare services, particularly in emergency situations [14].

Mousavi et al. explore the cognitive capabilities of LoRa technology, emphasizing its potential for smart healthcare applications. Their study indicates that LoRa can support a wide range of IoT applications, including health monitoring and disease management, by providing reliable communication infrastructure. This versatility is crucial for developing comprehensive healthcare solutions that leverage IoT technologies [15].

Khan presents an IoT framework for heart disease prediction that utilizes LoRa technology. The integration of IoT aspects into medical devices enhances the quality and efficiency of healthcare services, particularly for patients with chronic conditions. This application demonstrates the potential of LoRa to support proactive healthcare management and improve patient outcomes [16].

Petäjäjärvi et al. evaluate the suitability of LoRa LPWAN technology for remote health and wellbeing monitoring. Their study includes real-life experiments that demonstrate the effectiveness of LoRa for non-line-of-sight indoor operations, making it a viable option for health monitoring applications. This capability is particularly important for monitoring patients in various environments, including homes and healthcare facilities [17].

Muzafar et al. assess the performance of LoRa SX1276 in IoT health monitoring applications, particularly in the context of the COVID-19 pandemic. Their findings highlight the advantages of integrating LoRa technology with health monitoring systems to enhance patient treatment and disease surveillance. This application is especially relevant in the current healthcare landscape, where remote monitoring has become increasingly important [18].

Wan et al. discuss a wearable IoT-enabled real-time health monitoring system that utilizes LoRa technology. Their research emphasizes the importance of embedding various sensors to collect biomedical parameters, enabling comprehensive health monitoring. This integration of wearable technology with LoRa enhances the ability to track patients' health conditions continuously [19].

Rawat et al. explore the role of LoRa technology in enabling public safety solutions during the COVID-19 pandemic. Their study highlights how LoRa devices can assist with contact tracing and ensure compliance with healthcare regulations, demonstrating its relevance in crisis situations. This application underscores the adaptability of LoRa technology in addressing urgent healthcare needs [20].

Mdhaffar et al. present an IoT-based health monitoring system utilizing LoRaWAN, emphasizing its effectiveness in remote patient monitoring. Their findings suggest that LoRa technology can facilitate continuous health tracking, improving patient care and enabling timely interventions. This capability is crucial for managing chronic conditions and enhancing overall healthcare delivery [21].

Gaitan proposes a long-distance communication architecture for medical devices based on the LoRaWAN protocol. This architecture allows for data communications over significant distances, making it suitable for remote health monitoring applications. The ability to transmit data over long ranges is particularly beneficial for healthcare providers operating in rural or underserved areas [22].

Islam et al. investigate the monitoring of human body signals through an IoT-based LoRa wireless network system. Their study emphasizes the potential of IoT technologies, including LoRa, to revolutionize healthcare by enabling real-time monitoring of patients' health conditions. This capability is essential for improving patient outcomes and facilitating proactive healthcare management [23].

Misran et al. discuss an IoT-based health monitoring system that leverages LoRa communication technology. Their research highlights the advantages of using LoRa for remote health monitoring, including low power consumption and long-range capabilities. This application is particularly relevant for developing sustainable healthcare solutions that can operate efficiently in various environments [24].

Taleb et al. explore energy consumption improvements in healthcare monitoring systems using LoRaWAN. Their study presents a LoRa-based low-power healthcare platform that enhances patient monitoring processes, demonstrating the energy efficiency of LoRa technology. This focus on energy consumption is crucial for developing sustainable healthcare solutions that can operate effectively over extended periods [25].

Yao et al. provide a survey on evolved LoRa-based communication technologies for emerging IoT applications, including healthcare. Their findings highlight the potential of LoRa technology to support a wide range of healthcare applications, emphasizing its adaptability and effectiveness. This survey underscores the importance of ongoing research to optimize LoRa technology for diverse medical applications [26].

Al-Shareeda reviews the challenges and future directions of long-range technology for IoT applications, including healthcare. Their study emphasizes the need for continued innovation in LoRa technology to address the evolving demands of healthcare systems. This focus on future developments is essential for ensuring that LoRa technology remains relevant in the rapidly changing healthcare landscape [27].

Pathinarupothi et al. discuss an IoT-based smart edge for global health, emphasizing remote monitoring with severity detection and alerts transmission. Their research highlights the potential of LoRa technology to enhance healthcare delivery by enabling timely interventions and improving patient outcomes. This application is particularly relevant in the context of managing chronic diseases and enhancing overall healthcare efficiency [28].

Leonardi et al. conduct a comparative assessment of LoRaWAN medium access control protocols, emphasizing their applicability in healthcare. Their findings suggest that LoRaWAN can effectively support various healthcare applications due to its low energy consumption and large coverage range. This capability is crucial for developing efficient healthcare monitoring systems that can operate across extensive geographical areas [29].

Younas presents a systematic literature review on QoS monitoring in IoT-driven healthcare. Their study emphasizes the importance of integrating IoT technologies, including LoRa, to enhance healthcare delivery and improve patient outcomes. This focus on quality of service is essential for ensuring that healthcare systems can meet the demands of patients and providers effectively [30].

