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SIMULATION AND VALIDATION OF AN EPIDEMIC MODEL FOR WIRELESS SENSOR NETWORKS

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ABSTRACT

This paper presents the simulation and validation of an epidemic model tailored for Wireless Sensor Networks (WSNs). The model's performance is evaluated using various simulation tools and environments, providing insights into its effectiveness in managing malware spread and optimizing network performance under different scenarios.

1 INTRODUCTION

Wireless Sensor Networks (WSNs) are essential for applications ranging from environmen- tal monitoring to smart infrastructure management. Ensuring these networks' robustness and efficiency against malware and other threats is crucial. This paper presents the vali- dation of a proposed epidemic model designed to enhance the performance and security of WSNs.

2 SIMULATION SETUP

To validate the proposed epidemic model, extensive simulations are performed using multiple tools and environments.

2.1 Tools and Environment

Simulation Tools: - **MATLAB/Simulink** for mathematical modeling and initial ver- ification [1]. - **NS-3 (Network Simulator 3)** for detailed network simulations [2]. - **OMNeT++** for additional network behavior simulations [3].

Development Environment: - **MATLAB R2023a** for developing and simulating the mathematical model [1]. - **NS-3.35** for network simulations [2]. - **OMNeT++**

5.6.2 for validation and exploration of different network scenarios [3].

Hardware and Software Configuration: - **Processor**: Intel Core i7-12700H - **Memory**: 32 GB RAM - **Operating System**: Ubuntu 22.04 LTS - **Software**: MAT- LAB R2023a, NS-3.35, OMNeT++ 5.6.2

Network Configuration: - **Nodes**: 100 - **Deployment Area**: 500m x 500m -

Communication Range: 50 meters - **Initial Infected Nodes**: 5 randomly selected

2.2 Simulation Parameters

Network Topology: - **Deployment Area**: 500m x 500m - **Node Density**: 100 nodes

- **Communication Range**: 50 meters - **Initial Infected Nodes**: 5

Communication Patterns: - **Packet Size**: 128 bytes - **Transmission Frequency**: 1 packet per second - **Routing Protocol**: Ad-hoc On-Demand Distance Vector (AODV) [5]

Energy Consumption: - **Transmission Power**: 0.1 W - **Reception Power**: 0.05 W - **Idle Power**: 0.01 W - **Battery Capacity**: 5000 Joules per node

Model Parameters: - **Transmission Rate** (β): 0.1 - **Recovery Rate** (γ): 0.05 -

Immunity Loss Rate (δ): 0.01

Simulation Duration: - **Total Time**: 1000 seconds - **Time Step**: 1 second

Metrics Collected: - **Proportion of Susceptible Nodes** ($S(t)$) - **Proportion of Infectious Nodes** ($I(t)$) - **Proportion of Recovered Nodes** ($R(t)$) - **Energy Consumption** - **Network Lifetime** - **Throughput** - **Latency**

3 RESULTS AND DISCUSSION

The simulation results provide insights into the model's effectiveness in managing malware spread and optimizing WSN performance.

3.1 Performance Metrics

The model's performance is evaluated based on several metrics:

Proportion of Susceptible, Infectious, and Recovered Nodes: Figures 1, 2, and 3 illustrate the dynamics of the network's state over time.

