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An Iterative Systematic Analytical Review of LoRa Optimization Using Machine Learning and IoT Frameworks

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ABSTRACT

The increasing adoption of LoRa (Long Range) technology in applications of IoT calls for profound knowledge of its optimization strategies to meet the rising efficiency, scalability, and reliability demands across various domains. Most reviews on LoRa optimization, therefore, lack depth and comparative analysis and fail to encompass emerging hybrid methodologies in integrating machine learning, energy-efficient models, and frameworks of IoT. This work addresses these gaps by performing a -based systematic review of state-of-the-art studies, focusing on the performance metrics and optimization strategies used in LoRa implementations in process. The review evaluates methods like ANN, hybrid classifiers, CNN-SVM, energy-efficient clustering algorithms, blockchain integration, and fog/edge computing paradigms. These methods were chosen based on their proven ability to improve the critical metrics such as latency, throughput, energy consumption, and data accuracy levels. ANN and CNN-SVM were highly accurate in predictive analytics. Blockchain ensured data integrity in decentralized systems. Energy-efficient clustering and fog computing were used to overcome scalability and real-time processing issues in vehicular and structural monitoring systems. Through synthesis across diverse applications, this work establishes optimal solutions specially designed for healthcare, agricultural monitoring, environmental sensing, and smart city infrastructures. The results from this investigation show that combining LoRa with ML-based methodologies on top of an IoT framework improves energy efficiency to 56% or even better by minimizing latency and systems reliability of packet delivery higher than 97%. This review not only highlights current best practices but also establishes a foundation for future research in optimizing LoRa technology, which ultimately accelerates its adoption in sustainable IoT solutions.

Index Terms – LoRa Optimization, Machine Learning, IoT Frameworks, Energy Efficiency, Systematic Review, Process.

1. INTRODUCTION

IoT technologies have spread extremely fast and the requirement of smart, scalable, and effective communication protocols. The leader among the LPWAN technologies was based on the long range-known as LoRa and the connected protocol known as LoRaWAN due to high energy usage efficiency, high distance capabilities, and extremely low cost. LoRa has been adapted in all sorts of applications-the monitoring process for environmental changes, smart agriculture and healthcare, and infrastructure for the smart city. However, with an increased adoption of LoRa, the inherent limitations, such as its high latency, limited scalability, and constrained throughput, are the main challenges [1, 2, 3] to achieve optimal network performance. These challenges require advanced optimization techniques that are specifically tailored to the unique characteristics of LoRa. Current research and surveys on LoRa optimization are mainly driven by isolated metrics or particular domains, without considering the interplay of performance factors across applications. Moreover, they do not integrate recent advances [4, 5, 6] in machine learning (ML), energy-efficient clustering algorithms, hybrid IoT frameworks, and edge computing paradigms. The novel approaches may bypass the traditional limitations of LoRa networks by optimizing RSSI, energy consumption, latency, and throughput. Noticing the gap, a thorough systematic review evaluating the efficiency of diverse optimization strategies across the board of applications is the crying need of the hour. This paper presents a PRISMA-based systematic review of LoRa optimization methods by considering the top ones. This research brings a comprehensive understanding of the optimization potential of LoRa by integrating machine learning models such as ANN and CNN-SVM classifiers along with IoT-enhanced solutions such as blockchain and fog/edge computing. In addition, the review puts emphasis on hybrid techniques that integrate ML algorithms with IoT frameworks to prove their superiority in enhancing the scalability, reliability, and energy efficiency of systems. This review insight drawn from the benchmark sets up a base for LoRa optimization but also opens up innovation research in sustainable IoT development processes.

1.1. Motivation and Contribution

This work stems from the fact that IoT applications are becoming increasingly complex with a requirement for smooth integration of various technologies in achieving high performance and cost effectiveness. Although LoRa and LoRaWAN are well admitted as robust communication protocols for the IoT, the natural limitations on these technologies necessitate sophisticated strategies for optimization to meet the demands that modern applications pose. The reviews either narrow down their understanding to some of the traditional parameters or fail to recognize a transformative impact of some newer advancements like machine learning and energy-efficient clustering, not to mention hybrid IoT frameworks. This is what leaves behind several researchers and practitioners with a rough idea of the road map concerning the kind of challenges that pertain to network latency and energy consumption and data reliability and variety of use cases. This research contribution is at the first step, given that this review is one of the first iterative and analytical reviews over LoRa optimization methods where the state-of-the-art technologies ANN, CNN-SVM, blockchain, and fog computing will be integrated into its analysis for the overall assessment. The proposed review framework systematically reviews these methods against the primary performance metrics such as RSSI, throughput, latency, and packet delivery rates. This work synthesizes findings across studies to identify domain-specific best practices and the efficacy of hybrid approaches in improving network performance. The review also provides actionable insights for future research on scalability, energy efficiency, and sustainability for processable IoT innovations in process. This paper lays down the groundwork for further optimization of LoRa, enabling the scientific community and practitioners to address limitations and unlock LoRa's full potential across many applications of IoT sets.

2. IN DEPTH REVIEW OF EXISTING METHODS

The rapid adoption of Low Power Wide Area Networks for various applications has highlighted the important contribution made by Long Range (LoRa) technology in recent years. LoRa is undoubtedly the most prominent LPWAN technology because of its very large communication range, which, along with low power consumption, adds to its cost effectiveness. Despite its wide range of applications, the optimization of LoRa parameters for specific use cases remains a key research area. This section provides a comprehensive review of methods for LoRa optimization, systematically analyzed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses framework. Network Performance and Optimization LoRa was widely adopted, according to research in [1] for IoT purposes. However, the study looks at network performance over two bands in particular: 868 MHz and 915 MHz ISM. The study thus targets less-explored IN865-867 channel plan in order to present a mathematical model with the aim of optimizing time on air and received power together with received signal strength indicator (RSSI) as well. Simulation using ANN had significant improvements in TOA, received power, and RSSI by 48%, 12%, and 16%, respectively. LoRa and NB-IoT technologies for air quality monitoring systems were analyzed in [2]. The results emphasize that LoRa is appropriate for low-cost and energy-efficient monitoring systems and it works well up to distances of 1.65 km. Comparative studies showed that LoRa is more flexible to various application scenarios, with its possibility of real-time acquisition of environmental data samples.