Communication Technologies

Communication technologies are fundamental to the development and functionality of the Internet of Things (IoT), enabling devices to connect, communicate, and share data. This section examines several prominent communication technologies, including Wi-Fi, Bluetooth, Zigbee, Raspberry Pi, cellular networks, and LoRa technology. Each of these technologies has unique characteristics that make them suitable for various applications, from personal devices to large-scale industrial systems.

- Wi-Fi technology, based on the IEEE 802.11 standards, is widely used for providing high-speed internet access in homes, offices, and public spaces. Its ability to support high data transfer rates and a relatively broad coverage area makes it ideal for applications requiring substantial bandwidth, such as video streaming and online gaming. Wi-Fi operates in the 2.4 GHz and 5 GHz frequency bands, allowing multiple devices to connect simultaneously. However, its performance can be adversely affected by interference from other devices operating in the same frequency range, as well as physical barriers such as walls and furniture [31]. The integration of Wi-Fi with IoT devices has led to significant advancements in smart home technologies, enabling seamless connectivity and control of various appliances and systems [32].
- Bluetooth technology, particularly Bluetooth Low Energy (BLE), is designed for short-range communication and is widely used in personal area networks. BLE is characterized by its low power consumption, making it suitable for battery-operated devices such as wearables and health monitoring systems. The technology operates in the 2.4 GHz ISM band and allows devices to connect over distances of up to 100 meters, depending on the environment [33]. Bluetooth has been extensively adopted in various applications, including smart helmets and other wearable devices, where low energy consumption is crucial [31]. The versatility of Bluetooth technology has also led to its integration with other communication protocols, enhancing the functionality of IoT devices [34]
- Zigbee is another wireless communication protocol that is particularly well-suited for low-power, low-data-rate applications. It operates on the IEEE 802.15.4 standard and is commonly used in home automation, industrial control, and smart lighting systems. ZigBee’s mesh networking

capability allows devices to communicate over longer distances by relaying messages through intermediate nodes, which enhances the reliability and scalability of IoT networks [35]. The protocol's low power consumption and cost-effectiveness make it an attractive option for applications that require frequent communication between devices, such as environmental monitoring and smart metering [36]. ZigBee’s ability to operate in crowded frequency bands, alongside technologies like Wi-Fi and Bluetooth, has been a significant factor in its adoption for IoT applications [37].

- Cellular networks, particularly those utilizing Long-Term Evolution (LTE) technology, provide robust connectivity for mobile devices and IoT applications. LTE has evolved to support IoT through technologies such as LTE-M and NB-IoT. LTE-M is designed for applications requiring mobility and higher data rates, while NB-IoT focuses on ultra-low power consumption and wide area coverage, making it suitable for static IoT devices [38]. The integration of these technologies into existing cellular infrastructure allows for seamless connectivity and scalability in IoT deployments. NB-IoT, in particular, is designed to support massive machine-type communications (mMTC), enabling a large number of devices to connect to the network with minimal power requirements [39]. This capability is essential for applications such as smart metering, environmental monitoring, and asset tracking, where devices may be deployed in remote or challenging environments [40].

LoRa Technology and its Theoretical Background

LoRa (Long Range) is a wireless communication technology tailored for long-range, low-power, and low-data-rate applications, making it ideal for the Internet of Things (IoT). Operating in unlicensed spectrum bands, LoRa enables devices to communicate over distances up to 15 km in rural areas and several kilometres in urban settings. It uses Chirp Spread Spectrum (CSS) modulation to achieve robust communication even in the presence of interference and noise, figure (1) below illustrate the structure of LoRa network.

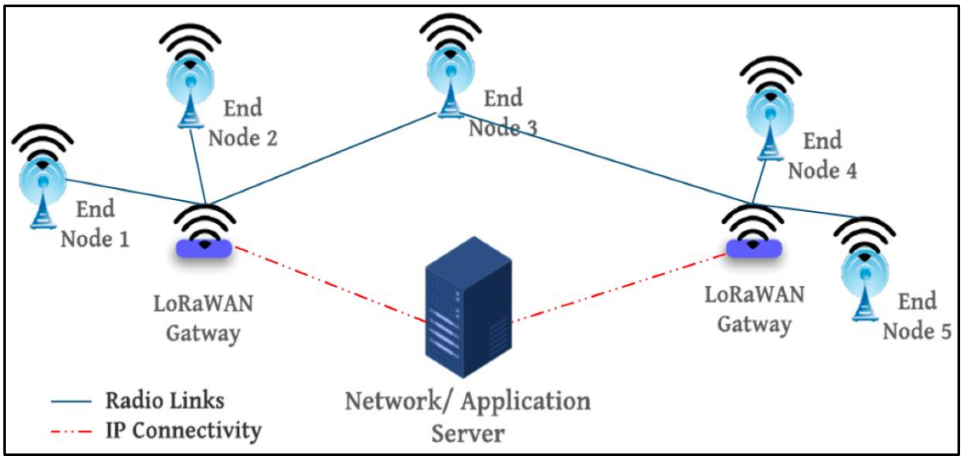

Figure 1: Structure of LoRa network

Advantages of LoRa

1-Long-Range Communication: LoRa technology allows for communication over extensive distances without the need for repeaters. This is particularly beneficial in rural or remote areas where infrastructure is minimal.

