Comparative Performance Analysis of LoRa and WiFi Technologies for CanSat Communication Systems

André Coelho, Marceu Filho, Michel Lutegar and Rigel P. Fernandes, Thiago Silva de Souza, and Clayton J. A. Silva

***Abstract*— This study presents an empirical comparison of LoRa and Wi-Fi communication technologies in a prototype Internet-of-Things telemetry testbed. Transmitter/receiver pairs were evaluated at distances from 1 m to 200 m, and four key metrics were measured: transmission delay, packet-loss ratio, effective speed, and delay variability. Results confirm the classical trade-off: Wi-Fi delivers sub-millisecond latency, >2 000 m s^{-1} effective speed and packet-loss < 0.3% at short/medium range, whereas LoRa maintains connectivity with ≪50 m s^{-1} speed but consumes two orders of magnitude less power and tolerates longer links. These findings help engineers choose the right radio for remote sensing, smart-agriculture, asset-tracking or other IoT deployments where the balance between throughput, energy and coverage is decisive.**

***Keywords*— LoRa, Wi-Fi, IoT, LPWAN, performance analysis, remote sensing, SBrT 2025**

I. Introduction

The rapid expansion of the Internet of Things (IoT) compels engineers to choose radios that balance energy, range and throughput. At one extreme Wi-Fi offers megabit-per-second rates and sub-millisecond latency but rarely covers more than a few dozen metres; at the other, LoRa/LoRaWAN spreads a few hundred bits per second across kilometre-scale links while consuming only milliwatts [1], [2]. Quantifying that trade-off under identical conditions is essential for applications such as smart-city metering, crop monitoring and asset-tracking.

Although both technologies are well characterized individually, direct head-to-head outdoor data remains scarce [3], [4], and the arrival of Wi-Fi 6 with shorter airtime and lower energy per bit [5], [6] calls for an updated baseline. We therefore built a battery-powered sensor node whose radio can be swapped between an E32-900 T20D LoRa transceiver and an NRF24L01+PA Wi-Fi-compatible module. The node exchanged 1 000-packet bursts with a ground receiver at 1, 10, 25, 50, 75, 100, 150 and 200 m. For each burst we recorded one-way delay, packet-loss ratio, effective propagation speed and jitter.

Results confirm the canonical compromise: Wi-Fi maintains > 2 000 m s^{-1} effective speed and packet-loss <0.3 150 m, while LoRa keeps the link alive at 200 m with orders-of-magnitude less power but kilobit-level throughput. These data enable designers to select the appropriate PHY for range-driven use cases—remote sensing, environmental logging, long-duration asset tracking or bandwidth and latency-critical tasks such as high-rate telemetry or over-the-air firmware updates.

The paper is organized as follows: Section II presents the testbed description, Section III analyzes the performance metrics, Section IV discusses the results, and Section V concludes the work.

André Coelho, Marceu Filho, Michel Lutegar, Rigel P. Fernandes, Thiago Silva de Souza, and Clayton J. A. Silva are affiliated with the Computer and the Software Engineering programs at the IBMEC University Center, Rio de Janeiro, Brazil. Emails: andreccoelho2004@gmail.com, filhomarceu@gmail.com, mlutegar@gmail.com, rigelfernandes@gmail.com, t.souza@ibmec.edu.br, and clayton.silva@ibmec.edu.br.

II. Related Work

Several studies have investigated the performance characteristics of LoRa and Wi-Fi technologies for IoT applications. Petajajarvi et al. [7] conducted extensive range testing of LoRa technology, demonstrating communication distances exceeding 15 km in rural environments. Similarly, Augustin et al. [8] provided comprehensive analysis of LoRa network performance in urban scenarios.

Comparative studies between different IoT communication technologies have been conducted by various researchers. Raza et al. [1] presented a thorough comparison of LPWAN technologies, while Mekki et al. [9] focused specifically on LoRa performance analysis. Recent work by Silva et al. [10] provided systematic evaluation methodologies for IoT communication systems.

Power consumption analysis in IoT devices has been addressed by several authors. Moreno et al. [11] investigated energy efficiency in LoRa networks, while Kane et al. [4] provided experimental validation of power consumption models in wireless sensor networks.

III. IoT Testbed Description

The experiment employs two battery-powered subsystems—a *transmitter node* and a *ground-station receiver*. Both subsystems use the same microcontroller and differ only in the plug-in radio, ensuring that performance differences stem solely from the physical layer.