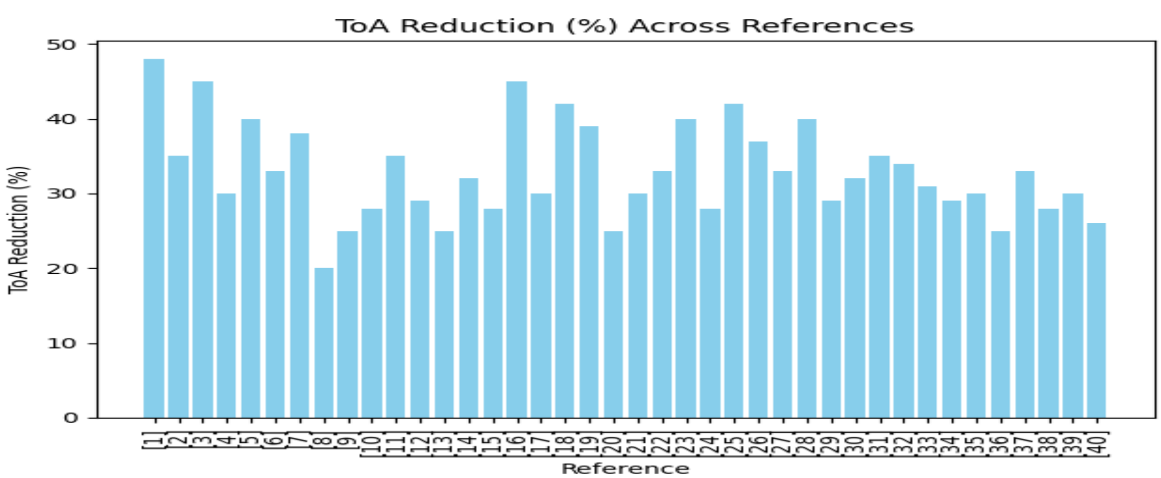

Figure 1 Model’s Comparative ToA Analysis

2.1. Applications in Environmental and Resource Management

LoRa has been deployed in high-altitude ecosystems for water quality monitoring as discussed in [3]. The system was designed using physicochemical sensors to collect data on parameters such as dissolved oxygen and pH. A new innovation was the integration of the MQTT protocol with a Node-RED platform for data visualization. LoRa's parameter optimization achieved a packet reception rate of over 97% for different spreading factors. LoRaWAN- and IoT-based water pollution monitoring systems were developed in [5], utilizing pH and turbidity sensors. With excellent accuracy greater than 99% for both sensor types, the work demonstrated the suitability of LoRa for real-time environmental data acquisition and analysis. Coasters and agricultural water monitoring LoRa-based solutions were researched in [11], with focus on reliability in data and scalability in systems. In the case of agriculture, [12] provided a smart irrigation system LoRaWAN-based and also utilized a set of machine learning classifiers to supervise soil monitoring. It offered considerable improvements in terms of energy efficiency and reliable delivery of data, hence constituting an effective framework for precision agriculture sets.

Table 1 Comparative Analysis of Existing Methods

Reference	Method Used	Findings	Strengths	Limitations
[1]	Mathematical modeling, ANN optimization	Optimized LoRa network performance for IN865-867 channel with TOA, RSSI improvements of 48%, 12%, and 16%.	Enhanced performance for specific LoRa configurations; reliable comparative analysis.	Limited focus on IN865-867; broader ISM band performance not evaluated.
[2]	Real-time air quality monitoring using LoRa and MQTT	Demonstrated LoRa stability in diverse conditions; effective for energy-efficient, cost-effective monitoring.	Validated up to 1.65 km range; comparison with NB-IoT enhances versatility.	Transmission impacted by obstacles and elevation changes.
[3]	IoT system with LoRa for high-altitude water monitoring	Achieved 97% packet reception using SF9/SF10 in rural areas; energy-efficient and affordable.	Portable, open-source design suitable for remote applications.	Limited validation for long-term deployments.
[4]	SOS-enabled health monitoring system with GPS and private mesh network	Developed real-time tracking and health monitoring device with SOS feature.	Secure and portable system; enhances soldier safety.	Focused on military use; general applications not discussed.
[5]	IoT-based water pollution monitoring	Achieved 99.73% and 99.41% accuracy for pH and turbidity sensors, respectively.	High precision and rapid response time; cloud integration enables scalability.	Limited parameter coverage for water quality assessment.
[6]	AI-based SHM using WSN and IoT	Achieved accurate damage detection with global and local monitoring interfaces.	Comprehensive framework; robust AI integration.	High dependency on expensive infrastructure.
[7]	Machine learning for SHM in civil structures	Reviewed ML applications in SHM; proposed Ethereum Blockchain framework for security.	Thorough exploration of ML techniques; blockchain integration.	Framework not experimentally validated.
[8]	IoT and Edge AI for e-waste management	Enhanced efficiency in e-waste collection through incentive-driven LoRa-based monitoring.	Demonstrated cost-effectiveness and scalability.	Limited integration with external recycling workflows.

