IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 11, June 2026
Impact Factor: 8.2

Evolution of Fault-Tolerant Routing Protocols for Mission-Critical Mobile Ad Hoc Network 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 an indispensable communication technology for mission-critical applications such as military operations, disaster response, emergency healthcare, search-and-rescue missions, and industrial automation. Unlike conventional wireless networks, MANETs operate without fixed infrastructure, relying on dynamically formed wireless links among mobile nodes. However, the highly dynamic topology, limited bandwidth, constrained energy resources, node mobility, and frequent link failures significantly affect network reliability. Fault-tolerant routing protocols have evolved to address these challenges by ensuring reliable communication despite node failures, network partitioning, congestion, and malicious attacks.*

This review paper presents a comprehensive overview of the evolution of fault-tolerant routing protocols developed for mission-critical MANET applications. The study categorizes routing protocols into proactive, reactive, hybrid, multipath, bio-inspired, cross-layer, software-defined, and machine learning-based approaches. Their strengths, limitations, and applicability to mission-critical environments are critically analyzed. Furthermore, recent advancements in artificial intelligence, blockchain, edge computing, unmanned aerial vehicles (UAVs), and Software Defined Networking (SDN) are discussed as emerging directions toward next-generation fault-tolerant MANETs.

Keywords: Mobile Ad Hoc Networks, Fault Tolerance, Routing Protocols, Disaster Recovery, Military Communication.

I. INTRODUCTION

Mission-critical applications demand uninterrupted communication under highly unpredictable conditions where network infrastructure may be unavailable or destroyed. Mobile Ad Hoc Networks (MANETs) provide decentralized communication by allowing mobile nodes to self-organize and establish routes dynamically. These characteristics make MANETs ideal for battlefield communication, emergency rescue operations, intelligent transportation systems, healthcare monitoring, and remote industrial environments.

Despite these advantages, MANETs experience numerous failures resulting from node mobility, battery depletion, wireless interference, congestion, hardware malfunction, environmental obstacles, and cyber-attacks. Traditional routing protocols primarily focus on discovering shortest paths rather than ensuring network survivability during failures.

Fault-tolerant routing protocols have therefore become an essential research area. These protocols aim to maintain communication continuity through redundancy, adaptive routing, multipath transmission, predictive failure detection, energy-aware routing, and intelligent route recovery mechanisms. Over the past two decades, routing strategies have evolved from simple reactive techniques toward intelligent, context-aware, and self-healing architectures.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 11, June 2026
Impact Factor: 8.2

II. EVOLUTION OF FAULT-TOLERANT ROUTING PROTOCOLS

The evolution of fault-tolerant routing protocols can be divided into several generations.

I. First Generation (1995–2002)

The earliest MANET routing protocols primarily focused on establishing communication under dynamic topologies. Examples include:

1. DSDV
2. OLSR
3. AODV
4. DSR

Fault tolerance was limited because these protocols relied on single shortest paths.

II. Second Generation (2003–2008)

Researchers introduced:

1. Multipath routing
2. Backup routes
3. Local repair mechanisms
4. Route caching

Representative protocols include:

1. AOMDV
2. TORA
3. SMR

These protocols significantly improved resilience.

III. Third Generation (2009–2015)

Research shifted toward:

1. Energy-aware routing
2. QoS-aware routing
3. Cross-layer optimization
4. Cluster-based routing

Protocols became capable of adapting to changing network conditions while minimizing failures.

IV. Fourth Generation (2016–2021)

Modern protocols integrated:

1. Machine Learning
2. Swarm Intelligence
3. Fuzzy Logic
4. Trust Management
5. Blockchain

Routing decisions became predictive rather than reactive.

V. Fifth Generation (2022–Present)

Current research investigates:

1. AI-driven routing
2. SDN-based MANETs
3. UAV-assisted routing
4. Edge intelligence

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 11, June 2026
Impact Factor: 8.2

5. Digital Twins
6. Federated Learning

These techniques aim to build self-healing autonomous networks.