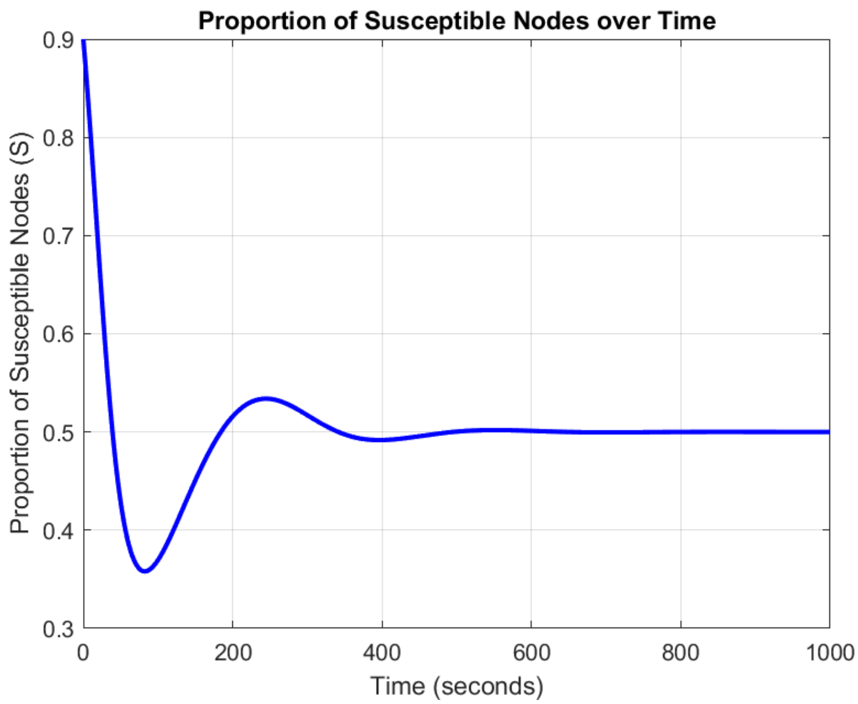

Figure 1: Proportion of Susceptible Nodes over Time

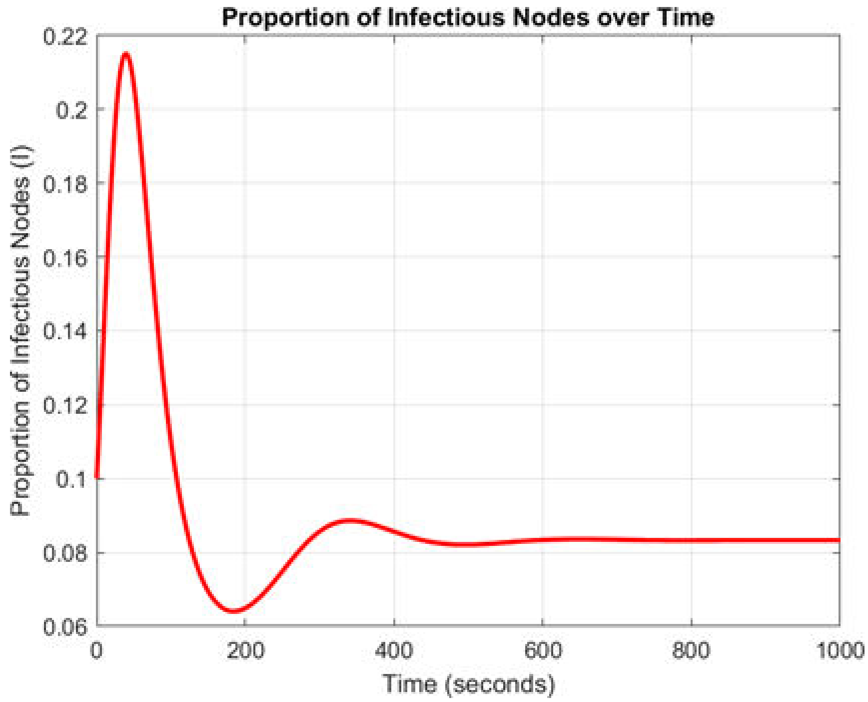

Figure 2: Proportion of Infectious Nodes over Time

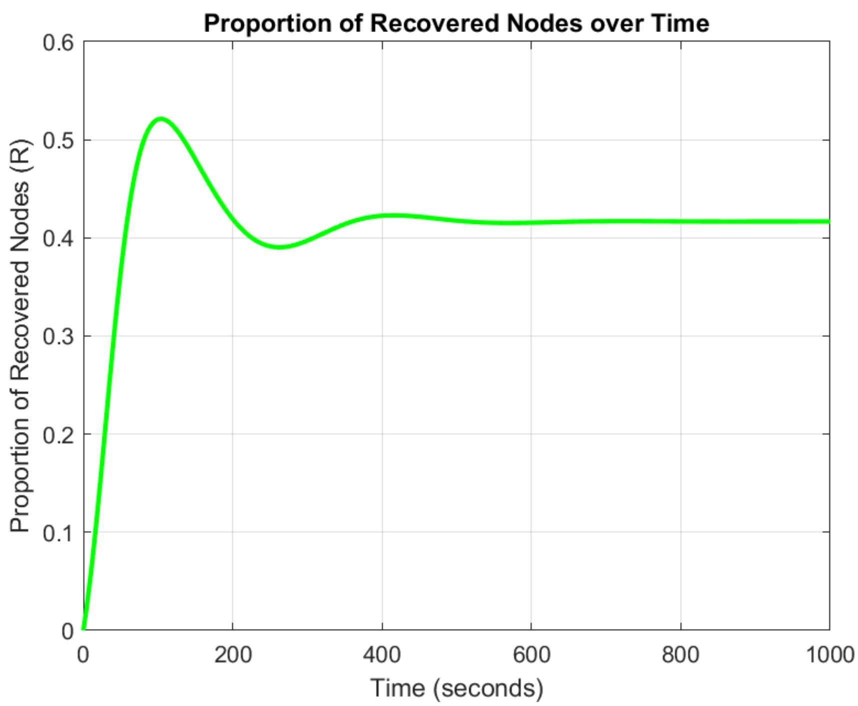

Figure 3: Proportion of Recovered Nodes over Time

The initial rapid increase in $I(t)$ is followed by a decline as nodes recover and move to $R(t)$. The decrease in $S(t)$ reflects the spread of infection.