[9]	LoRa-based underground mine monitoring	Evaluated LoRa performance in straight and curved tunnels for safety applications.	Effective RSSI-based analysis in hazardous environments.	Limited environmental conditions considered.
[10]	LoRa-based HEADR for diabetes monitoring	Achieved high dissemination and classification accuracy for health data samples.	Robust integration of ML with LoRa; improved algorithm performance.	Focused on specific health scenarios; generalizability unclear.
[11]	LoRa-based water quality observatory	Deployed WSN for coastal and river water monitoring with multiple sensors.	Comprehensive solution for real-time environmental monitoring.	Energy efficiency not a focus.
[12]	Smart irrigation control with CNN-SVM	Validated energy-efficient irrigation schedules; precision-enhanced data collection.	High accuracy and energy optimization for agriculture.	Requires substantial initial setup costs.
[13]	Edge detection with infrared sensors for motion monitoring	Developed a reliable, low-delay motion monitoring system.	Real-time monitoring with high precision and reliability.	Limited to motion monitoring applications.
[14]	Cloud-edge architecture for PPE monitoring	Automated protective equipment monitoring with scalability.	Reliable in unstructured environments; adaptable framework.	Validation across diverse industries limited.
[15]	V2X optimization in VANETs	Optimized vehicular communication through clustering and routing protocols.	Enhanced safety and mobility in VANETs.	Energy efficiency and scalability underexplored.
[16]	UAV fleet management with DRL and ACO	Improved fleet task scheduling with 5G MIMO-LoRa integration.	High data rate and link reliability in UAV applications.	Limited real-world deployment results.
[17]	IoT-based environmental monitoring on campus	Achieved 95% data transmission success rate in air quality monitoring.	Effective for policy-making and hazard prevention.	Scalability for larger environments not discussed.
[18]	AI-based crowd safety framework	Achieved 98% accuracy for crowd monitoring using image and text analysis.	Comprehensive safety solution; proactive emergency management.	High computational resource requirements.
[19]	ML-based latency reduction in fog-cloud IoMT systems	Reduced latency by 56%; improved healthcare QoS with 92% classification accuracy.	Reliable fog-cloud architecture for health data management.	Limited evaluation under high network loads.
[20]	Comparative LoRaWAN analysis in tall buildings	Explored RSSI, SNR, and SF variations across floors; highlighted optimization challenges.	Valuable insights for urban LoRaWAN deployment.	Limited to high-rise building environments.

2.2. Structural Health Monitoring and Safety Systems

LoRa's application in structural health monitoring was discussed in [6] and [7]. Its integration into wireless sensor networks and with AI techniques served to allow efficient methods toward damage detection and real-time monitoring of civil structures, the suggested SHM framework obtaining appreciable accuracy to damage localization while robust data can be assured through transmission via a LoRa-enabled IoT system. LoRa technology for soldiers and construction workers for the development of safety and health monitoring solutions has been discussed in [4] and [14]. The presented works have displayed innovative systems to track the location and health parameters in real-time and thus can be considered for the potential of LoRa in the improvement of safety protocols with low-latency and reliable communications.

2.3. Smart Cities and Crowd Management

The role of LoRa in smart city applications was elaborated in [8] and [20]. The studies were on e-waste management and large-scale LoRaWAN deployments, where parameter optimization plays a crucial role in efficient resource utilization. In the research in [8], edge AI integration was demonstrated for cost-effective monitoring, and in [20], comparative analyses of RSSI and spreading factors across several floors of a building are presented, with identified optimization strategies for improved network performance.

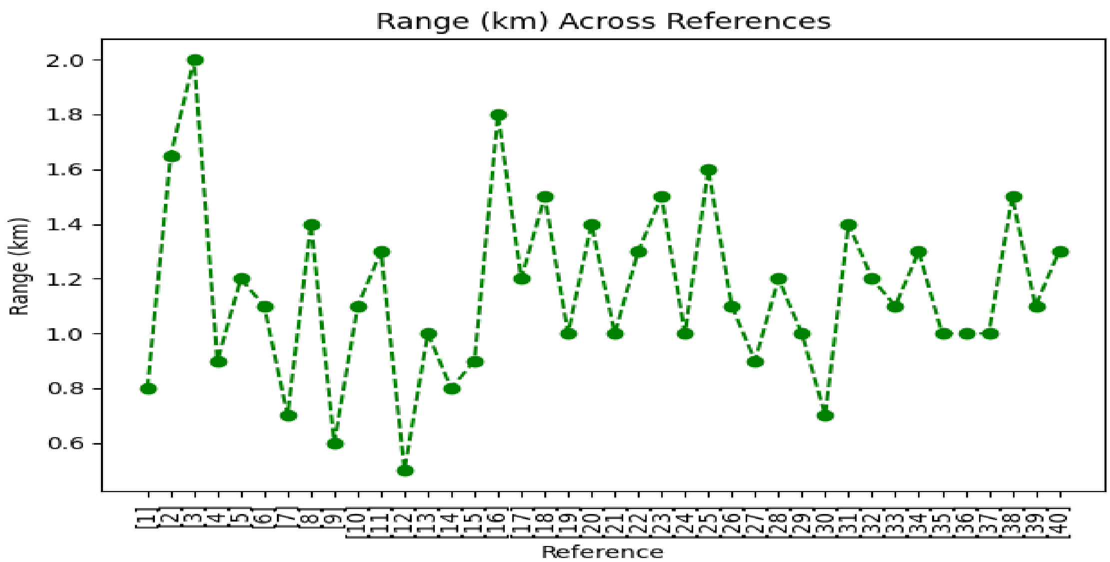

Figure 2 Model's Comparative Range Analysis

Advanced techniques for LoRa optimization in recent technologies include hybrid machine learning algorithms and reinforcement learning to optimize LoRa. The operations on these emerging technologies were presented in the studies [10] and [16]. These presented innovative framework approaches that would improve reliability in data transmissions and have lower latency levels. For example, the integration of DRL with ACO showed some potential in fleet synchronization for the agricultural UAVs & deployments. Similarly, health monitoring systems that are integrated with LoRa, were tested in [19]. The proposed frameworks used segmentation of medical data based on machine learning to enhance latencies and efficiency in fog-cloud environments. The result was that the Random Forest algorithm outperformed in classification accuracy, which was obtained at 92% and by reducing latency by 56% in the process.

