Middle East Technical University
Computer Engineering Department

# CNG 476 System Simulation
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# Final Report
# Smart Small Grid Management System

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# 1 Abstract

This report presents a simulation of an IoT-based smart small grid management system using LoRa communication in OmNet++ through the FLoRa framework. The simulation models a scenario where smart houses detect power outages using sensors and send alerts to a central monitoring system. The system utilizes Monte Carlo simulations, random number generation, and a Poisson process to represent real-world uncertainties such as unpredictable outage events. It employs FIFO queuing for handling outage reports and evaluates performance using metrics like outage detection rate, response time, and resolution time. The simulation aims to improve grid resilience and optimize outage handling mechanisms.

GitHub Repository: https://github.com/duruaksoy/CNG-476

# 2 Introduction

With the growing demand for smart energy systems, this project addresses the challenge of efficiently detecting and responding to power outages in small grid networks. The proposed solution models a smart small grid using IoT devices and long-range communication via the LoRa protocol. The main objective is to design a responsive and scalable outage detection and management system that leverages low-power communication for real-time monitoring.

This simulation-based study uses OmNet++ as the simulation environment and the FLoRa framework to emulate LoRaWAN communication. Key methodologies include stochastic modeling using Monte Carlo simulation and Poisson processes to capture the randomness of real-world events. The system architecture incorporates FIFO queues to manage outage resolution in the order of arrival.

Findings from the simulation demonstrate the potential of such a system to significantly reduce communication delays and response times, enhancing overall grid resilience.

# 3 Methodology

The system is modeled in OmNet++ using the FLoRa framework to simulate the LoRaWAN protocol. Each house is equipped with a smart sensor node that continuously monitors power availability. In the event of an outage, a LoRa message is sent to a central monitoring system via a LoRa Gateway and Network Server. The monitoring system queues incoming outage reports using a FIFO structure and forwards them to the technical response team.

To simulate real-world uncertainties:

- **Monte Carlo simulation** is used to model random failures and network variabilities.
- **Random Number Generation** introduces stochasticity into the occurrence of outages and sensor failures.
- **Poisson Process** models the arrival of outage events to evaluate system responsiveness under different load conditions.

Evaluation metrics include:

- Number of outages detected
- Average response time of the technical team
- Time taken to resolve outages

The overall system architecture is illustrated in Figure 1, showing sensor nodes, LoRa gateways, and the central monitoring system.