III. CLASSIFICATION OF FAULT-TOLERANT ROUTING PROTOCOLS

Category	Example Protocols	Fault-Tolerance Mechanism	Advantages	Limitations
Proactive	DSDV, OLSR	Periodic routing updates	Low delay	High overhead
Reactive	AODV, DSR	On-demand route discovery	Low control traffic	Route discovery latency
Hybrid	ZRP	Zone-based routing	Balanced performance	Complex implementation
Multipath	AOMDV, SMR	Multiple backup paths	High reliability	Additional overhead
Cluster-based	CBRP	Cluster heads	Scalability	Cluster maintenance
Geographic	GPSR	Position-based routing	Less routing information	GPS dependency
Bio-inspired	ACO, BeeAdHoc	Swarm optimization	Adaptive routing	Computational complexity
AI-based	Deep Reinforcement Learning	Predictive routing	Intelligent decisions	Large training data
Blockchain-based	SecureMANET	Distributed trust	High security	Increased latency
SDN-based	SDN-MANET	Centralized control	Flexible management	Controller reliability

IV. MAJOR FAULT SOURCES IN MANETS

Fault Type	Cause	Network Impact
Node Failure	Battery exhaustion	Route break
Link Failure	Mobility	Packet loss
Hardware Failure	Device malfunction	Communication interruption
Congestion	Heavy traffic	Increased delay
Wireless Interference	Noise	Reduced throughput
Malicious Attack	Blackhole, Wormhole	Data loss
Environmental Obstacles	Buildings, terrain	Signal attenuation
Network Partition	Sparse deployment	Disconnected topology

V. FAULT-TOLERANCE TECHNIQUES

Modern routing protocols employ several techniques:

1. Multipath Routing

Multiple independent routes ensure communication continues when the primary path fails.

Examples:

i. AOMDV

ii. MP-DSR

DOI: 10.48175/568

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 11, June 2026
Impact Factor: 8.2

2. Local Route Repair
Instead of rediscovering the entire route, nearby nodes repair broken links.
Benefits:
i. Reduced latency
ii. Lower overhead

2. Route Caching
Previously discovered routes are stored for future communication.
Protocols:
i. DSR

3. Energy-Aware Routing
Nodes with higher remaining battery are preferred.
Advantages:
i. Increased network lifetime
ii. Lower node failures

4. Cross-Layer Optimization
Information is shared between:
i. MAC layer
ii. Physical layer
iii. Network layer
This improves routing decisions.

5. Trust-Based Routing
Malicious nodes are detected using trust evaluation mechanisms.
Applications:
i. Military MANETs
ii. Secure emergency communication

6. AI-Based Prediction
Machine learning predicts:
i. Link failures
ii. Congestion
iii. Node mobility
before failures occur.

VI. COMPARISON OF POPULAR FAULT-TOLERANT ROUTING PROTOCOLS

Protocol	Routing Type	Multipath	Energy Efficient	Security	Fault Recovery	Mission-Critical Suitability
DSDV	Proactive	No	Low	Low	Poor	Moderate
OLSR	Proactive	No	Moderate	Moderate	Moderate	Good
AODV	Reactive	No	Moderate	Moderate	Good	Very Good
DSR	Reactive	Route Cache	Moderate	Moderate	Good	Good
AOMDV	Reactive	Yes	Good	Moderate	Excellent	Excellent

IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429 Volume 6, Issue 11, June 2026 Impact Factor: 8.2

TORA	Reactive	Yes	Good	Moderate	Excellent	Excellent
ZRP	Hybrid	Partial	High	Moderate	Very Good	Excellent
GPSR	Geographic	Yes	High	Low	Good	Good
AntHocNet	Bio-inspired	Yes	High	Moderate	Excellent	Excellent
DRL Routing	AI-Based	Yes	Very High	High	Outstanding	Outstanding

VII. MISSION-CRITICAL MANET APPLICATIONS

Application	Communication Requirements	Fault-Tolerance Importance
Military Battlefield	Reliable real-time communication	Very High
Disaster Recovery	Infrastructure-free networking	Very High
Search and Rescue	Continuous connectivity	High
Emergency Healthcare	Low latency	High
UAV Swarms	Dynamic routing	Very High
Smart Transportation	Reliable vehicle communication	High
Industrial IoT	Network reliability	High
Border Surveillance	Secure communication	Very High

VIII. CONCLUSION

Fault-tolerant routing has evolved from simple single-path routing mechanisms to intelligent, adaptive, and self-healing communication frameworks capable of supporting mission-critical MANET applications. Early protocols such as DSDV, AODV, and DSR established the foundations for decentralized communication but struggled with frequent route failures and limited resilience. Subsequent developments introduced multipath routing, local route repair, energy-aware strategies, and cross-layer optimization, substantially improving reliability in dynamic environments. More recent approaches leverage artificial intelligence, swarm intelligence, blockchain, Software Defined Networking (SDN), and edge computing to anticipate failures, optimize route selection, and enhance network security.