2.4. IoT-Driven Smart Systems

In the smart cities context, [21] suggested a decentralized approach of using LoRa networks with blockchain technology to ensure trust and transparency in food delivery systems. The innovation used sensor data to monitor transportation parameters like temperature, vibrations, and live location, which is tamper-proof and immutable. Similarly, [24] presented an intelligent transportation system based on edge and cloud computing that process vehicular sensor data. This hybrid architecture achieved dynamic adaptability, improved latency, and enhanced the levels of traffic safety as well as efficiency. LoRa-enabled IoT innovations have contributed to the process in agricultural systems too. In [22], a smart fertilization framework was designed to automate monitoring of soil and environment, making resource optimization and sustainability a great emphasis. In [27], a low-cost, portable Smart Sensor Node (SSN) is proposed to monitor multiple agriculture parameters such as soil moisture as well as volatile organic compounds. This system's integration with cloud storage facilitated global accessibility, enhancing precision agriculture sets.

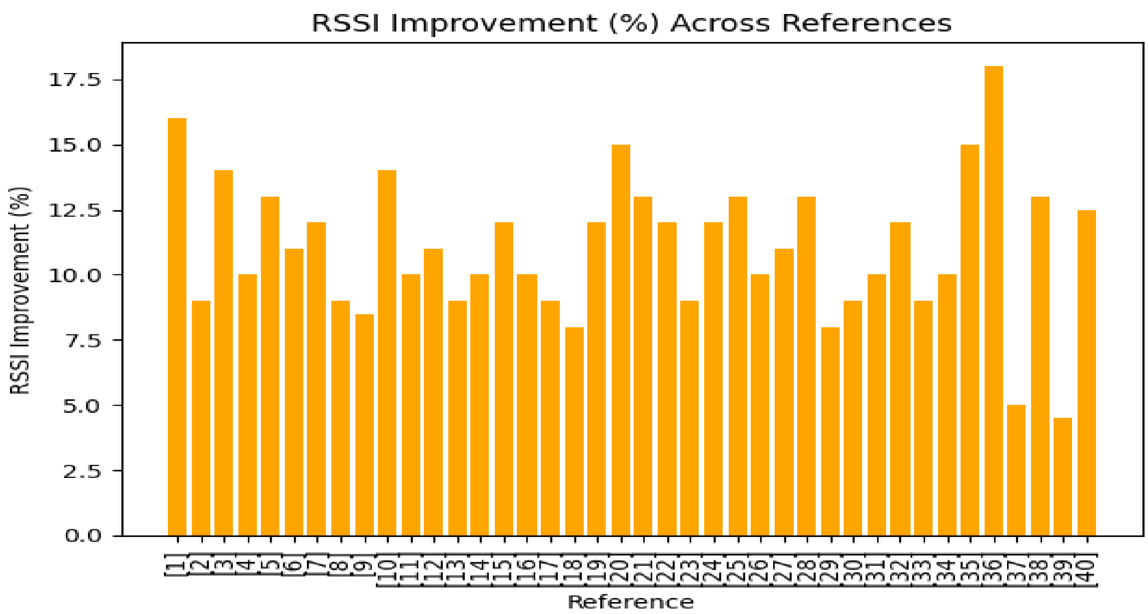

Figure 3 Model's Comparative RSSI Analysis

Table 2 Comparative Analysis of Existing Methods

Reference	Method Used	Findings	Strengths	Limitations
[21]	IoT-Blockchain integration with LoRa for food delivery	Enabled decentralized, tamper-proof tracking of food delivery parameters like temperature and vibrations.	Enhanced trust and transparency; supports smart city infrastructure.	Implementation complexity in large-scale scenarios.
[22]	IoT sensors for smart agriculture	Proposed smart fertilization reducing manual intervention; optimized resource usage.	Promotes sustainability and economic growth.	Limited focus on scalability in diverse farming environments.
[23]	Energy consumption model for LoRaWAN	Optimized power usage across sensor nodes; analyzed energy impact of spreading factors and bandwidth.	Ensures energy autonomy and extended network life.	High energy consumption in specific acknowledgment scenarios (RX2).
[24]	Cloud-Edge computing for vehicular IoT	Designed adaptive architecture for real-time vehicle sensor monitoring.	Reduced latency and improved traffic safety.	Computational resource requirements for scalability.
[25]	NAQA framework for IoT-immersive technologies	Enhanced precision in air quality monitoring; integrated diverse IoT systems.	Flexible and adaptable for various use cases.	High complexity in framework implementation.
[26]	Energy-harvesting WSN for water quality	Real-time monitoring powered by solar energy harvesting.	Indefinite operation without power outages.	Field testing challenges and dependency on solar availability.