2-Low Power Consumption: Designed for battery-operated devices, LoRa enables devices to operate for up to 10 years on a single battery due to its low power consumption [41].
3-High Network Capacity: A single LoRa gateway can handle thousands of devices, making it scalable and cost-effective for large deployments [4].
4-Robustness to Interference: The use of CSS modulation provides resilience against interference and multipath fading, enhancing communication reliability [42].
5-Secure Communication: LoRaWAN protocol incorporates end-to-end encryption at the network and application levels using AES-128 encryption standards [43].
6-Cost-Effective Deployment: Operating in unlicensed ISM bands eliminates licensing fees, reducing the overall cost of deployment.

Theoretical Performance and Equations

Chirp Spread Spectrum (CSS) Modulation

LoRa uses CSS modulation, where the signal frequency increases or decreases over time (up-chirp or down-chirp). The basic chirp signal $s(t)$ is defined as:

$$s(t) = \exp\left(j2\pi \left(f_0 t + \frac{K}{2} t^2\right)\right), 0 \leq t \leq T_s$$

Where:

- f_0 = initial frequency
- K = chirp rate ($K = \frac{\Delta f}{T_s}$)
- Δf = frequency sweep range (bandwidth B)
- T_s = symbol duration
- j = imaginary unit

Spreading Factor (SF)

The Spreading Factor determines the number of chips per symbol and is given by:

$$SF = \log_2\left(\frac{B \times T_s}{N}\right)$$

Where:

- N = number of symbols
- B = bandwidth
- T_s = symbol duration

The symbol rate R_s is:

$$R_s = \frac{B}{2^{SF}}$$

Data Rate (DR)

The effective data rate depends on the bandwidth, spreading factor, and coding rate (CR):

$$DR = R_s \times CR = \frac{B}{2^{SF}} \times CR$$

Where CR is typically between $\frac{4}{5}$ and $\frac{4}{8}$ representing the rate of the error-correcting code.

Time on Air (ToA)

The time a LoRa frame occupies the channel is crucial for battery life and network capacity. ToA is calculated as:

$$ToA = \left(\frac{N_{preamble} + N_{payload}}{R_S}\right)$$

Where:

- $N_{preamble}$ = number of preamble symbols
- $N_{payload}$ = number of payload symbols

Parameters Controlling LoRa Network Behaviour

1- Bandwidth (B):
  - Typical values: 125 kHz, 250 kHz, 500 kHz.
  - Effect: Higher bandwidth increases data rate but decreases sensitivity and range.

2- Spreading Factor (SF):
  - Values range from 7 to 12.
  - Effect: Higher SF increases sensitivity and range but decreases data rate and increases ToA.

3- Coding Rate (CR):
  - Values range from 4/5 to 4/8.
  - Effect: Higher CR improves error correction capability but reduces data rate.

4- Transmission Power (P_tx):
  - Regulated by regional specifications (e.g., max 14 dBm in Europe).
  - Effect: Higher power increases range but consumes more energy.

5- Payload Size:
  - Limited to 51 bytes for SF12 and up to 222 bytes for SF7 at 125 kHz bandwidth.
  - Effect: Larger payloads increase ToA and energy consumption.

6- Frequency Channels:
  - Operates in ISM bands (e.g., 868 MHz in Europe, 915 MHz in the USA).
  - Effect: Frequency selection affects regulatory compliance and propagation characteristics.

7- Antenna Characteristics:
  - Gain and orientation impact the range and reliability.
  - Effect: Higher gain antennas can increase range but may introduce directionality.

Environmental Factors:

- Obstacles, terrain, and atmospheric conditions.
- Effect: Can attenuate signals, reducing range and reliability.