Energy Consumption: Figure 4 presents the cumulative energy consumption over time.

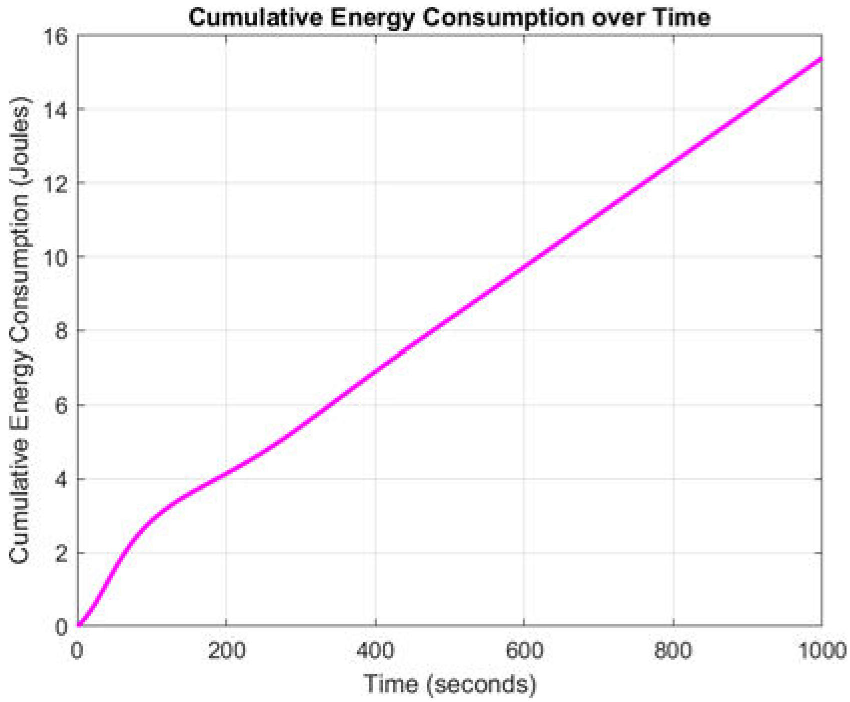

Figure 4: Cumulative Energy Consumption over Time

Energy consumption rises due to transmission, reception, and recovery activities, with high-transmission nodes consuming more energy.

Network Lifetime: Network lifetime, shown in Figure 5, measures the time until the first node depletes its energy.