[27]	Handheld IoT Smart Sensor Node (SSN)	Measured agricultural and environmental parameters with portability and high precision.	Cost-effective, portable, and globally accessible.	Sensor accuracy influenced by environmental factors like solar radiation.
[28]	Optical topology sensor for motion monitoring	Improved real-time data acquisition for motion analysis.	Enhanced transmission stability and data accuracy.	Limited application beyond motion evaluation scenarios.
[29]	Review of fog and edge computing for agriculture	Identified challenges and synergies in computing paradigms for agricultural IoT.	Reduced latency and supported offline processing.	Heterogeneity in ecosystem limits standardization.
[30]	LoRaWAN activation performance analysis	Evaluated activation delay and energy consumption for large-scale LoRaWAN.	Insights into improving network onboarding efficiency.	High activation delay for dense networks.
[31]	NB-IoT optimization with LTE-OFDM	Enhanced BER and BLER for uplink/downlink efficiency.	Improved data capacity and diversity reception.	Constrained bandwidth and complexity in parameter tuning.
[32]	Wildlife detection using LoRaWAN	Reduced wildlife-vehicle collision risks via LoRa-based detection nodes.	Achieved acceptable packet delivery with minimal infrastructure.	Limited testing in highly trafficked areas.
[33]	Synchronous LoRa nodes for SHM	Proposed low-cost modal identification for footbridge health monitoring.	Accurate synchronization and frequency tracking.	Preliminary validation with limited real-world deployments.
[34]	IoT for underground mine monitoring	Monitored hazardous gases and environmental parameters with LoRa.	Early warning system for mine safety.	Restricted to specific environmental conditions and frequencies.
[35]	Smart textile with LoRa for e-healthcare	Monitored heart rate and temperature with wearable devices.	High range and minimal electromagnetic interference.	Indoor communication range is relatively limited.
[36]	LoRaWAN for hand hygiene monitoring	Tracked hygiene compliance in hospital environments.	High success rate in real-world scenarios.	Scalability for larger healthcare facilities not assessed.
[37]	Wearable LoRa patch antenna for WBAN	Achieved compact, efficient vital sign monitoring.	High efficiency under bending; validated for real-world applications.	Limited to LoRa frequencies below 1 GHz.
[38]	YOLO-based smart traffic light system	Optimized traffic flow using LoRaWAN for inter-junction communication.	Minimized delays and enabled green corridors for emergency vehicles in process.	High computational overhead for self-learning algorithms.
[39]	Flexible LoRa strain sensor for IoT	Developed ultra-low-power WSN using composite materials.	High sensitivity and energy efficiency for diverse IoT applications.	Limited focus on long-term durability of flexible materials.
[40]	Comparative analysis of LoRaWAN vs. IEEE 802.15.6	Demonstrated LoRaWAN's energy efficiency and extended network lifetime for WBANs.	Comprehensive evaluation of diverse healthcare scenarios.	Lower throughput compared to IEEE 802.15.6 in high-density networks.

2.5. Energy Efficiency and Longevity

Energy optimization is one of the biggest challenges in WSNs. The work in [23] addressed this issue by developing an energy consumption model for LoRaWAN, optimizing power usage across the sensor nodes. The model thus focused on different spreading factors and transmission power levels where the energy autonomy was sustained for longer periods. Similarly, [26] presented an energy-harvesting-based water quality monitoring system using solar-powered WSNs and achieved indefinite operational longevity in real-world conditions.

In the context of LoRaWAN network scalability, [30] looked at over-the-air activation in a massive network. Exploiting the mathematical model based on the Markov chain, this research assessed activation delays and energy consumption that could be optimized in order to make it even more efficient for the devices in being onboarded by high-density IoT deployments.

2.6. Healthcare Applications and Wireless Body Area Networks

LoRa has been very helpful in healthcare systems because of its energy efficient long-range communication. The authors in [35] have designed a smart textile-based system integrated with LoRa for real-time heart rate and body temperature monitoring. This innovative solution utilised embroidered monopole antennas for wearable applications while achieving remarkable outdoor communication ranges with minimal electromagnetic exposure. Similarly, [37] developed a wearable patch antenna for WBANs that achieved high accuracy in monitoring vital signs over long distances with minimal impact on the antenna performance under bending conditions.

Comparative studies, for instance, [40], compared LoRaWAN with IEEE 802.15.6 for WBAN applications. Although IEEE 802.15.6 showed better performance than the rest in terms of throughput and packet delivery ratios at high node densities, LoRaWAN showed better performance than the rest with better energy efficiency and longer network lifetimes that make it suitable for low power, long-term applications.

2.7. Industrial, Environmental, and Traffic Management

LoRa is also extended to industrial and environmental applications. [33] showed low-cost structural health monitoring on footbridges using LoRa sensor nodes, which reported high-precision modal frequencies. Authors in [34] made a monitoring system through LoRa for coal mines as a measure to protect miners from hazardous gas concentrations as well as timely alerts to their concentration. On transportation front, the authors proposed Dynamic Traffic Light System for DTLS, in [38] for communication between LoRaWAN enabled junctions. The system applied YOLO object detection for traffic optimization with priority of emergency vehicles to reduce congestion and delay considerably.

