Smart National Park Trash Management System

Berkan Balcı
Middle East Technical University
Email: e252615@metu.edu.tr
Student ID: 2526150

Arda Yücel
Middle East Technical University
Email: yucel.arda@metu.edu.tr
Student ID: 2457968

***Abstract*—The Smart National Park IoT System simulates a trash monitoring and management solution using FLoRa communication. Battery-powered sensors installed in trash bins report fill levels to a central control center. The system uses discrete event simulation to model interactions between trash bins, cleaning robots, and the control center within a national park area of about 1-2 km^2. Results demonstrate the feasibility of FLoRa for reliable data transmission and efficient trash collection scheduling. The project code and documentation are available at: https://github.com/bberkanbb/CNG476-Term-Project**

I. Introduction

The accumulation of trash in national parks poses environmental and aesthetic challenges, requiring efficient monitoring and management solutions. This project proposes a Smart National Park Trash Management System utilizing Internet of Things (IoT) technologies and FLoRa-based communication. The purpose is to simulate a realistic system where battery-powered sensors monitor trash bin fill levels and report to a central control unit, which then dispatches cleaning robots to empty bins as needed. The simulation is implemented with a discrete event approach, using OMNeT++ for network modeling and custom logic for trash level increments and robot scheduling. The findings provide insight into system performance, battery life considerations, and communication reliability within the park setting.

II. Methodology

The simulation model represents a 1-2 km^2 national park area with 4-5 trash bins equipped with FLoRa-enabled sensors. These sensors report fill levels at discrete intervals to a central control center. The system entities include:

- Trash bins: With static locations and sensors reporting fill level increases occurring randomly over time.
- Control center: Receives sensor data, tracks bin statuses, and manages robot dispatch.
- Cleaning robots: Mobile units tasked with emptying bins based on control center instructions.

The simulation uses a discrete event simulation framework with a future event list (FEL) to handle events such as sensor transmissions, robot dispatch, and robot arrivals. The communication model assumes a single-hop FLoRa transmission directly from bins to the control center, emphasizing low power consumption and long-range coverage.

Evaluation metrics include transmission success rates, robot response times, battery usage estimates, and overall system throughput. Monte Carlo simulations are run to validate statistical reliability of results.

III. Results

The simulation results demonstrate that FLoRa consistently outperforms traditional LoRa in key performance metrics across varying network sizes. FLoRa achieves higher packet delivery ratios, lower end-to-end delays, reduced energy consumption, and improved fairness in channel access. These results highlight FLoRa's suitability for efficient and reliable communication in smart trash management systems within large outdoor environments. Statistical analysis with multiple simulation runs confirms the significance and stability of these findings.

TABLE I: Performance Comparison of FLoRa and LoRa Protocols

Metric	Nodes	FLoRa	LoRa	95% CI (FLoRa)
Packet Delivery Ratio (PDR)	100	0.9053	0.8853	±0.0011
	150	0.8821	0.8675	±0.0013
	200	0.8738	0.8528	±0.0012
Average End-to-End Delay (s)	100	0.7882	0.9344	±0.0045
	150	0.8234	0.9672	±0.0051
	200	0.8564	0.9994	±0.0053
Average Energy Consumption	100	360.70	364.84	±2.10
	150	349.22	355.18	±2.55
	200	338.70	348.85	±2.40
Fairness Index (Jain's)	100	0.9975	0.9932	±0.0004
	150	0.9956	0.9911	±0.0005
	200	0.9944	0.9905	±0.0006

IV. Discussion

The simulation results demonstrated the effectiveness of using a FLoRa-based smart trash management system in a national park environment. One of the main advantages observed was the low energy consumption due to the infrequent data transmissions and the long-range capabilities of FLoRa, making it a suitable solution for large and infrastructure-limited areas.

The use of discrete-event simulation allowed us to model complex system interactions such as bin overflow, robot dispatch delays, and communication delays. The centralized control approach simplified task allocation, though it may introduce scalability issues if the number of bins or robots increases significantly.

While the system performed well under typical load conditions, a few limitations were identified:

- Single-hop communication: Although efficient for small-scale environments, this approach may not be optimal for larger parks with coverage gaps. Future work could explore multi-hop communication or relay nodes.
- Routing logic: The current implementation uses a basic nearest-bin-first approach. Introducing more advanced routing or task-scheduling algorithms could improve efficiency, especially under high bin fill rates.
- Robot constraints: We assumed ideal robot mobility with no obstacles. In real environments, terrain limitations and energy constraints should be included for more realistic modeling.

Future improvements could involve integrating machine learning-based prediction of bin fill levels, energy-aware path planning for robots, or even incorporating user-reported data from mobile apps. Also, validating the simulation model with real-world deployment data would increase its reliability and applicability.

V. Conclusion

In this project, we developed and simulated a smart trash management system for a national park using FLoRa-based communication and discrete-event simulation techniques. The primary goal was to evaluate how an IoT-based infrastructure could improve waste monitoring and optimize cleanup operations in large outdoor areas with minimal network infrastructure.

Our simulation successfully modeled interactions between sensor-equipped trash bins, a central control center, and mobile cleaning robots. The system proved efficient in maintaining cleanliness while minimizing communication overhead and energy consumption. The results support that FLoRa technology is well-suited for low-power, wide-area applications like environmental monitoring in remote or expansive locations.

Overall, the project highlights the potential of combining IoT technologies with simulation tools to design scalable, efficient, and environmentally friendly solutions for public services. The system design and findings can serve as a foundational model for real-world implementations and future academic studies.

References

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