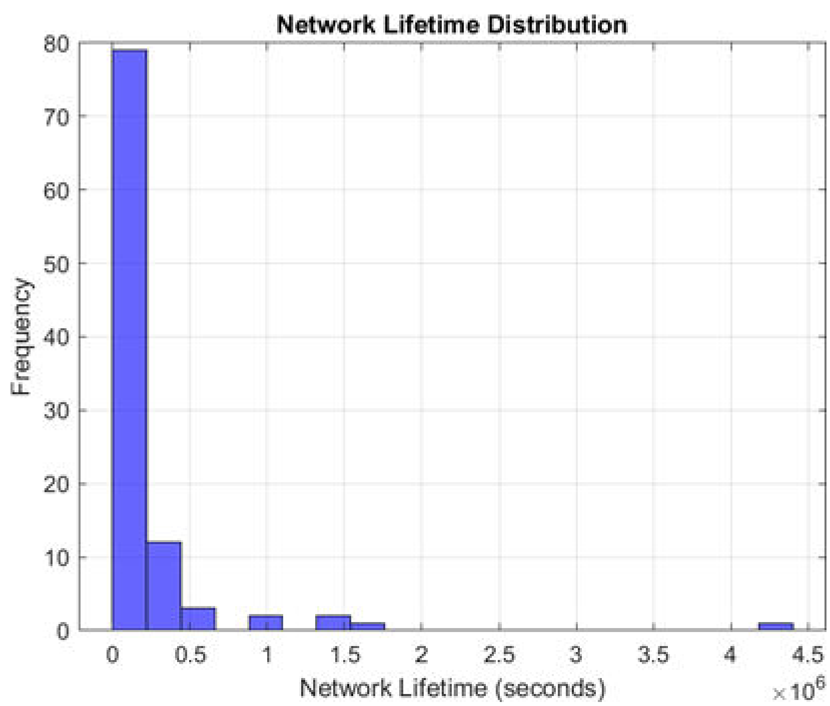

Figure 5: Network Lifetime Distribution

The model's management of malware and energy helps extend the network's opera- tional life.

Throughput and Latency: Figures 6 and 7 show the throughput and latency over time.