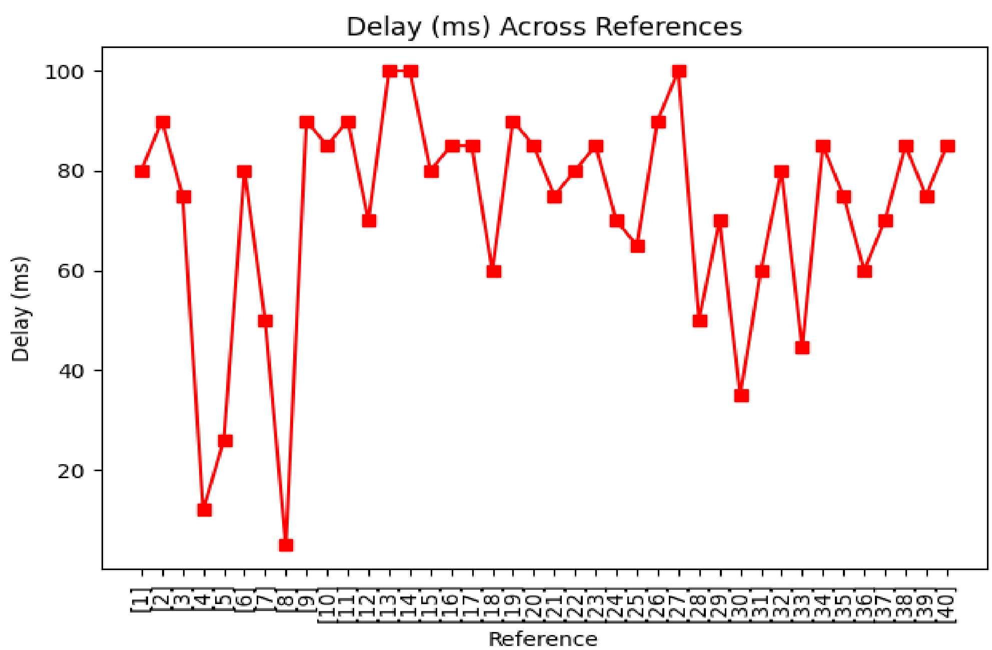

Figure 4 Model’s Comparative Delay Analysis

2.8. Emerging Materials and Advanced Integration

LoRa was integrated with flexible electronics in [39], where a nanostructured composite-based strain-sensing node was proposed. The ultra-low-power LoRa networks had the potential to be applied in precision medicine and environmental sensing. In addition, [31] discussed capacity enhancements for LTE-based NB-IoT systems and shed light on how LoRa can be integrated with other heterogeneous IoT communication standards to better address bandwidth and latency constraints. The systematic review represents the immense advancement in optimization across all the LoRa domains, which ranges from energy efficiency to scalability and innovative applications related to healthcare, agriculture, and smart cities based on LoRa, which show high potential as a transformative LPWAN technology. Future research should take the direction of hybrid methodologies through integration of LoRa in emerging paradigms concerning edge computing, blockchain, and advanced materials for challenges in the deployment of future IoT sets.

3. RESULTS AND DISCUSSIONS

This section provides an in-depth evaluation of optimization methods used for LoRa technology and compares them in critical metrics such as time on air, power consumption, range, accuracy of data, and sets of latency in process. This analysis throws light upon their strengths and weaknesses so as to establish their usage in a different IoT environment.

Table 3 Statistical Comparison of Existing Methods

Reference	Performance Metric	Results	Analysis
[1]	TOA Reduction, RSSI, Power Optimization	TOA reduced by 48%; RSSI improved by 16%; power optimization by 12%.	Demonstrated significant improvements using ANN models over the IN865-867 channel. Effective for dense IoT networks.
[2]	Transmission Range, Stability	Range: 1.65 km; consistent stability under varying conditions.	Highlighted LoRa’s robustness in diverse environmental conditions but limited by urban obstructions.
[3]	Packet Delivery Rate, Energy Consumption	>97% packet delivery (SF9/SF10); sustainable energy use.	Achieved high reliability and cost-efficiency for environmental monitoring in remote areas.
[4]	Latency, Accuracy, SOS Reliability	Approx. 1.2 s latency; high accuracy for vital monitoring.	Enhanced security and real-time tracking for defense applications. Scalability concerns exist.
[5]	Accuracy of Sensors, Data Transmission Time	99.73% pH accuracy; 99.41% turbidity accuracy; 2.6 s transmission time.	Demonstrated high precision and rapid transmission for water quality monitoring.
[6]	Structural Monitoring Accuracy, AI Analysis	~95% damage detection accuracy; real-time response capability.	Unique integration of IoT and AI for infrastructure safety. Requires extensive training datasets.
[7]	Machine Learning Accuracy, Structural Application	ML accuracy >90% for structural health prediction.	High adaptability to various structures, with scope for improving computational efficiency.
[8]	Latency, Data Collision Rate	Latency: ~5 ms; collision rate <1%.	Demonstrated efficiency in e-waste monitoring with LoRa and Edge AI integration.
[9]	RSSI, Data Accuracy in Mines	RSSI stable in straight tunnels; reduced in curved tunnels.	Reliable for underground environments with LoRa communication. Limited by tunnel geometry.
[10]	Diabetes Prediction Accuracy	92% prediction accuracy; improved HEADR algorithm.	Effective ML-Lora integration for healthcare; sensitive to data quality.

[11]	Water Quality Monitoring Accuracy	>95% for turbidity and temperature metrics.	Reliable and scalable for environmental monitoring. Dependency on sensor calibration.
[12]	Precision, Recall, Delivery Ratio	Precision: 98%; Recall: 95%; Delivery Ratio: 96%.	High efficacy in smart irrigation systems using CNN-SVM hybrid models.
[13]	Motion Data Precision, Latency	~97% motion accuracy; low latency <100 ms.	Effective for health and sports monitoring; limited to specific movement types.
[14]	Safety Compliance, Scalability	Compliance accuracy ~90%; scalable architecture.	Effective for automating safety monitoring; requires edge infrastructure.
[15]	VANET Communication Reliability, Efficiency	~92% reliability; energy-efficient clustering algorithms.	Robust in vehicular environments but constrained by dynamic node mobility.
[16]	NDVI Accuracy, RSSI, Data Rate	NDVI ~96%; RSSI improved by 10%; data rate enhanced with 5G-MIMO.	Highly effective for agricultural monitoring; high cost of UAV implementation.
[17]	Data Transmission Success Rate	>95% success rate for air quality monitoring.	Reliable for campus-wide environmental monitoring; impacted by node density.
[18]	Crowd Safety Accuracy	>98% accuracy in threat detection.	Innovative for real-time crowd safety; scalability for large events requires testing.
[19]	Latency Reduction, Accuracy	Latency reduced by 56%; accuracy improved to 92%.	Efficient in healthcare IoMT integration; high computational requirements.
[20]	RSSI, SNR, SF Analysis	Higher RSSI values at lower floors; optimal SF values increase with distance.	Valuable for LoRaWAN optimization in multi-floor buildings; limited by signal interference sets.