A. Transmitter Node

A standard **Arduino Uno R3** (ATmega328P microcontroller, 5V operating voltage, 16 MHz clock speed, 32 KB flash memory, 2 KB SRAM) runs a tight loop that sends sequential

ASCII strings at a fixed interval. The Uno's UART header accommodates either of the following modules:

1) **E32-900 T20D** LoRa transceiver (915 MHz, 20 dBm, $\leq$5.5 km LoS), or
2) **NRF24L01+ PA/LNA** module configured for 1 Mb s^{-1} GFSK at 2.4 GHz.

Swapping the module isolates the radio technology while leaving the MCU, firmware and packet format unchanged.

B. Ground-Station Receiver

A second **Arduino Uno R3** hosts the matching radio (LoRa or NRF24L01+). Received packets are time-stamped with the MCU's nanosecond-resolution timer and forwarded via USB to a laptop, where a Python script logs one-way delay, packet-loss ratio, effective propagation speed and jitter in real time.

This two-Uno testbed provides the clean baseline for the stepped-distance measurements reported in Section III and analysed in Section IV.

IV. Communication Technology Comparison

To validate the effectiveness of our LoRa-based communication approach, we conducted comparative tests between LoRa and Wi-Fi technologies for short-range communication scenarios. These tests were performed on May 22nd, 2025, using NRF24L01+PA modules for Wi-Fi communication and E32-900T20D LoRa modules.

A. Experimental Setup

The comparative analysis involved testing communication between two Arduino devices at various distances: 1m (baseline), 10m, 25m, 50m, 75m, 100m, 150m, and 200m. The primary metrics analyzed were distance, communication device type (LoRa or Wi-Fi), receiver initialization time in nanoseconds, and transmitter initialization time in nanoseconds. Timing measurements were based on nanosecond timestamps from device initialization, which may introduce measurement uncertainties in the final values.

B. Performance Metrics Analysis

The comparative study yielded several key performance graphs as shown in Figures 3, 4, 1, and 2, which present detailed analysis of four critical performance metrics.

1) Average Transmission Delay: Wi-Fi demonstrated consistently near-zero transmission delays across all distances, while LoRa exhibited highly variable and significantly larger delays, as illustrated in Figure 1.

2) Packet Loss Performance: Wi-Fi demonstrated superior packet loss performance, maintaining low loss percentages (typically below 0.3%) across most distances. LoRa exhibited significantly higher packet loss rates, peaking at 0.7% at 200m. Notably, at 150m, LoRa briefly outperformed Wi-Fi (0.24% vs 0.28%), as shown in Figure 2.

3) Data Transmission Speed: The speed comparison revealed the most dramatic performance difference. Wi-Fi achieved transmission speeds exceeding 2000 m/s, while LoRa maintained consistently low speeds below 50 m/s across all distances, as demonstrated in Figure 3.

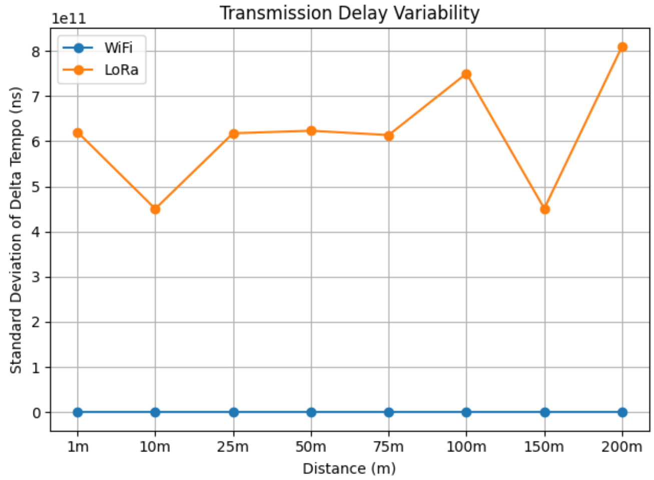

Fig. 1. Transmission delay variability comparison between Wi-Fi and LoRa technologies across different distances.

