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# A Review of Energy-Efficient and Fault-Tolerant Routing Mechanisms for Emergency-Based Manet Applications

**Masineni Sudhakar[1] and Dr. Ashok Gupta[2]**

[1]Research Scholar, [2]Professor

Department of Computer Applications

Sunrise University, Alwar (Rajasthan)

**Abstract:** *Mobile Ad Hoc Networks (MANETs) have emerged as one of the most suitable communication technologies for emergency and disaster response scenarios where conventional communication infrastructure is unavailable or damaged. These networks enable rapid deployment, self-organization, and infrastructure-less communication among mobile devices. However, emergency-based MANET applications face significant challenges due to dynamic topology, limited battery power, frequent node failures, bandwidth constraints, and unpredictable environmental conditions.*

*Consequently, routing protocols must simultaneously achieve energy efficiency and fault tolerance to ensure reliable communication. This review paper presents a comprehensive analysis of existing energy-efficient and fault-tolerant routing mechanisms proposed for emergency-based MANET applications. The paper categorizes routing protocols into proactive, reactive, hybrid, cluster-based, bio-inspired, and artificial intelligence-based approaches. Furthermore, it compares recent routing mechanisms based on routing strategy, energy consumption, fault tolerance capability, packet delivery ratio, delay, scalability, and application suitability. Finally, the paper highlights existing research gaps and suggests future research directions focusing on machine learning, blockchain, software-defined networking, UAV-assisted communication, and edge intelligence.*

**Keywords:** MANET, Emergency Networks, Energy Efficiency, Fault Tolerance, Routing Protocol, Disaster Management, Wireless Networks.

## I. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) consist of autonomous wireless nodes capable of establishing communication without relying on fixed infrastructure. Every node performs dual functions as both host and router, enabling multi-hop communication across the network. Because of these characteristics, MANETs have become highly suitable for emergency situations including earthquake rescue operations, flood monitoring, wildfire management, military missions, pandemic healthcare support, and search-and-rescue operations.

In emergency scenarios, network reliability directly influences rescue efficiency and human survival. Communication failures may delay medical assistance, hinder coordination among rescue teams, and increase casualties. Unlike conventional environments, emergency networks operate under harsh conditions characterized by damaged infrastructure, frequent node mobility, battery limitations, unpredictable failures, and network partitioning.

Routing protocols therefore play a critical role in maintaining reliable communication. Traditional routing protocols primarily focus on shortest path selection but often ignore energy consumption and fault recovery. Energy depletion of relay nodes and unexpected failures may disconnect the network, resulting in packet loss and communication breakdown.

Recent research has therefore focused on developing routing mechanisms that optimize energy consumption while simultaneously improving fault tolerance. Such mechanisms increase network lifetime, improve packet delivery ratio, reduce routing overhead, and ensure continuous communication during disasters.

## II. CHARACTERISTICS OF EMERGENCY-BASED MANET APPLICATIONS

Emergency MANETs possess several unique characteristics:

1. Infrastructure-less deployment
2. Dynamic network topology
3. High node mobility
4. Limited battery capacity
5. Frequent communication interruptions
6. Resource constraints
7. Real-time communication requirements
8. High reliability demands
9. Rapid network deployment
10. Self-healing capability

**Applications include:**

1. Disaster recovery
2. Military communication
3. Fire rescue operations
4. Forest monitoring
5. Earthquake response
6. Flood rescue
7. Medical emergency services
8. Border surveillance

## III. CHALLENGES IN EMERGENCY MANET ROUTING

| Challenge | Description | Impact |
|---|---|---|
| Dynamic topology | Continuous movement of nodes | Frequent route failures |
| Limited battery | Battery-operated devices | Reduced network lifetime |
| Node failure | Hardware or energy failure | Communication disruption |
| Bandwidth limitation | Limited wireless capacity | Congestion |
| High mobility | Frequent neighbor changes | Route instability |
| Interference | Wireless signal interference | Packet loss |
| Scalability | Large number of nodes | Routing complexity |
| Security threats | Malicious attacks | Data compromise |

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## IV. CLASSIFICATION OF ROUTING PROTOCOLS

**1. Proactive Routing**

Examples:

1. DSDV
2. OLSR
3. WRP

**Advantages**

Low route discovery delay

Updated routing tables

**Limitations**

High routing overhead

High energy consumption

**2. Reactive Routing**

Examples

1. AODV
2. DSR
3. TORA

**Advantages**

1. Low control overhead
2. Better energy conservation

**Limitations**

1. Route discovery latency
2. Frequent route reconstruction

**3. Hybrid Routing**

**Examples**

1. ZRP
2. HSR

**Advantages**

1. Balanced performance
2. Reduced overhead

**Limitations**

1. Increased complexity

**4. Cluster-Based Routing**

**Examples**

2. LEACH
3. HEED
4. CBRP

**Advantages**

1. Better scalability
2. Energy balancing

**Limitations**

1. Cluster maintenance overhead

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**Bio-inspired Routing**

**Examples**

1. Ant Colony Optimization (ACO)
2. Particle Swarm Optimization (PSO)
3. Bee Colony Optimization

**Advantages**

1. Adaptive routing
2. Fault recovery
3. Energy optimization

**Limitations**

1. Computational complexity

**6. AI-Based Routing**

**Examples**

1. Reinforcement Learning
2. Deep Learning
3. Genetic Algorithms
4. Fuzzy Logic

**Advantages**

1. Intelligent route selection
2. Predictive failure detection
3. Adaptive optimization

**Limitations**

1. High computational requirements

## V. ENERGY-EFFICIENT ROUTING MECHANISMS

Energy-efficient routing aims to minimize battery consumption while extending overall network lifetime.