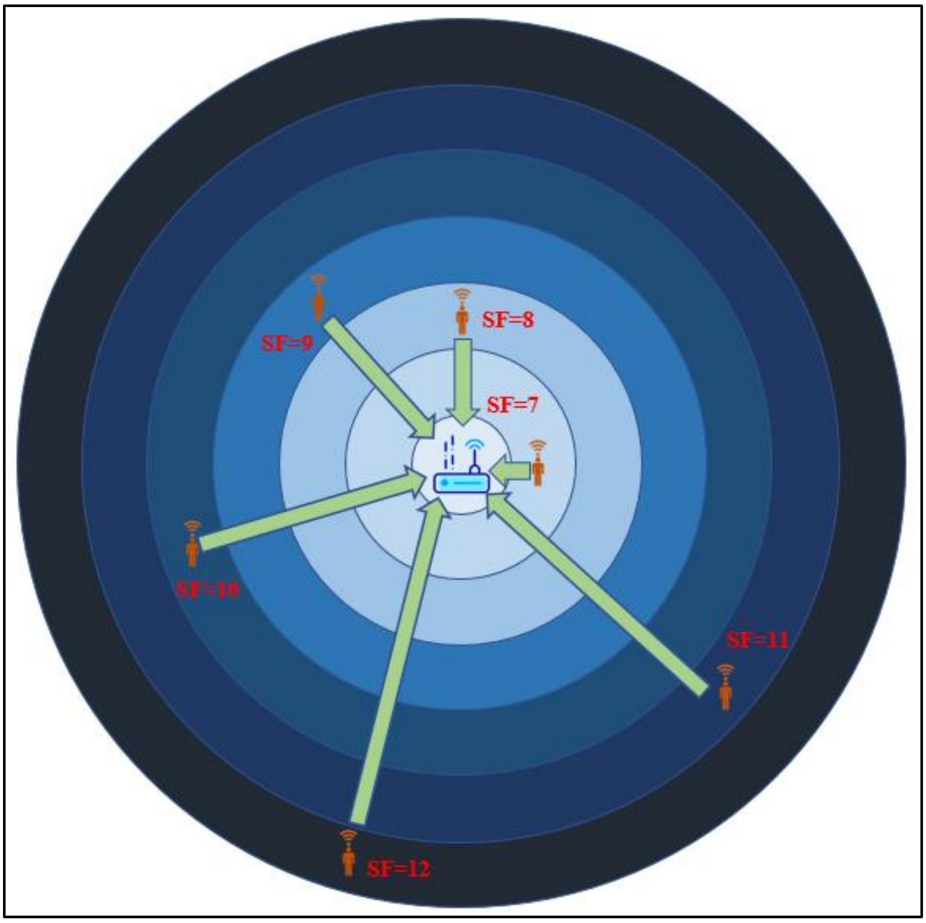

Figure 2: Increasing of spreading factor while being far from gateway

The comparison of communication technologies with LoRa can be abbreviated in table 1.

Table 1: Comparison of communication technologies with LoRa

Parameter	Wi-Fi	Bluetooth	Zigbee	Cellular	LoRa
Frequency Band	2.4 GHz, 5 GHz	2.4 GHz	2.4 GHz	Licensed bands (varies by region)	**Unlicensed ISM bands (e.g., 868 MHz, 915 MHz)**
Range	Up to 100 m (indoor)	Up to 100 m (Bluetooth 5.0)	Up to 100 m (indoor)	Several km to tens of km	**Up to 15 km (rural), several km (urban)**

Parameter	**Wi-Fi**	**Bluetooth**	**Zigbee**	**Cellular**	**LoRa**
Data Rate	Up to 9.6 Gbps (Wi-Fi 6)	Up to 2 Mbps (Bluetooth 5.0)	Up to 250 kbps	Up to 1 Gbps (4G LTE Advanced)	**0.3 kbps to 50 kbps**
Power Consumption	High	Low	Very Low	High	**Very Low**
Network Topology	Star	Star	Mesh	Star	**Star (LoRaWAN)**
Bandwidth	Wide	Narrow	Narrow	Wide	**Narrow**
Latency	Low	Low	Moderate	Low	**High (suitable for non-real-time data)**
Security Features	WPA3, WPA2	AES-128	AES-128	SIM-based authentication	**AES-128 encryption (network and application level)**
Typical Applications	Internet access, streaming	Audio devices, peripherals	Home automation, sensor networks	Mobile telephony, broadband internet	**IoT sensors, smart agriculture, asset tracking**
Advantages	High data rates, widespread adoption	Low power, easy pairing	Low power, mesh networking	Wide coverage, high data rates	**Long range, very low power consumption, high network capacity, robust to interference, cost-effective deployment**

Role of LoRa in Medical Applications

The transmission of medical signals is a critical aspect of healthcare monitoring systems, particularly in the context of remote patient monitoring and telemedicine. The data rates required for medical signals can vary significantly based on the type of data being transmitted. For instance, vital signs such as heart rate, blood pressure, and temperature can typically transmitted at low data rates, often in the range of a few bits per second to several kilobits per second, as in (table 2). This is because these signals are relatively simple and do not require high bandwidth for effective monitoring. For example, a heart rate monitor may only need to send a few bytes of data every minute, which translates to a very low data rate.

LoRa (Long Range) technology, a prominent LPWAN solution, is particularly suitable for medical applications due to its inherently low data transfer rates, which align well with the requirements of vital medical signals. LoRa networks typically operate at data rates ranging from 0.29 kbps to 50 kbps, depending on the configuration of the network and the specific application. This range is compatible with the transmission needs of many medical monitoring applications, where the focus is on sending small packets of data at infrequent intervals rather than continuous high-bandwidth streams [44].

Table 2: Data rates of biomedical signals

Type of Biomedical Signal	Required Data Rate	Notes
Electrocardiogram (ECG)	0.1 – 1 kbps	Requires periodic transmission of low-complexity signals
Electroencephalogram (EEG)	1 – 10 kbps	Demands higher complexity and frequent data transmission
Electromyogram (EMG)	0.5 – 5 kbps	Needs medium complexity data transmission
Pulse Oximetry	0.1 – 0.5 kbps	Involves simple and stable data transmission
Blood Pressure Monitoring	0.05 – 0.2 kbps	Requires low-complexity periodic data transmission
Glucose Level Monitoring	0.05 – 0.1 kbps	Involves simple and frequent data transmission

Challenges in Transmitting Medical Signals via LoRa Networks

The transmission of medical signals via LoRa networks presents several challenges that must be addressed to ensure reliable and effective communication in healthcare applications. LoRa technology, known for its long-range capabilities and low power consumption, is particularly appealing for medical use cases, including remote patient monitoring and telemedicine. However, the unique characteristics of medical signals and the operational constraints of LoRa networks necessitate careful consideration of various factors to optimize performance. These factors include:

- Data Rate Limitations: One of the primary challenges in using LoRa for medical signals is its relatively low data transfer rate, which typically ranges from 0.29 kbps to 50 kbps. While this data rate is sufficient for transmitting simple vital signs such as heart rate or temperature, it may not be adequate for more complex signals or high-frequency data streams. For instance, continuous electrocardiogram (ECG) monitoring requires higher data rates to capture rapid changes in heart activity accurately [45].
- Packet Loss and Reliability: LoRa networks can experience packet loss due to interference, collisions, and environmental factors. The ALOHA protocol used in LoRa networks can lead to packet collisions when multiple devices attempt to transmit simultaneously, particularly in dense network scenarios. This can result in retransmissions, which not only consume additional power but also delay critical medical data transmission [46] [47].

