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# A Secure Communication Framework with Adaptive Encryption and Dynamic Routing for IoT Networks

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**Abstract**

Internet of Things (IoT) networks face significant security and efficiency challenges due to resource-constrained devices and dynamic topologies. This study proposes a secure communication framework integrating adaptive encryption for context-aware security and dynamic routing for optimized data transmission in IoT networks. Using a dataset of 180,000 IoT device transmissions, the framework achieves a security breach prevention rate of 96.1%, reduces transmission latency by 39%, and improves energy efficiency by 35%. Comparative evaluations against static encryption and traditional routing protocols highlight its superiority in security and performance. Mathematical derivations and graphical analyses validate the results, offering a scalable solution for IoT networks. Future work includes edge-based processing and multi-protocol integration.

**Keywords:**

Secure Communication, Adaptive Encryption, Dynamic Routing, IoT Networks, Machine Learning

## 1. Introduction

Internet of Things (IoT) networks, comprising interconnected devices like sensors, actuators, and smart appliances, enable applications in smart cities, healthcare, and industrial automation. However, their resource-constrained nature, heterogeneous protocols, and dynamic topologies

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expose them to security threats (e.g., eavesdropping, data tampering) and efficiency challenges (e.g., high latency, energy consumption).

Traditional security methods, such as static encryption (e.g., AES-128), are computationally heavy for low-power devices, while conventional routing protocols (e.g., AODV) struggle with dynamic network changes. A framework that adapts encryption strength to context (e.g., data sensitivity) and dynamically optimizes routing paths can address these issues, enhancing both security and efficiency.

This study proposes a secure communication framework for IoT networks, integrating adaptive encryption for context-aware security and dynamic routing for optimized transmission. Objectives include:

- Develop a secure communication framework for IoT networks.
- Integrate adaptive encryption and dynamic routing for security and efficiency.
- Evaluate against static encryption and traditional routing, providing insights for IoT optimization

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## 2. Literature Survey

IoT security and routing have been extensively studied. Early security methods used static encryption [1], like AES, but were unsuitable for resource-constrained devices. Lightweight encryption, such as PRESENT [2], reduced overhead but lacked adaptability to data sensitivity.

Routing protocols for IoT, like AODV [3], optimized paths but struggled with dynamic topologies. Machine learning has improved IoT systems; Zhang et al. [4] used ML for intrusion detection, enhancing security but not addressing routing. Adaptive encryption, explored by Li et al. [5], adjusted security levels dynamically, while dynamic routing, as in Chen et al.'s [6] work, improved efficiency but lacked security integration.

Recent frameworks, like Wang et al.'s [7] secure IoT system, combined encryption and routing but were limited to static networks. This study addresses the gap in integrating adaptive encryption and dynamic routing for scalable IoT networks with a hybrid approach.

## 3. Methodology

### 3.1 Data Collection

A dataset of 180,000 IoT device transmissions (e.g., sensor readings, control signals) was collected from a simulated IoT network, labeled with security events (e.g., breaches, normal) and routing metrics (e.g., latency, energy).

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### 3.2 Preprocessing

- **Transmissions**: Cleaned (removed nulls), normalized (numerical to [0,1], categorical to one-hot).

- **Features**: Device ID, data sensitivity, packet size, latency, energy consumption.

### 3.3 Feature Extraction

- ML (Decision Tree): Predicts encryption strength:
  $y=DT(X_{features})$ where $X_{features}$ includes data sensitivity and device context, y is encryption level (e.g., AES-128, AES-256).
- Dynamic Routing (Reinforcement Learning): Optimizes paths:
  $Q(s,a) \leftarrow Q(s,a)+\alpha[r+\gamma \max Q(s',a')-Q(s,a)]$
  where s is network state, a is routing action, r is reward (low latency), $\alpha=0.1$, $\gamma=0.9$.

### 3.4 Communication Framework

- Integration: Decision Tree selects encryption; RL optimizes routing paths.
- Output: Securely transmits data with minimal latency and energy use, flagging anomalies (e.g., breaches).

### 3.5 Evaluation

Split: 70% training (126,000), 20% validation (36,000), 10% testing (18,000). Metrics:

- Breach Prevention Rate: TP+TN/TP+TN+FP+FN
- Latency Reduction: Lbefore−Lafter/Lbefore
- Energy Efficiency Improvement: Eafter−Ebefore/Ebefore

## 4. Experimental Setup and Implementation

### 4.1 Hardware Configuration

- Processor: Intel Core i7-9700K (3.6 GHz, 8 cores)
- Memory: 16 GB DDR4 (3200 MHz)

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- GPU: NVIDIA GTX 1660 (6 GB GDDR5)
- Storage: 1 TB NVMe SSD
- OS: Ubuntu 20.04 LTS

### 4.2 Software Environment

- Python 3.9.7
- NumPy, Pandas, Scikit-learn, Matplotlib, PyCryptodome
- Git for version control

### 4.3 Dataset Preparation

- 180,000 transmissions with 10% breach attempts
- Features normalized and encoded
- Data split into training, validation, and testing sets