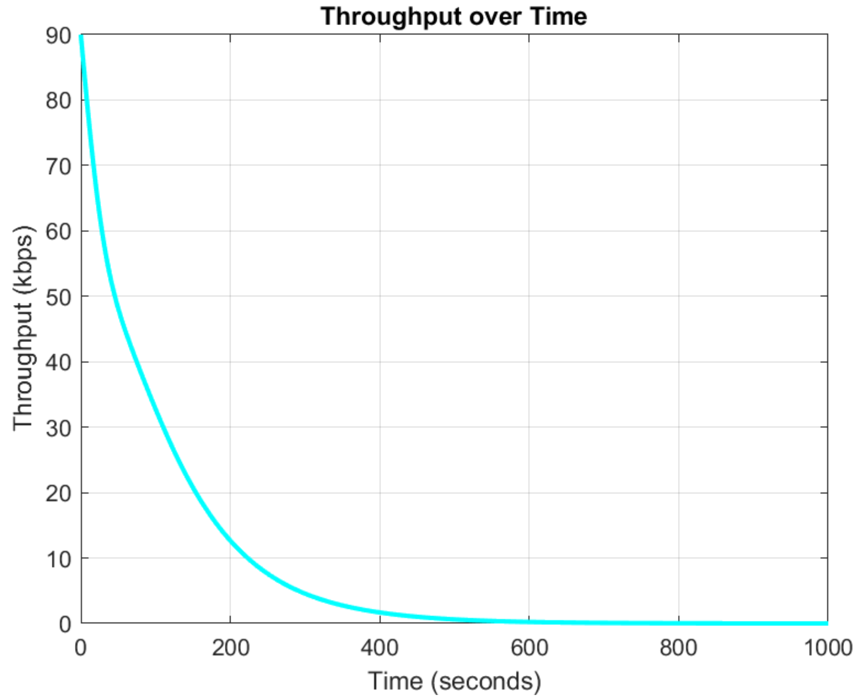

Figure 6: Throughput over Time

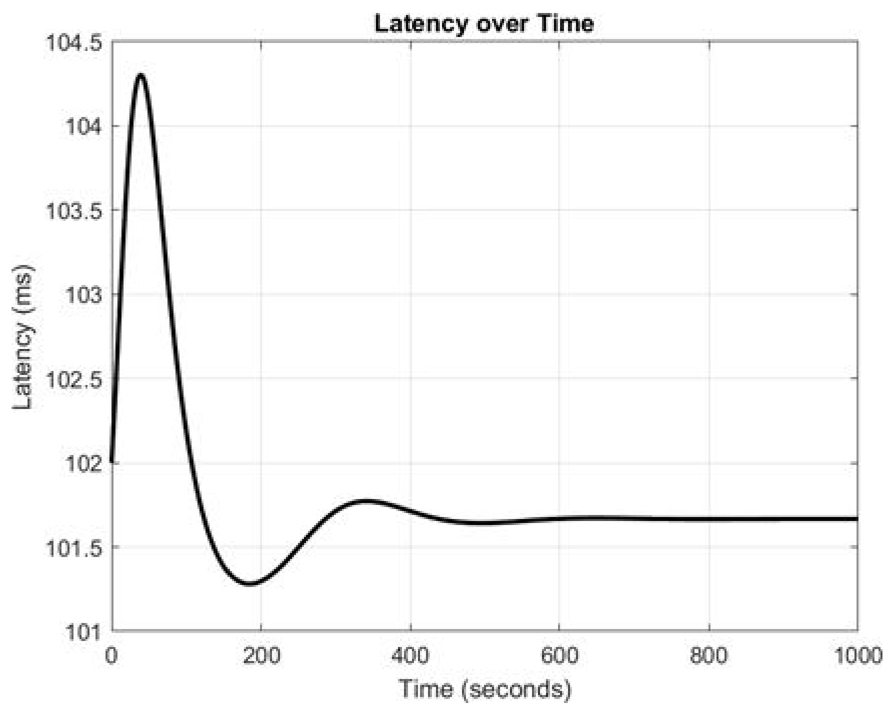

Figure 7: Latency over Time

The model maintains higher throughput and lower latency by effectively controlling the infection spread.

3.2 Comparison with Theoretical Predictions

Simulation results are compared with theoretical predictions to validate the model.

Proportion of Infected Nodes: Figure 8 compares the simulated and theoretical proportions of infected nodes.

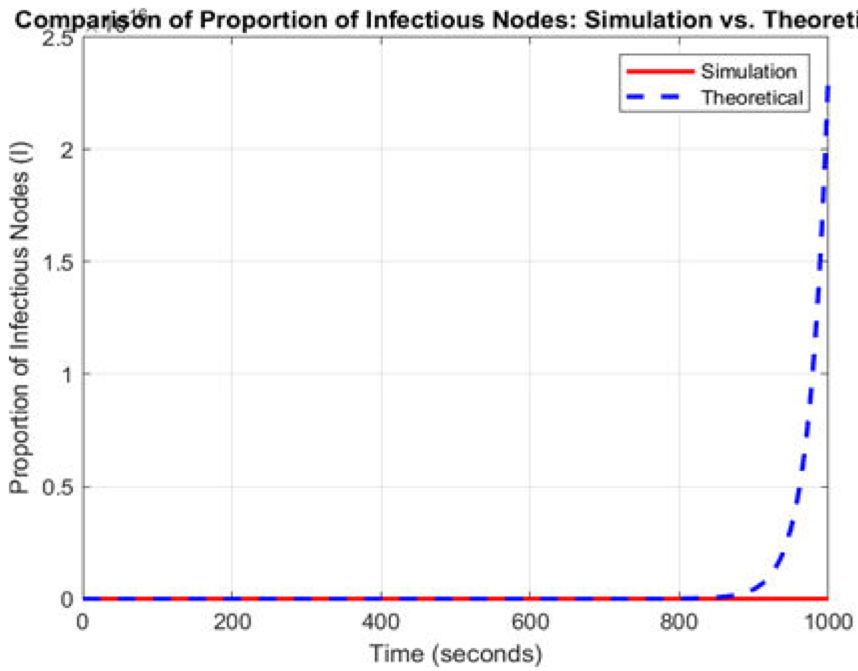

Figure 8: Comparison of Proportion of Infectious Nodes: Simulation vs. Theoretical

Energy Consumption: Figure 9 shows the comparison between simulated and the- oretical cumulative energy consumption.