- Latency Issues: The latency associated with LoRa networks can be problematic for time-sensitive medical applications. The need for retransmissions due to packet loss can introduce delays that are unacceptable in scenarios where real-time monitoring is crucial, such as in emergency medical situations [48].
- Scalability Concerns: As the number of connected medical devices increases, the scalability of LoRa networks becomes a significant concern. The shared communication medium can lead to congestion, further exacerbating packet loss and latency issues. This is particularly relevant in hospital environments where numerous devices may need to communicate simultaneously [47] [49].
- Environmental Interference: LoRa operates in unlicensed frequency bands, which can be crowded with other wireless signals. This interference can degrade the quality of the communication link, impacting the reliability of medical signal transmission [50] [51].

Methods to Overcome These Challenges:

- Adaptive Data Rate (ADR) Mechanisms: Implementing adaptive data rate schemes can optimize the transmission parameters based on the network conditions and the specific requirements of the medical signals being transmitted. By dynamically adjusting the Spreading Factor (SF) and transmission power, the network can improve throughput and reduce packet loss. This adaptability is crucial for balancing the trade-offs between range, data rate, and power consumption [52] [53].
- Multi-Hop Network Protocols: Utilizing multi-hop LoRa network protocols can enhance data transmission reliability and reduce latency. By allowing data to be relayed through intermediate nodes, the network can extend its range and improve signal strength, thereby minimizing packet loss. This approach can be particularly beneficial in complex hospital environments where direct communication with a gateway may not always be feasible [54].
- Collision Avoidance Techniques: Implementing collision avoidance mechanisms, such as time-slot allocation or frequency hopping, can help mitigate the impact of packet collisions in dense networks. By scheduling transmissions or using different frequency channels, the likelihood of simultaneous transmissions can be reduced, enhancing overall network reliability [46].
- Data Compression and Encoding: Employing data compression techniques can help reduce the amount of data transmitted, making it easier to fit within the constraints of LoRa's data rate. For example, encoding vital signs into smaller packets or using efficient data representation methods can facilitate quicker transmission without compromising the integrity of the medical signals [55].

CONCLUSION

LoRa technology has proven to be an essential tool in the expansion of IoT, particularly in healthcare, where it’s long-range, low-power characteristics are crucial for remote patient monitoring and telemedicine. Despite challenges such as limited data rates, packet collisions, and scalability concerns, the adaptability and cost-effectiveness of LoRa make it a viable solution for many IoT applications. With continued development in adaptive data rate mechanisms, multi-hop protocols, and other technical enhancements, LoRa's role in medical applications is likely to expand further. This review gives insight about the chosen communication technology for certain application, as well as in case of LoRa the preferred spreading factor for the required coverage area and data rate. Future research should focus on addressing security concerns, improving transmission reliability, and optimizing network scalability to support the growing demand for connected health solutions.

References

[1] J. M. Fernández-Batanero, M. Montenegro-Rueda, J. Fernández-Cerero, and E. López Menéses, “Adoption of the Internet of Things in higher education: opportunities and challenges,” *Interact. Technol. Smart Educ.*, vol. 21, no. 2, pp. 292–307, Jan. 2024, doi: 10.1108/ITSE-01-2023-0025.

[2] A. Mentsiev, T. Aygumov, and S. Abdurashidov, “Using internet of things technologies to optimize agriculture and increase productivity,” *E3S Web Conf.*, vol. 462, p. 01037, 2023, doi: 10.1051/e3sconf/202346201037.

[3] X. Yao, J. Zhou, Y. Lin, Y. Li, H. Yu, and Y. Liu, “Smart manufacturing based on cyber-physical systems and beyond,” *J. Intell. Manuf.*, vol. 30, no. 8, pp. 2805–2817, Dec. 2019, doi: 10.1007/s10845-017-1384-5.

[4] M. Centenaro, L. Vangelista, A. Zanella, and M. Zorzi, “Long-range communications in unlicensed bands: the rising stars in the IoT and smart city scenarios,” *IEEE Wirel. Commun.*, vol. 23, no. 5, pp. 60–67, Oct. 2016, doi: 10.1109/MWC.2016.7721743.

[5] M. Papaioannou *et al.*, “A Survey on Security Threats and Countermeasures in Internet of Medical Things (IoMT),” *Trans. Emerg. Telecommun. Technol.*, vol. 33, no. 6, p. e4049, 2022, doi: 10.1002/ett.4049.

[6] S. R. Gopal and V. S, “A Hybrid Approach to Enhance Scalability, Reliability and Computational Speed in LoRa Networks,” *Int. J. Adv. Comput. Sci. Appl.*, vol. 11, no. 9, 2020, doi: 10.14569/IJACSA.2020.0110955.