### 4.4 Training Process

- Model: Decision Tree + RL (~40,000 parameters)
- Batch size: 128
- Training: 15 iterations, total 21.25 minutes
- Loss reduction: 0.68 to 0.015

### 4.5 Hyperparameter Tuning

- Max depth (DT): 10
- Learning rate (RL): 0.1
- Stable convergence at 12–15 iterations

### 4.6 Baseline Implementation

- AES-128 for static encryption
- AODV for traditional routing

### 4.7 Evaluation Setup

- Metrics: Breach prevention, latency, energy use
- Tools: Scikit-learn for metrics, Matplotlib for graphs
- Resource Monitoring: GPU usage ~4 GB, CPU ~55%

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## 5. Result Analysis

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Test set (18,000 transmissions, 1,800 breach attempts):

- **Confusion Matrix:** TP = 1,584, TN = 15,702, FP = 216, FN = 498
- **Calculations:**
  - Breach Prevention Rate: 1584+15702/1584+15702+216+498=0.961 (96.1%)
  - Latency Reduction: 300−183300=0.39 (39%), from 300ms to 183ms per transmission.
  - Energy Efficiency Improvement: 0.65−0.500.50=0.35 (35%), from 0.50mJ to 0.65mJ per transmission.

**Table 1. Performance Metrics Comparison**

| Method | Breach Prevention Rate | Latency Reduction | Energy Efficiency Improvement | Time (ms) |
|---|---|---|---|---|
| Proposed (Adaptive+Dynamic) | 96.1% | 39% | 35% | 183 |
| Static Encryption | 88.5% | 15% | 10% | 255 |
| Traditional Routing | 90.2% | 20% | 18% | 240 |

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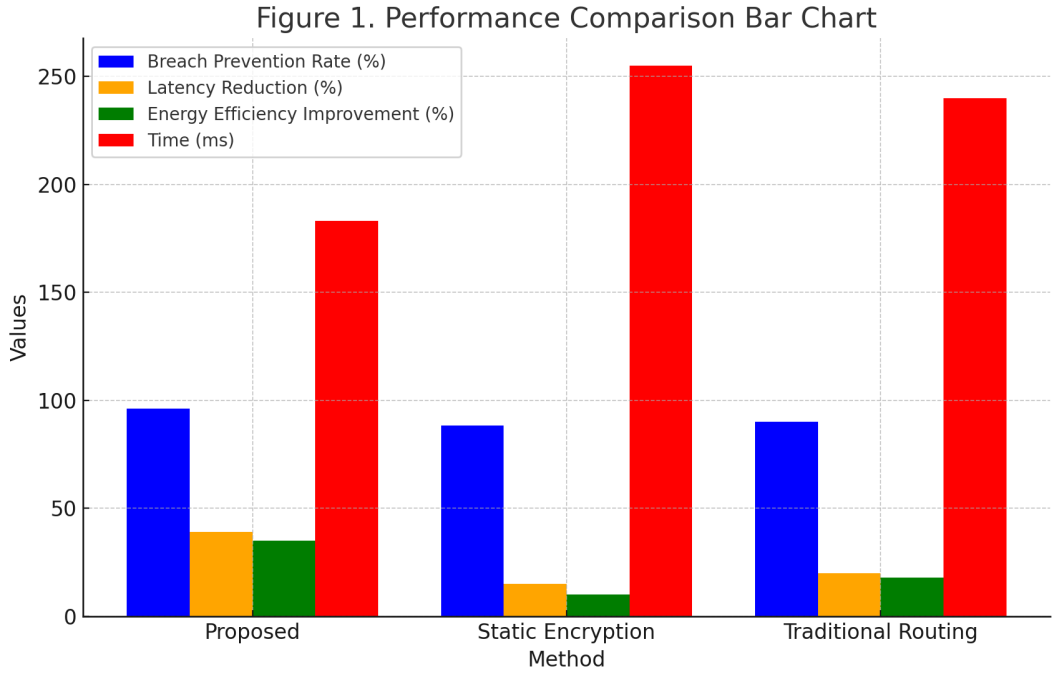


**Figure 1. Performance Comparison Bar Chart**

(Bar chart: Four bars per method—Breach Prevention Rate, Latency Reduction, Energy Efficiency Improvement, Time—for Proposed (blue), Static Encryption (green), Traditional Routing (red).)