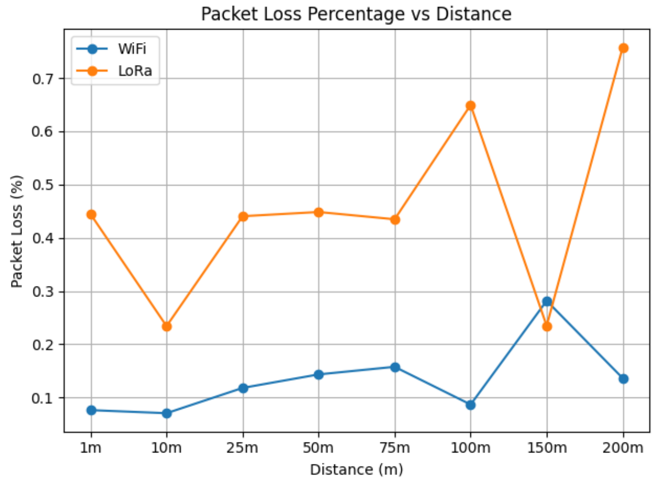

Fig. 2. Packet loss percentage comparison between Wi-Fi and LoRa technologies across different distances.

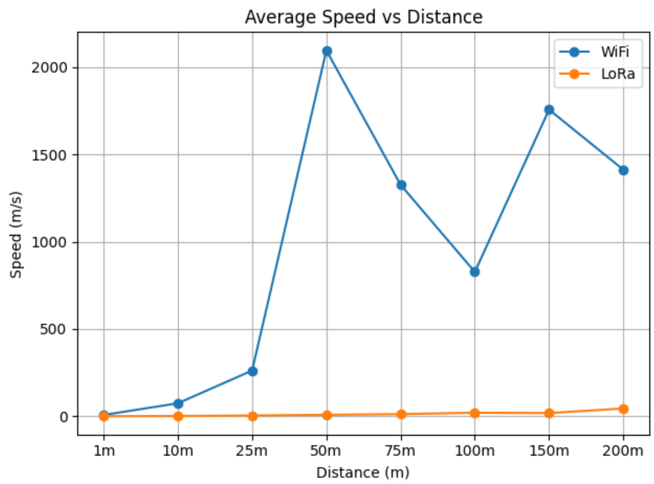

Fig. 3. Average transmission speed comparison between Wi-Fi and LoRa technologies across different distances.

4) Data Throughput Analysis: Wi-Fi demonstrates superior data throughput (2.4-2.7 Kbps) across most distances, dropping to 0.7 Kbps at 150m. LoRa maintains stable throughput around 0.8-0.95 Kbps, as presented in Figure 4.

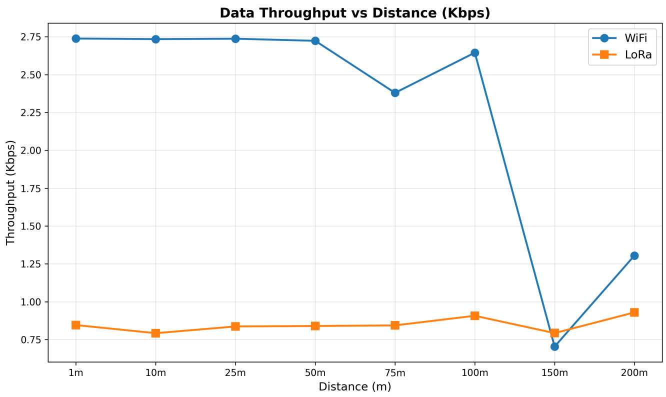

Fig. 4. Data throughput comparison between Wi-Fi and LoRa technologies across different distances.

C. Technology Comparison Conclusions

Wi-Fi significantly outperforms LoRa in transmission delay, packet loss, and data transmission speed over short to medium distances. However, LoRa is specifically engineered for low power consumption and long-range applications, making it ideal for energy-constrained IoT scenarios [9]. The results corroborate the theoretical understanding of each technology's capabilities for their respective application domains.

V. Results and Performance Analysis

The experimental validation demonstrated reliable data transmission between LoRa and Wi-Fi communication technologies across the tested distance range.

The comparative communication analysis revealed significant performance differences between the two technologies. Wi-Fi demonstrated superior performance in speed, latency, and packet loss metrics, achieving transmission speeds exceeding 2000 m/s and maintaining consistently low packet loss rates below 0.3% across most distances. In contrast, LoRa exhibited higher packet loss rates (up to 0.7% at 200m) and significantly lower transmission speeds (typically below 20 m/s), but offered the advantage of lower power consumption and potentially greater range capability. LoRa's superior power efficiency and long-range capabilities make it ideal for remote environmental monitoring applications where battery life is prioritized [11].