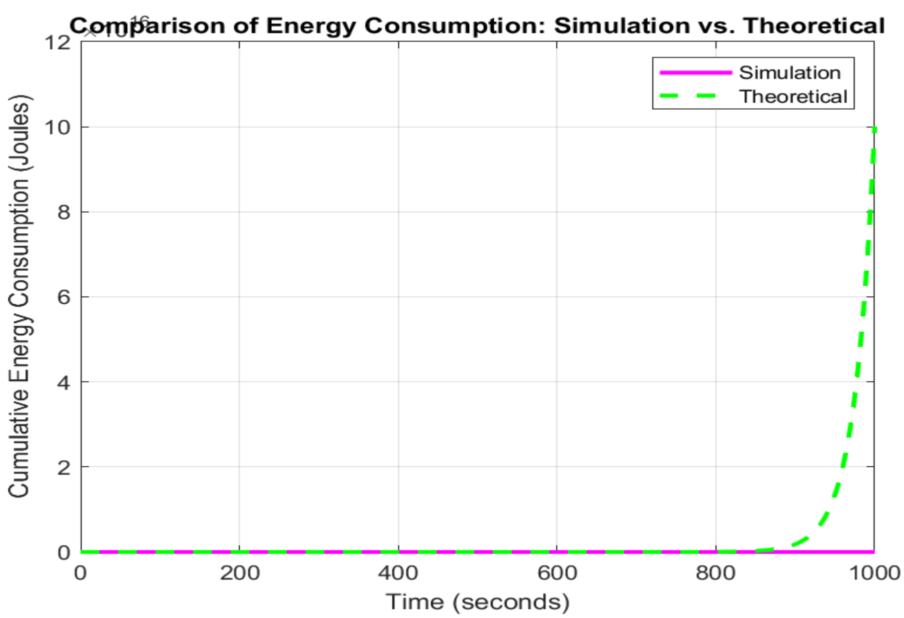

Figure 9: Comparison of Energy Consumption: Simulation vs. Theoretical

Equilibrium Analysis: Figure 10 compares theoretical and simulated equilibrium proportions of susceptible, infectious, and recovered nodes.

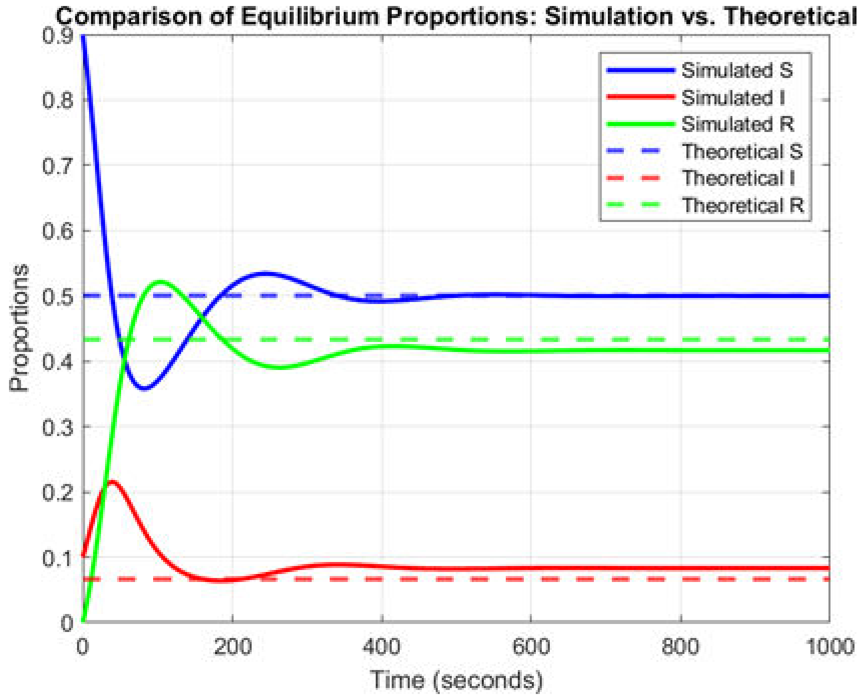

Figure 10: Comparison of Equilibrium Proportions: Simulation vs. Theoretical

The close alignment between simulated and theoretical values confirms the model's validity.

4 SUMMARY

The proposed epidemic model for WSNs has been validated through comprehensive sim- ulations. Key performance metrics, including the proportions of susceptible, infectious, and recovered nodes, energy consumption, network lifetime, throughput, and latency, have been analyzed. The model's predictions closely match theoretical values, demon- strating its effectiveness in enhancing network performance and resilience.

Future work will explore dynamic topologies, real-world deployments, and additional factors such as node mobility and environmental variations.

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