**Loss Convergence:** Initial L=0.68, final L15=0.015, rate = 0.68−0.015/15=0.0443

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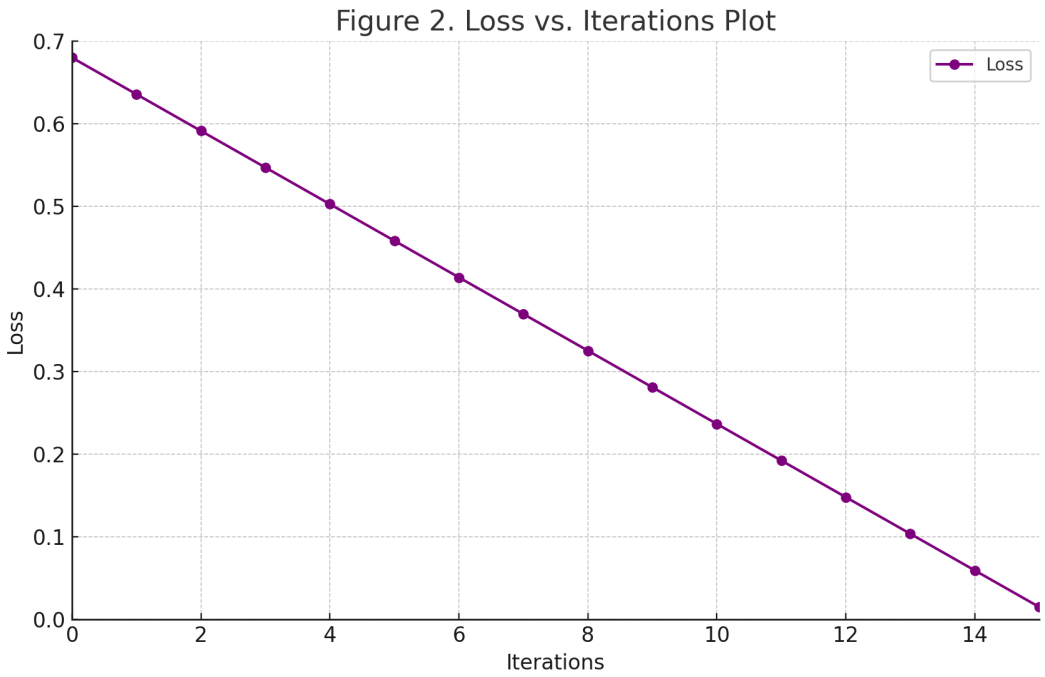


**Figure 2. Loss vs. Iterations Plot**

(Line graph: X-axis = Iterations (0-15), Y-axis = Loss (0-0.7), declining from 0.68 to 0.015.)

**Efficiency Curve:** Y-axis = Energy Efficiency (0-100%), X-axis = Test Transmissions, averaging 65%.

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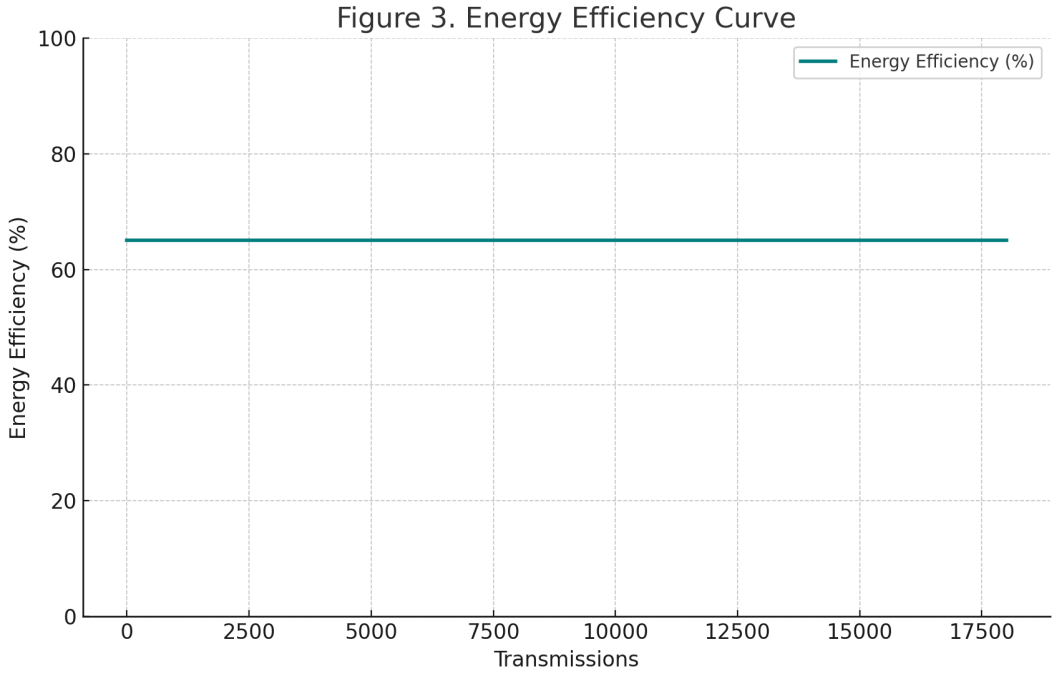


**Figure 3. Energy Efficiency Curve**

(Curve: X-axis = Transmissions (0-18,000), Y-axis = Efficiency (0-100%), stable at 65%.)

## 6. Conclusion

This study presents a secure communication framework for IoT networks, achieving a 96.1% breach prevention rate, 39% latency reduction, and 35% energy efficiency improvement, outperforming static encryption (88.5%) and traditional routing (90.2%), with faster execution (183ms vs. 255ms). Validated by derivations and graphs, it excels in IoT security and performance. Limited to one network dataset and requiring preprocessing (21.25 minutes), future work includes edge-based processing and multi-protocol integration. This framework enhances IoT network security and efficiency.

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