[7] U. Raza, P. Kulkarni, and M. Sooriyabandara, “Low Power Wide Area Networks: An Overview,” *IEEE Commun. Surv. Tutor.*, vol. 19, no. 2, pp. 855–873, 2017, doi: 10.1109/COMST.2017.2652320.

[8] G. Zachos, G. Mantas, I. Essop, K. Porfyrakis, J. C. Ribeiro, and J. Rodriguez, “Prototyping an Anomaly-Based Intrusion Detection System for Internet of Medical Things Networks,” in *2022 IEEE 27th International Workshop on Computer Aided Modeling and Design of Communication Links and Networks (CAMAD)*, Nov. 2022, pp. 179–183. doi: 10.1109/CAMAD55695.2022.9966912.

[9] M. Papaioannou *et al.*, “A Survey on Security Threats and Countermeasures in Internet of Medical Things (IoMT),” *Trans. Emerg. Telecommun. Technol.*, vol. 33, no. 6, p. e4049, 2022, doi: 10.1002/ett.4049.

[10] A. Dimitrievski *et al.*, “Rural Healthcare IoT Architecture Based on Low-Energy LoRa,” *Int. J. Environ. Res. Public. Health*, vol. 18, no. 14, Art. no. 14, Jan. 2021, doi: 10.3390/ijerph18147660.

[11] “Performance Evaluation of LoRa Considering Scenario Conditions.” Accessed: Oct. 15, 2024. [Online]. Available: https://www.mdpi.com/1424-8220/18/3/772

[12] “Monitoring and Support for Elderly People Using LoRa Communication Technologies: IoT Concepts and Applications.” Accessed: Oct. 15, 2024. [Online]. Available: https://www.mdpi.com/1999-5903/12/11/206

[13] N. Sultana, F. Huq, M. A. Razzaque, and M. M. Rahman, “User Utility Maximization in Narrowband Internet of Things for Prioritized Healthcare Applications,” *Sensors*, vol. 22, no. 3, Art. no. 3, Jan. 2022, doi: 10.3390/s22031192.

[14] V. Kalokidou, M. Nair, and M. A. Beach, “LoRaWAN Performance Evaluation and Resilience under Jamming Attacks,” in *2022 Sensor Signal Processing for Defence Conference (SSPD)*, Sep. 2022, pp. 1–5. doi: 10.1109/SSPD54131.2022.9896225.

[15] S. M. Mousavi, A. Khademzadeh, and A. M. Rahmani, “Cognitive Long-range: Towards efficient public communication infrastructure for Internet of Things,” *Int. J. Commun. Syst.*, vol. 35, no. 12, p. e5207, 2022, doi: 10.1002/dac.5207.

[16] M. A. Khan, “An IoT Framework for Heart Disease Prediction Based on MDCNN Classifier,” *IEEE Access*, vol. 8, pp. 34717–34727, 2020, doi: 10.1109/ACCESS.2020.2974687.

[17] J. Petäjäjärvi, K. Mikhaylov, R. Yasmin, M. Hämäläinen, and J. Iinatti, “Evaluation of LoRa LPWAN Technology for Indoor Remote Health and Wellbeing Monitoring,” *Int. J. Wirel. Inf. Netw.*, vol. 24, no. 2, pp. 153–165, Jun. 2017, doi: 10.1007/s10776-017-0341-8.

[18] M. I. Z. Azhar Muzafar, A. Mohd Ali, and S. Zulkifli, “A Study on LoRa SX1276 Performance in IoT Health Monitoring,” *Wirel. Commun. Mob. Comput.*, vol. 2022, no. 1, p. 6066354, 2022, doi: 10.1155/2022/6066354.

[19] J. Wan *et al.*, “Wearable IoT enabled real-time health monitoring system,” *EURASIP J. Wirel. Commun. Netw.*, vol. 2018, no. 1, p. 298, Dec. 2018, doi: 10.1186/s13638-018-1308-x.

[20] A. S. Rawat, J. Rajendran, H. Ramiah, and A. Rana, “LoRa (Long Range) and LoRaWAN Technology for IoT Applications in COVID-19 Pandemic,” in *2020 International Conference on Advances in Computing, Communication & Materials (ICACCM)*, Aug. 2020, pp. 419–422. doi: 10.1109/ICACCM50413.2020.9213067.

[21] A. Mdhaffar, T. Chaari, K. Larbi, M. Jmaiel, and B. Freisleben, “IoT-based health monitoring via LoRaWAN,” in *IEEE EUROCON 2017 -17th International Conference on Smart Technologies*, Jul. 2017, pp. 519–524. doi: 10.1109/EUROCON.2017.8011165.

[22] N. C. Gaitan, “A Long-Distance Communication Architecture for Medical Devices Based on LoRaWAN Protocol,” *Electronics*, vol. 10, no. 8, Art. no. 8, Jan. 2021, doi: 10.3390/electronics10080940.

[23] M. Shahidul Islam, M. T. Islam, A. F. Almutairi, G. K. Beng, N. Misran, and N. Amin, “Monitoring of the Human Body Signal through the Internet of Things (IoT) Based LoRa Wireless Network System,” *Appl. Sci.*, vol. 9, no. 9, Art. no. 9, Jan. 2019, doi: 10.3390/app9091884.