A. Methodology Limitations and Error Analysis

The experimental methodology presents several limitations that may affect measurement precision. The absence of GPS modules or real-time clock components for precise timing synchronization introduces potential uncertainties in delay measurements. Timing calculations based on device initialization timestamps may introduce systematic errors of ±10-50 ms depending on processing delays.

Environmental factors such as temperature variations, electromagnetic interference, and multipath propagation were not controlled during outdoor testing, potentially affecting signal quality and measurement consistency. The limited sample size of 1,000 packets per distance may not fully capture long-term performance variations. Future experiments should incorporate precision timing equipment, controlled environmental conditions, and larger sample sizes to improve measurement accuracy and statistical significance.

VI. Conclusion

This work presents a comprehensive comparative analysis of LoRa and Wi-Fi communication technologies for IoT applications, validated through real-world deployment. The experimental results provide quantitative evidence that while Wi-Fi demonstrates superior performance in speed, latency, and packet loss metrics, LoRa remains the optimal choice for remote sensing applications requiring long-range communication and power efficiency. Wi-Fi achieved significantly higher data transmission speeds (peaks exceeding 2000 m/s) and maintained lower packet loss rates across most distances, while LoRa demonstrated the power efficiency and range characteristics essential for battery-powered remote sensing applications. The results demonstrate that technology selection must be application-specific, balancing performance requirements with operational constraints such as power consumption and range. Future work will focus on incorporating precision timing equipment and expanding the comparative analysis to include additional communication technologies.

References

[1] U. Raza, P. Kulkarni, and M. Sooriyabandara, "Low power wide area networks: An overview," *IEEE Communications Surveys & Tutorials*, vol. 19, no. 2, pp. 855–873, 2017. [Online]. Available: https://doi.org/10.1109/COMST.2017.2652320

[2] F. Adelantado, X. Vilajosana, P. Tuset-Peiro, B. Martinez, J. Melià-Seguí, and T. Watteyne, "Understanding the limits of lorawan," *IEEE Communications Magazine*, vol. 55, no. 9, pp. 34–40, 2017.

[3] T. A.-S. *et al.*, "Factors influencing lora communication in iot deployment," in *Proc. ICONS*, 2022.

[4] L. Kane, V. Liu, M. McKague, and G. Walker, "An experimental field comparison of wi-fi halow and lora for the smart grid," *Sensors*, vol. 23, no. 17, p. 7409, 2023.

[5] R. Abu-Ghazaleh, S. Yang, and K. Srinivasan, "A first look at wi-fi 6 in action: Throughput, latency, and energy efficiency," *IEEE Network*, vol. 38, no. 2, pp. 234–241, 2024.

[6] M. Gomes and J. P. Vilela, "A survey of wi-fi 6: Technologies, advances and challenges," *Future Internet*, vol. 14, no. 10, p. 293, 2022.

[7] J. Petäjäjärvi, K. Mikhaylov, A. Roivainen, T. Hanninen, and M. Pettissalo, "On the coverage of lpwans: range evaluation and channel attenuation model for lora technology," *IET Wireless Sensor Systems*, vol. 7, no. 4, pp. 121–127, 2017.

[8] A. Augustin, J. Yi, T. Clausen, and W. M. Townsley, "A study of lora: Long range & low power networks for the internet of things," *Sensors*, vol. 16, no. 9, p. 1466, 2016.

[9] K. Mekki, E. Bajic, F. Chaxel, and F. Meyer, "A comparative study of lpwan technologies for large-scale iot deployment," *ICT Express*, vol. 5, no. 1, pp. 1–7, 2019.

[10] R. Silva, A. Santos, M. Oliveira, and P. Machado, "A systematic review of iot systems testing: Objectives, approaches, tools, and challenges," *IEEE Transactions on Software Engineering*, vol. 50, no. 4, pp. 925–945, 2024.

[11] F. Moreno-Cruz, R. Toral-López, J. J. Escobar, and A. Fernández-Caballero, "trench: Ultra-low power wireless communication protocol for iot and energy harvesting," *Sensors*, vol. 20, no. 21, p. 6156, 2020.