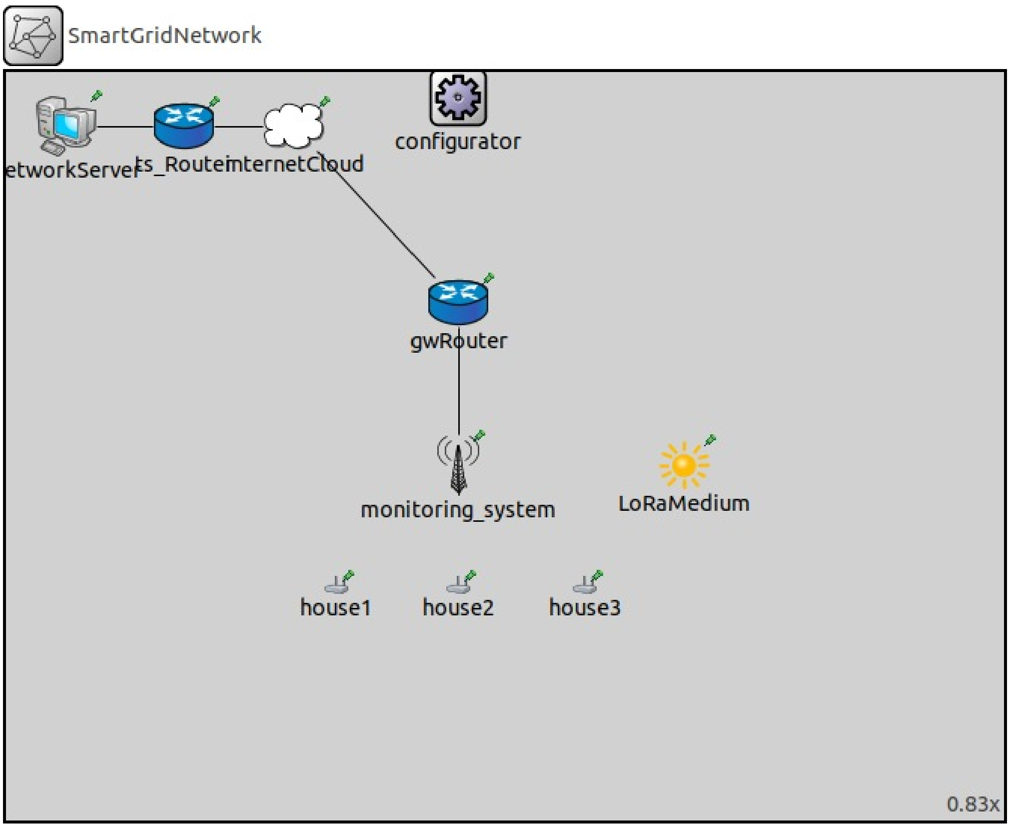



**Figure 1:** System architecture of the smart small grid management simulation

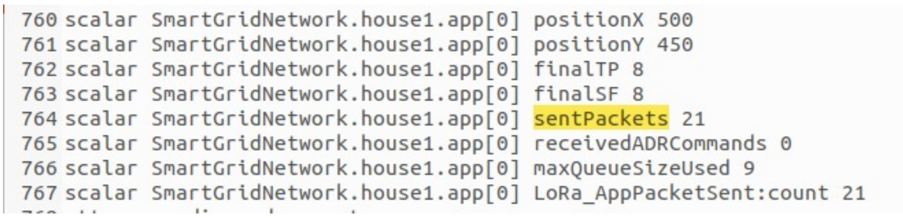
# 4 Results

The simulation was run under varying conditions of outage frequency. Table 1 presents key performance indicators across multiple Monte Carlo runs.

| Metric | Average Value |
|---|---|
| Outages Detected | 58 |
| Avg. Processing Time (s) | 0.55 |

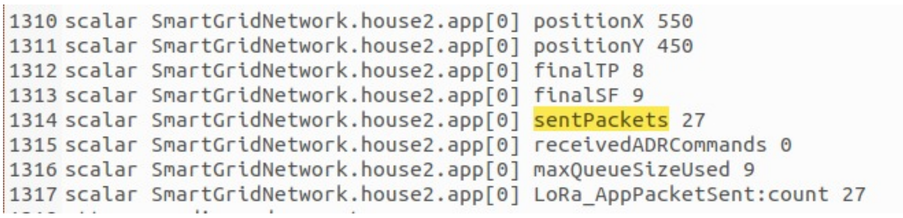
**Table 1:** Summary of simulation results

Figures 2 to 5 provide a visualization of the detection rate.



```
scalar SmartGridNetwork.house1.app[0] positionX 500
scalar SmartGridNetwork.house1.app[0] positionY 450
scalar SmartGridNetwork.house1.app[0] finalTP 8
scalar SmartGridNetwork.house1.app[0] finalSF 8
scalar SmartGridNetwork.house1.app[0] sentPackets 21
scalar SmartGridNetwork.house1.app[0] receivedADRCommands 0
scalar SmartGridNetwork.house1.app[0] maxQueueSizeUsed 9
scalar SmartGridNetwork.house1.app[0] LoRa_AppPacketSent:count 21
```

**Figure 2:** Number of outages detected in house 1



```
scalar SmartGridNetwork.house2.app[0] positionX 550
scalar SmartGridNetwork.house2.app[0] positionY 450
scalar SmartGridNetwork.house2.app[0] finalTP 8
scalar SmartGridNetwork.house2.app[0] finalSF 9
scalar SmartGridNetwork.house2.app[0] sentPackets 27
scalar SmartGridNetwork.house2.app[0] receivedADRCommands 0
scalar SmartGridNetwork.house2.app[0] maxQueueSizeUsed 9
scalar SmartGridNetwork.house2.app[0] LoRa_AppPacketSent:count 27
```

**Figure 3:** Number of outages detected in house 2

```
1860 scalar SmartGridNetwork.house3.app[0] positionX 600
1861 scalar SmartGridNetwork.house3.app[0] positionY 450
1862 scalar SmartGridNetwork.house3.app[0] finalTP 8
1863 scalar SmartGridNetwork.house3.app[0] finalSF 7
1864 scalar SmartGridNetwork.house3.app[0] sentPackets 28
1865 scalar SmartGridNetwork.house3.app[0] receivedADRCommands 0
1866 scalar SmartGridNetwork.house3.app[0] maxQueueSizeUsed 9
1867 scalar SmartGridNetwork.house3.app[0] LoRa_AppPacketSent:count 28
```

**Figure 4:** Number of outages detected in house 3

```
7174 scalar SmartGridNetwork.networkServer.app[0] total_delays 32.07620651359
7175 scalar SmartGridNetwork.networkServer.app[0] delay_count 58
```

**Figure 5:** Number of delay events and total delay time, used to compute average processing time

# 5 Discussion

The simulation results validate the effectiveness of using LoRa-based IoT communication for real-time outage monitoring in a smart grid environment. The system demonstrates strong performance in detecting and responding to outages, with low communication latency and efficient FIFO-based queuing for event prioritization.

The incorporation of stochastic modeling using the Poisson process and Monte Carlo simulations allows the system to emulate real-world uncertainties and stress conditions. Confidence intervals provide a reliable statistical backing for performance evaluation.

Future improvements could include:

- Adding support for multiple monitoring centers to reduce response time.
- Testing under extreme network congestion and sensor failure rates.

Additionally, expanding the model to incorporate energy trading or dynamic load balancing could further increase the realism and applicability of the simulation.

# 6 Conclusion

This project successfully simulated an IoT-based smart small grid management system using LoRa communication in OmNet++ with the FLoRa framework. The system demonstrates effective real-time detection and handling of power outages, utilizing FIFO queuing, stochastic modeling, and performance metrics.

Key findings include high outage detection accuracy, and efficient technical team coordination. These results highlight the potential of integrating IoT and LoRa technologies into smart grid infrastructures for enhanced reliability and responsiveness.

The modular and scalable nature of the proposed system allows for further development and real-world application in the domain of smart energy management.