[24] N. Misran, M. S. Islam, G. K. Beng, N. Amin, and M. T. Islam, “IoT Based Health Monitoring System with LoRa Communication Technology,” in *2019 International Conference on Electrical Engineering and Informatics (ICEEI)*, Jul. 2019, pp. 514–517. doi: 10.1109/ICEEI47359.2019.8988869.

[25] H. Taleb, A. Nasser, G. Andrieux, N. Charara, and E. M. Cruz, “Energy Consumption Improvement of a Healthcare Monitoring System: Application to LoRaWAN,” *IEEE Sens. J.*, vol. 22, no. 7, pp. 7288–7299, Apr. 2022, doi: 10.1109/JSEN.2022.3150716.

[26] F. Yao, Y. Ding, S. Hong, and S.-H. Yang, "A Survey on Evolved LoRa-Based Communication Technologies for Emerging Internet of Things Applications," *Int. J. Netw. Dyn. Intell.*, pp. 4–19, Dec. 2022, doi: 10.53941/ijndi0101002.

[27] M. A. Al-Shareeda, A. A. Alsadhan, H. H. Qasim, and S. Manickam, "Long range technology for internet of things: review, challenges, and future directions," *Bull. Electr. Eng. Inform.*, vol. 12, no. 6, Art. no. 6, Dec. 2023, doi: 10.11591/eei.v12i6.5214.

[28] R. K. Pathinarupothi, P. Durga, and E. S. Rangan, "IoT-Based Smart Edge for Global Health: Remote Monitoring With Severity Detection and Alerts Transmission," *IEEE Internet Things J.*, vol. 6, no. 2, pp. 2449–2462, Apr. 2019, doi: 10.1109/JIOT.2018.2870068.

[29] L. Leonardi, L. Lo Bello, F. Battaglia, and G. Patti, "Comparative Assessment of the LoRaWAN Medium Access Control Protocols for IoT: Does Listen before Talk Perform Better than ALOHA?," *Electronics*, vol. 9, no. 4, Art. no. 4, Apr. 2020, doi: 10.3390/electronics9040553.

[30] M. I. Younas, M. J. Iqbal, A. Aziz, and A. H. Sodhro, "Toward QoS Monitoring in IoT Edge Devices Driven Healthcare—A Systematic Literature Review," *Sensors*, vol. 23, no. 21, Art. no. 21, Jan. 2023, doi: 10.3390/s23218885.

[31] P. Lee *et al.*, "Trends in Smart Helmets With Multimodal Sensing for Health and Safety: Scoping Review," *JMIR MHealth UHealth*, vol. 10, no. 11, p. e40797, Nov. 2022, doi: 10.2196/40797.

[32] A. Souri, A. Hussien, M. Hoseyninezhad, and M. Norouzi, "A systematic review of IoT communication strategies for an efficient smart environment," *Trans. Emerg. Telecommun. Technol.*, vol. 33, no. 3, p. e3736, 2022, doi: 10.1002/ett.3736.

[33] S. Rahat and A. Anpalagan, "Bluehoc-based simulation study of user data throughput in Bluetooth-enabled devices," *Int. J. Commun. Netw. Distrib. Syst.*, vol. 5, no. 4, pp. 412–428, Jan. 2010, doi: 10.1504/IJCNDS.2010.035558.

[34] A. H. Mohd Aman, E. Yadegaridehkordi, Z. S. Attarbashi, R. Hassan, and Y.-J. Park, "A Survey on Trend and Classification of Internet of Things Reviews," *IEEE Access*, vol. 8, pp. 111763–111782, 2020, doi: 10.1109/ACCESS.2020.3002932.

[35] X. Meng, "Design and Implementation of Electrical Parameter Monitoring System Based on ZigBee Wireless Communication," *Mob. Inf. Syst.*, vol. 2022, no. 1, p. 4189774, 2022, doi: 10.1155/2022/4189774.

[36] M. Erazo-Rodas, M. Sandoval-Moreno, S. Muñoz-Romero, M. Huerta, D. Rivas-Lalaleo, and J. L. Rojo-Álvarez, "Multiparametric Monitoring in Equatorian Tomato Greenhouses (III): Environmental Measurement Dynamics," *Sensors*, vol. 18, no. 8, Art. no. 8, Aug. 2018, doi: 10.3390/s18082557.

[37] P. Li, Y. Yan, P. Yang, X.-Y. Li, and Q. Lin, "Coexist WiFi for ZigBee Networks With Fine-Grained Frequency Approach," *IEEE Access*, vol. 7, pp. 135363–135376, 2019, doi: 10.1109/ACCESS.2019.2941963.

[38] J. Ding, M. Nemati, C. Ranaweera, and J. Choi, "IoT Connectivity Technologies and Applications: A Survey," *IEEE Access*, vol. 8, pp. 67646–67673, 2020, doi: 10.1109/ACCESS.2020.2985932.

[39] P. C. Nugraha, I. D. G. H. Wisana, D. Titisari, and F. Amrinsani, “Optimal Long Distance ECG Signal Data Delivery Using LoRa Technology,” *J. Biomim. Biomater. Biomed. Eng.*, vol. 55, pp. 239–249, 2022, doi: 10.4028/p-6z381m.