**Common techniques include:**

2. Minimum energy routing
3. Residual energy-based routing
4. Load balancing
5. Sleep scheduling
6. Cluster head rotation
7. Cross-layer optimization
8. Multipath routing
9. Energy-aware transmission power control

**Benefits include:**

1. Longer network lifetime
2. Reduced battery depletion
3. Balanced energy utilization
4. Lower routing overhead

## VI. FAULT-TOLERANT ROUTING MECHANISMS

Fault tolerance enables communication despite node failures.

Common approaches include:

1. Multipath routing
2. Backup route maintenance

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3. Local route repair
4. Self-healing algorithms
5. Failure prediction
6. Distributed routing
7. Redundant communication paths

**Advantages**

1. Higher reliability
2. Increased packet delivery
3. Reduced communication interruption

## VII. COMPARATIVE ANALYSIS OF MAJOR ROUTING PROTOCOLS

| Protocol | Type | Energy Efficient | Fault Tolerant | Delay | Scalability | Suitable for Emergency |
|---|---|---|---|---|---|---|
| DSDV | Proactive | Medium | Low | Low | Medium | Moderate |
| OLSR | Proactive | Medium | Medium | Low | High | Moderate |
| AODV | Reactive | High | Medium | Medium | High | High |
| DSR | Reactive | High | Medium | Medium | Medium | High |
| TORA | Reactive | Medium | High | Low | High | Very High |
| ZRP | Hybrid | High | High | Low | High | Excellent |
| LEACH | Cluster | Very High | Medium | Low | High | Excellent |
| HEED | Cluster | Very High | High | Low | High | Excellent |
| ACO | Bio-inspired | Very High | Very High | Low | High | Excellent |
| RL-Based Routing | AI | Excellent | Excellent | Very Low | Excellent | Outstanding |

## VIII. LITERATURE SUMMARY TABLE

| Author | Year | Routing Technique | Energy Saving | Fault Tolerance | Major Contribution | Limitation |
|---|---|---|---|---|---|---|
| Perkins et al. | 1999 | AODV | High | Medium | On-demand routing | Route discovery delay |
| Johnson et al. | 1996 | DSR | High | Medium | Source routing | Large packet headers |
| Clausen et al. | 2003 | OLSR | Medium | Medium | Link-state optimization | High overhead |
| Haas et al. | 2002 | ZRP | High | High | Hybrid routing | Zone management |
| Heinzelman et al. | 2000 | LEACH | Very High | Medium | Cluster-based routing | Cluster instability |
| Younis et al. | 2004 | HEED | Very High | High | Balanced clustering | Extra control packets |
| Dorigo et al. | 2006 | ACO | Very High | Very High | Bio-inspired routing | Computational cost |
| Sutton et al. | 2018 | Reinforcement Learning | Excellent | Excellent | Intelligent routing | Training complexity |

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## IX. PERFORMANCE COMPARISON

| Parameter | Conventional Routing | Energy-Efficient Routing | Fault-Tolerant Routing | Hybrid Intelligent Routing |
|---|---|---|---|---|
| Packet Delivery Ratio | Medium | High | Very High | Excellent |
| End-to-End Delay | Medium | Medium | Low | Very Low |
| Network Lifetime | Low | High | High | Very High |
| Energy Consumption | High | Low | Medium | Very Low |
| Routing Overhead | High | Medium | Medium | Low |
| Reliability | Medium | High | Very High | Excellent |
| Scalability | Medium | High | High | Excellent |

## X. CONCLUSION

Energy-efficient and fault-tolerant routing mechanisms are fundamental to the successful deployment of emergency-based MANET applications. While traditional routing protocols such as AODV, DSR, and OLSR provide effective communication under moderate network conditions, they struggle to meet the stringent reliability and energy requirements of disaster scenarios.

Recent advances in cluster-based, bio-inspired, and artificial intelligence-driven routing have significantly improved network lifetime, packet delivery ratio, and fault recovery capabilities. Hybrid intelligent routing protocols that integrate energy awareness, multipath communication, predictive fault detection, and adaptive optimization offer the greatest potential for future emergency networks. Nevertheless, challenges related to scalability, computational complexity, security, and real-world deployment remain open. Future research should emphasize AI-driven adaptive routing, edge intelligence, blockchain-enabled trust management, UAV-assisted networking, and sustainable communication architectures to build highly reliable, energy-efficient, and resilient emergency MANET systems suitable for next-generation disaster management.

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