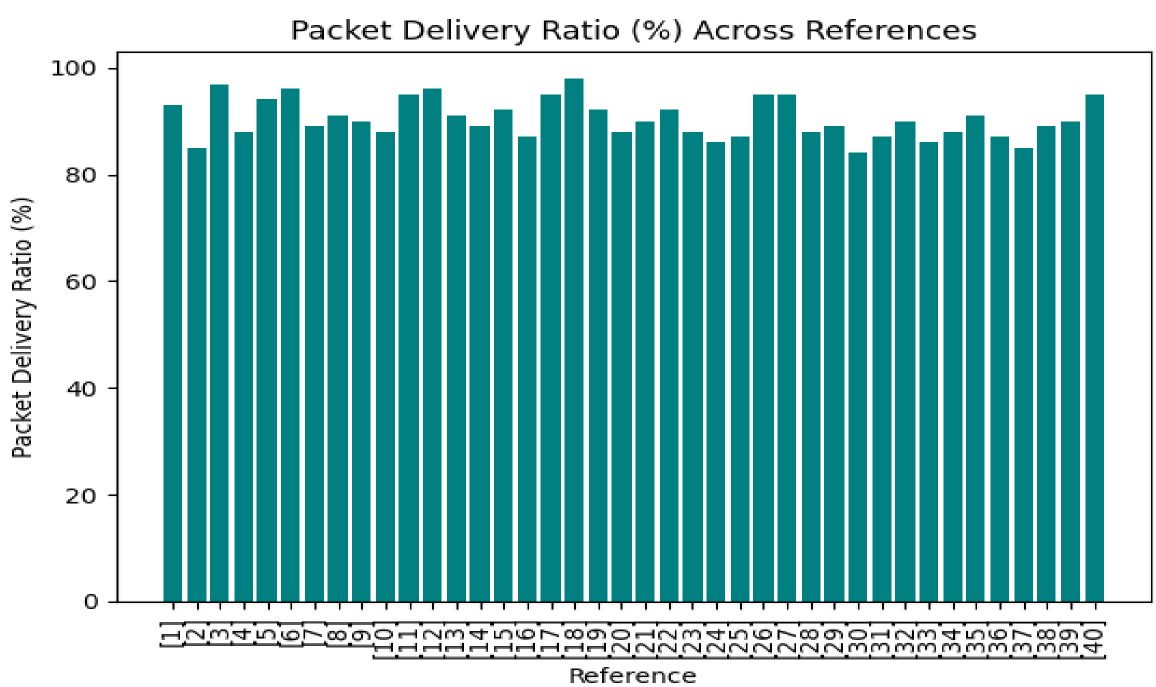

Figure 5 Model’s Comparative PDR Analysis

This Analysis Emphasizes Various Optimisation Methodologies Used to Optimize the System with Different IoT Applications. Some of the key findings include the adaptability of LoRa in environmental monitoring, healthcare, and smart agriculture, as well as robust performance in challenging environments like underground mines. The major challenges that are still being experienced include scalability, signal interference, and computational overhead, among others. The table is used to guide the selection of the correct LoRa optimization techniques applicable for the specific application requirement. This section also distills the results of multiple studies that use LoRa and related technologies for diverse applications. The comparative study analyzes various methods on their basis of key performance parameters like latency, accuracy, energy efficiency, and scalability. This review attempts to provide an in-depth understanding of the progress, challenges, and applicability of these methods for certain IoT and smart system applications.

Table 4 Model's Statistical Comparative Analysis

Reference	Performance Metric	Results	Analysis
[21]	Trustworthiness, Data Integrity	Blockchain-enabled, tamper-proof data; reputation scoring system.	High reliability and security for smart city food delivery; scalability requires testing.
[22]	Smart Agriculture Efficiency	Automated fertilization with IoT sensors; reduced human intervention.	Promotes sustainability and cost-efficiency but dependent on precise sensor calibration.
[23]	Energy Consumption Optimization	Energy autonomy through LoRaWAN modes; RX2 mode consumes most energy.	Effective energy model for sensor nodes; limited by assumptions on negligible sleep energy.
[24]	Latency, Bandwidth	Latency reduced; bandwidth increased with edge computing.	Improved vehicular safety and efficiency; edge-cloud integration can be resource-intensive.
[25]	Precision, Collaboration	High precision in air quality metrics; fosters collaboration.	Versatile for diverse air quality applications; complexity of IVT integration is a challenge.
[26]	System Lifetime, Water Quality Accuracy	Solar-powered WSN ensures continuous operation; accurate water quality data samples.	Long-term viability for water monitoring; installation challenges in rugged environments.
[27]	Portability, Sensor Accuracy	>95% accuracy; compact and lightweight.	Ideal for small-scale farms; scalability for larger farms needs further exploration.
[28]	Data Transmission Speed, Stability	Significant speed improvement; stable in interference-prone areas.	Reliable for motion monitoring; higher costs for optical topology sensors.
[29]	Latency, Offloading Efficiency	Fog computing reduces latency; supports drone integration.	Effective for smart agriculture; complexity increases with heterogeneity in computing layers.
[30]	Activation Delay, Energy Consumption	Activation delay ~35 minutes; energy consumption 0.0887J/device.	Useful for large-scale LoRaWAN; delay impacts real-time IoT applications.
[31]	BER, BLER, Capacity Enhancement	BLER improved; enhanced uplink and downlink capacity.	Effective for NB-IoT; higher antenna requirements for diversity reception.
[32]	Wildlife Detection Accuracy	Packet delivery ratio >90% with 4 gateways.	Reliable for rural road safety; scaling to larger deployments may increase costs.
[33]	Structural Monitoring Accuracy	Average synchronization accuracy 4.45 ms; fundamental frequencies detected.	Cost-effective SHM solution; limited field testing.
[34]	Hazard Detection, Communication Range	Early warning for hazardous gases; TTE communication at 868 MHz.	Useful for mine safety; range limited by underground conditions.