[40] “Multiple Interacting Narrowband Interferences Suppression Algorithm for OFDM Systems | IEEE Journals & Magazine | IEEE Xplore.” Accessed: Oct. 16, 2024. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/9052655

[41] “LoRaWAN® Specification v1.0,” LoRa Alliance®. Accessed: Oct. 16, 2024. [Online]. Available: https://hz1.37b.myftpupload.com/resource_hub/lorawan-specification-v1-0/

[42] “Range and coexistence analysis of long range unlicensed communication | IEEE Conference Publication | IEEE Xplore.” Accessed: Oct. 16, 2024. [Online]. Available: https://ieeexplore.ieee.org/document/7500415

[43] R. Sanchez-Iborra and M.-D. Cano, “State of the Art in LP-WAN Solutions for Industrial IoT Services,” *Sensors*, vol. 16, no. 5, Art. no. 5, May 2016, doi: 10.3390/s16050708.

[44] E. D. Ayele, C. Hakkenberg, J. P. Meijers, K. Zhang, N. Meratnia, and P. J. M. Havinga, “Performance analysis of LoRa radio for an indoor IoT applications,” in *2017 International Conference on Internet of Things for the Global Community (IoTGC)*, Jul. 2017, pp. 1–8. doi: 10.1109/IoTGC.2017.8008973.

[45] J. Rubio-Aparicio, F. Cerdan-Cartagena, J. Suardiaz-Muro, and J. Ybarra-Moreno, “Design and Implementation of a Mixed IoT LPWAN Network Architecture,” *Sensors*, vol. 19, no. 3, Art. no. 3, Jan. 2019, doi: 10.3390/s19030675.

[46] C. Li, X. Guo, L. Shangguan, Z. Cao, and K. Jamieson, “CurvingLoRa to Boost LoRa Network Capacity via Concurrent Transmission,” Jan. 13, 2022, *arXiv*: arXiv:2201.05179. doi: 10.48550/arXiv.2201.05179.

[47] B. Reynders, Q. Wang, P. Tuset-Peiro, X. Vilajosana, and S. Pollin, “Improving Reliability and Scalability of LoRaWANs Through Lightweight Scheduling,” *IEEE Internet Things J.*, vol. 5, no. 3, pp. 1830–1842, Jun. 2018, doi: 10.1109/JIOT.2018.2815150.

[48] R. Serati, B. Teymuri, N. A. Anagnostopoulos, and M. Rasti, “ADR-Lite: A Low-Complexity Adaptive Data Rate Scheme for the LoRa Network,” in *2022 18th International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob)*, Oct. 2022, pp. 296–301. doi: 10.1109/WiMob55322.2022.9941614.

[49] H. Alahmadi, F. Bouabdallah, and A. Al-Dubai, “A New Annulus-based Distribution Algorithm for Scalable IoT-driven LoRa Networks,” in *ICC 2021 - IEEE International Conference on Communications*, Jun. 2021, pp. 1–6. doi: 10.1109/ICC42927.2021.9500407.

[50] Z. Zinonos, S. Gkelios, A. F. Khalifeh, D. G. Hadjimitsis, Y. S. Boutalis, and S. A. Chatzichristofis, “Grape Leaf Diseases Identification System Using Convolutional Neural Networks and LoRa Technology,” *IEEE Access*, vol. 10, pp. 122–133, 2022, doi: 10.1109/ACCESS.2021.3138050.

[51] N. H. A. Rahman, Y. Yamada, M. H. Husni, and N. H. A. Aziz, “Feasibility of LoRa Implementation for Remote Weather Monitoring System through Field Measurement and Case Study

Analysis," *Int. J. Integr. Eng.*, vol. 10, no. 7, Art. no. 7, Nov. 2018, Accessed: Oct. 16, 2024. [Online]. Available: https://publisher.uthm.edu.my/ojs/index.php/ijie/article/view/3501

[52] F. Azizi, B. Teymuri, R. Aslani, M. Rasti, J. Tolvaneny, and P. H. J. Nardelli, "MIX-MAB: Reinforcement Learning-based Resource Allocation Algorithm for LoRaWAN," in *2022 IEEE 95th Vehicular Technology Conference: (VTC2022-Spring)*, Jun. 2022, pp. 1–6. doi: 10.1109/VTC2022-Spring54318.2022.9860807.

[53] D. Magrin, M. Capuzzo, and A. Zanella, "A Thorough Study of LoRaWAN Performance Under Different Parameter Settings," *IEEE Internet Things J.*, vol. 7, no. 1, pp. 116–127, Jan. 2020, doi: 10.1109/JIOT.2019.2946487.

[54] D. L. Mai and M. K. Kim, "Multi-Hop LoRa Network Protocol with Minimized Latency," *Energies*, vol. 13, no. 6, Art. no. 6, Jan. 2020, doi: 10.3390/en13061368.

[55] the Department of Information and Communication Engineering, Chaoyang University of Technology, Taichung City, Taiwan, C.-C. Wei, P.-Y. Su, the Department of Information and Communication Engineering, Chaoyang University of Technology, Taichung City, Taiwan, S.-T. Chen, and the Department of Information and Communication Engineering, Chaoyang University of Technology, Taichung City, Taiwan, "Comparison of the LoRa Image Transmission Efficiency Based on Different Encoding Methods," *Int. J. Inf. Electron. Eng.*, vol. 10, no. 1, pp. 1–4, Mar. 2020, doi: 10.18178/IJIEE.2020.10.1.712.