Although these advancements have significantly increased MANET robustness, challenges related to scalability, energy efficiency, mobility prediction, and cybersecurity remain. Future fault-tolerant routing protocols are expected to incorporate autonomous decision-making, explainable AI, federated learning, digital twins, and 6G technologies to achieve highly resilient, secure, and adaptive communication. Such innovations will be essential for ensuring dependable connectivity in military operations, disaster management, emergency healthcare, intelligent transportation, and other mission-critical applications where uninterrupted communication is vital for operational success.

REFERENCES

1. Abid, S. A., Othman, M., & Shah, N. (2015). A survey on DHT-based routing for large-scale mobile ad hoc networks. *ACM Computing Surveys, 47*(3), 1–46.
2. Abid, S. A., Shah, N., & Othman, M. (2015). DHT-based routing protocols for large-scale MANETs: Design and challenges. *ACM Computing Surveys, 47*(3), 1–46.
3. Ahmed, R. E. (2011). A fault-tolerant routing protocol for mobile ad hoc networks. *Journal of Advances in Information Technology, 2*(2), 128–132.
4. Guo, Z., Malakooti, S., Sheikh, S., Al-Najjar, C., & Malakooti, B. (2011). Multi-objective OLSR for proactive routing in MANET with delay, energy, and link lifetime predictions. *Applied Mathematical Modelling, 35*(3), 1413–1426.

5. Guo, Z., Sheikh, S., & Malakooti, B. (2011). Delay, energy and link lifetime prediction for MANET routing. *Applied Mathematical Modelling, 35*(3), 1413–1426.
6. Hinds, A., Ngulube, M., Zhu, S., & Al-Aqrabi, H. (2013). A review of routing protocols for mobile ad hoc networks (MANET). *International Journal of Information and Education Technology, 3*(1), 1–5.
7. Hinds, A., Zhu, S., & Al-Aqrabi, H. (2013). Mobile ad hoc network routing protocols: A comprehensive review. *International Journal of Information and Education Technology, 3*(1), 1–5.
8. Jain, R., Mehta, A., & Somani, V. (2013). Performance evaluation of fault tolerance protocols in MANET. *International Journal of Computer Applications, 61*(2), 29–33.
9. Kaur, K., & Kaur, K. (2015). Recent trends toward fault tolerance techniques in MANET. *International Journal of Computer Applications, 120*(22), 47–52.
10. Lan, Z. (2023). A comprehensive review of fault-tolerant routing mechanisms for the Internet of Things. *International Journal of Advanced Computer Science and Applications, 14*(7), 1036–1048.
11. Lan, Z. (2023). State-of-the-art fault-tolerant routing mechanisms for reliable IoT communication. *International Journal of Advanced Computer Science and Applications, 14*(7), 1036–1048.
12. Mohsin, A. H. (2022). Optimize routing protocol overheads in MANETs: Challenges and solutions—A review paper. *Wireless Personal Communications, 126*(4), 2871–2910.
13. Mohsin, A. H. (2022). Resource-efficient routing mechanisms in MANETs: Performance comparison and future directions. *Wireless Personal Communications, 126*(4), 2871–2910.
14. Mohsin, A. H., & Al-Hubaishi, A. (2022). Routing efficiency and quality of service optimization in mobile ad hoc networks. *Wireless Personal Communications, 126*(4), 2871–2910.
15. O, R., & Oyelakin, A. M. (2023). Approaches for solving routing and security issues in mobile ad hoc networks (MANETs): A review. *Journal of Information Technology and Computing, 4*(2), 20–30.
16. Sathiyavathi, V., Thenmozhi, R., & Selvakumar, K. (2023). Secure cluster-based fault-tolerant routing protocol for mobile ad hoc networks. *Journal of Intelligent & Fuzzy Systems, 44*(5), 7557–7572.
17. Sathiyavathi, V., Thenmozhi, R., Ramesh, L. S., Sabena, S., & Selvakumar, K. (2023). Clustering based secure error report fault tolerant routing in mobile adhoc networks. *Journal of Intelligent & Fuzzy Systems, 44*(5), 7557–7572.
18. Sridhar, S., & Baskaran, R. (2010). A survey on QoS based routing protocols for MANET. *International Journal of Computer Applications, 8*(3), 15–22.
19. Zahid, S., Ullah, K., Waheed, A., & Basar, S. (2022). Fault tolerant DHT-based routing in MANET. *Sensors, 22*(11), 4280.
20. Zahid, S., Ullah, K., Waheed, A., & Basar, S. (2022). Reliable distributed hash table routing for fault-tolerant MANET communication. *Sensors, 22*(11), 4280.