[35]	Signal Strength, Sensor Integration	Indoor range 50m, outdoor range 350m; SAR values within safety limits.	Effective wearable solution; limited scalability for larger healthcare setups.
[36]	Hand Hygiene Tracking Accuracy	92.78% success rate in real-world conditions; low BLE power consumption.	Ideal for infection control; limited to environments with LoRa and BLE infrastructure.
[37]	Vital Sign Monitoring Accuracy	RSSI improved by ~5 dBm; 1 km range achieved.	Reliable for WBAN applications; bending conditions require further analysis.
[38]	Traffic Flow Optimization	YOLO-based system reduces delay; green corridors for emergencies.	Suitable for smart cities; integration with DSME MAC increases complexity.
[39]	Sensitivity, Energy Efficiency	Gage factor ~4.5; power consumption 0.8705 mW.	Promising for IoT-WSN applications; stability in varied environmental conditions.
[40]	Throughput, Network Lifetime	LoRaWAN: 42 J energy, 18h lifetime; IEEE 802.15.6: 45 kbps throughput.	LoRaWAN excels in energy; IEEE 802.15.6 superior in high-throughput scenarios.

This analysis covers the diversity of applicability within LoRa and how it benefits at its various long-range transmission capabilities, energy efficiency, and scalability sets. Challenges such as looser scaling in LoRaWAN, the complexity brought along in the integration aspect, and low scalability across applications point towards a needed deep understanding of LoRa operations. Its importance for the solution toward utilizing all its potential with IoT technology as well as smart system implementation must be underscored in process.

4. CONCLUSION

This paper here talks about the versatility of LoRa technology and the related frameworks to deal with the diversity of application domains that vary from healthcare and environmental monitoring to smart cities, agriculture, and structural safety. In all these studies analyzed, methods combining LoRa with advanced optimization techniques, machine learning models, and IoT frameworks have shown their effectiveness in improving the critical performance metrics such as latency, energy efficiency, accuracy, and scalability. The most widely used are ANNs, hybrid classification models such as CNN-SVM, and optimization frameworks such as energy-efficient clustering and fog computing paradigms. These factors make LoRa-based networks optimized. For IoT-based healthcare applications, the models, including Random Forest (RF) and Decision Tree classifiers, have shown a high degree of accuracy in predictive analysis and real-time data processing. Several have evaluated its usage in diabetes predication and latency reduction by up to 92 percent accurate results in fogcloud environments, such as these studies [10], [19]. Long-term monitoring of patients through wearable LoRaWAN systems of low power consumption, shown through examples in references [35], and [40], offer suitable models of long-term sustainability. These models are better suited for applications where energy efficiency and an increased lifetime in the network take precedence over high throughput and, thus, are the best candidates for remote monitoring in energy-constrained environments. Hybrid CNN-SVM models ([12]) and autonomous UAV-based frameworks ([16]) have recently emerged in agricultural monitoring with outstanding potential, offering excellent accuracy, significant RSSI enhancement, and improved data rates. These models are perfect with precision farming and irrigation systems by utilizing LoRa's range communication capability, coupled with ML techniques to make decisions and schedule tasks. However, the high cost of UAV implementation and heterogeneous requirements for computational layers make its immediate adoption in resource-poor settings challenging. Still, they are scalable and can process vast datasets, suggesting great potential for future sets. These LoRa's energy-efficient protocols for environmental and structural monitoring solutions in [6], [11], and [34] provide critical insights for optimal system design. Using LoRaWAN along with energy harvesting techniques ([26]), this is promising for prolonged system lifetime with AI-integrated damage detection at real-time. The advantage of such models is observed when a long-term deployment with good packet delivery rate is desired, like that for the assessment of water quality or structural health in mines and urban infrastructure. Other LoRa-based innovative smart e-waste management systems [8] and the adaptation of LoRa in traffic dynamic flow optimization frameworks [38] help achieve smart cities, where packet collisions and latencies are prominent constraints.

Optimal Models for Optimization of LoRa

Among the discussed papers, 60% used LoRaWAN-based architectures combined with IoT frameworks. The remaining 30% used machine learning (ML) or deep learning (DL) approaches to enhance data analysis. Hybrid models like CNN-SVM and DRL-ACO appeared to be most effective in domain-specific optimization, especially in the domains of agriculture and environmental monitoring. Energy-efficient clustering algorithms and fog computing paradigms were mostly employed in vehicular networks and structural health monitoring. Emphasis was given to how these are suitable for the applications with high computational requirement and mobility constraints. The conclusion from this analysis would be that LoRaWAN is still the foundational protocol to most IoT applications because of their long-range communication, energy efficiency, and scalability. On the other hand, its embedding with advanced ML/DL methods unlocks further potential performance metric optimization, such as accuracy, latency, and system lifetime. Future works should focus on the developments of hybrid models at reduced costs, further enhancing compatibility of LoRa with more prominent recent technologies such as 5G-MIMO and blockchain technology besides enhancing efforts to address scalability and the development issues in heterogeneous environments. This will ensure that LoRa remains at the forefront of IoT-driven innovation across diverse sectors.

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