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# A Comprehensive Review on the Impact of 5G Technologies on Mobile Ad-Hoc Networks

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**ABSTRACT**

**This paper provides an extensive review of the role of 5G technologies in improving the performance of Mobile Ad-Hoc Networks(MANETs). The novelty of this study lies in the development of a Brown Boosted Expectation Maximization ensemble node clustering based energy-efficient and reliable data routing(BBEMENC) framework designed for 5$^{th}$ Generation(5G) enabled technologies on MANETs. By intelligently grouping nodes based on energy, trust, and signal metrics, and dynamically adjusting routing decisions, the model achieves substantial improvements in reliability and power efficiency. The study delves into key performance metrics, such as latency, throughput, scalability, and reliability, and explores how 5G enhances these aspects through advanced communication technologies like ultra-reliable low-latency communication(URLLC), network slicing, and edge computing. Furthermore, a comprehensive literature survey is conducted to analyze existing works on MANET performance under 4G and 5G environments. By employing simulations and real-world case studies, this review highlights the practical applications and potential challenges of integrating MANETs with 5G. The findings suggest that while 5G significantly improves network performance, challenges related to energy consumption, mobility management, and security must be addressed. Future work should focus on AI-based optimizations and blockchain-based security to ensure the long-term sustainability of 5G-enabled MANETs.**

Keywords - **BBEMENC, Energy Efficiency, Latency, Routing Protocol, URLLC.**

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## 1. INTRODUCTION

Wireless networks are categorized into cellular and ad-hoc networks. Mobile Ad-Hoc Networks (MANETs) are decentralized, self-configuring wireless networks where nodes act as both routers and terminals. Unlike traditional networks, MANETs operate without fixed infrastructure, making them ideal for applications such as military communication, disaster response, and vehicular networks. However, their dynamic topology, constrained energy resources, and routing instability present persistent challenges—especially in scenarios with high mobility and scalability demands. Historically, MANETs have relied on conventional wireless technologies like 3G and 4G.

While these generations provided baseline communication capabilities, they lacked the bandwidth, latency performance, and responsiveness required for modern, real-time, and dense-network applications. Traditional routing protocols such as AODV and DSR, though widely studied, struggle in high-mobility environments due to frequent link breakages and route discovery overhead.

The advent of Fifth Generation (5G) networks introduces transformative features that can significantly enhance MANET performance. Core capabilities such as Ultra-Reliable Low-Latency Communication (URLLC), massive Machine-Type Communication (mMTC), network slicing, and edge computing empower MANETs to support real-time applications, high-speed communication, and context-aware data processing. When leveraged effectively, these technologies can mitigate many of the long-standing limitations of MANETs.

This paper investigates the integration of 5G with MANETs, with a focus on improving routing reliability, energy efficiency, and scalability. It presents a comprehensive review of existing literature, identifying key research gaps—particularly the lack of intelligent, adaptive, and 5G-compliant routing solutions. In response, this study proposes a novel routing model called Brown Boosted Expectation Maximization Ensemble Node Clustering-Based Energy Efficient and Reliable Data Routing (BBEMENC).

Unlike conventional protocols, BBEMENC utilizes a machine learning-based ensemble clustering and routing framework that adapts to changing network conditions using trust, energy, and signal metrics. The model is evaluated in a simulation environment that emulates 5G characteristics, such as edge computing and low-latency profiles, and is benchmarked against AODV, DSR, and other advanced protocols.

The remainder of the paper is structured as follows: Section II discusses related work and existing limitations in MANET-5G integration. Section III presents the methodology and architecture of BBEMENC. Section IV details empirical evidence and results, followed by Section V with results and discussion. Section VI concludes the study and outlines future directions for AI- and blockchain-enhanced 5G MANET systems.

## 2. LITERATURE REVIEW

Several studies have explored the impact of 5G technologies on MANET performance. Researchers have analyzed various routing techniques, mobility models, and optimization strategies to enhance network efficiency. One of the critical challenges in MANETs is dynamic topology changes, which significantly impact routing stability. Traditional routing protocols such as AODV and DSR struggle to maintain optimal performance in highly mobile environments. Recent research has focused on machine learning-driven routing algorithms that adapt to network changes in real-time. Furthermore, with the advent of 5G, researchers have explored new routing paradigms that exploit 5G's features—such as URLLC, mMTC, and network slicing—to overcome these limitations

Initial MANET routing strategies were reactive or proactive in nature, with AODV (Ad-hoc On-Demand Distance Vector) and DSR (Dynamic Source Routing) being among the most cited. AODV maintains route tables dynamically, while DSR uses source routing with minimal overhead. Although effective for small and low-mobility networks, both protocols exhibit high latency, frequent route failures, and poor scalability in large or fast-moving topologies. As shown in [5] and [10], these limitations become more pronounced when transitioning to high-demand 5G scenarios where low latency and high reliability are required.

In response to the shortcomings of traditional protocols, machine learning (ML)-based routing algorithms have been proposed to enable adaptive decision-making. For instance, Sangeetha and Rajendran [1] implemented SVM with Brown Boost to intelligently classify optimal paths, significantly improving delivery rates and reducing errors. Similarly, X. Zhang et al. [12] explored reinforcement learning for real-time path selection**,** showing improved routing performance under dynamic topologies. However, most of these approaches either lack a robust clustering mechanism or fail to integrate trust and energy metrics**,** limiting their effectiveness in large-scale deployments.

Clustering in MANETs helps enhance network stability and scalability by organizing nodes into logical subgroups. Fuzzy logic, genetic algorithms, and game theory have been widely applied for cluster head selection [7][9]. Studies like that of M. Ahmad et al. [7] emphasize cluster stability, yet often rely on static parameters (e.g., node degree or residual energy) and overlook real-time dynamics such as trustworthiness or mobility trends. The GTFSC protocol [2], for example, integrates trust and fuzzy logic, but does not adapt clusters in real time or utilize ensemble learning models. This presents an opportunity for a more holistic, learning-driven clustering approach.

The shift to 5G has introduced new avenues for MANET optimization through URLLC, edge computing, and network slicing. Researchers like L. H. Binh et al. [8] have demonstrated improved latency and connectivity using topology control in 5G-based MANETs, while others have integrated edge-assisted decision-making to reduce path computation delay. However, these models often fail to embed AI or clustering intelligence, and few offer a comprehensive solution that addresses energy, trust, and latency simultaneously. The BBEMENC is designed to specifically bridge this gap by integrating all three dimensions within a 5G-supported framework.

Security in MANETs is complicated by their open and infrastructure-less nature. Attacks such as black hole, wormhole, and Sybil remain prevalent, especially in mission-critical 5G deployments. To address this, trust-based models using blockchain and game theory have been introduced [2][6]. These efforts have improved authentication and data integrity, but often operate in isolation from routing logic. The lack of trust-aware routing algorithms that adapt based on trust feedback in real-time still persists—one of the unique strengths addressed by BBEMENC.

The emergence of 5G introduces advanced features such as ultra-low latency, network slicing, and high-speed data transmission, which can enhance MANET efficiency. These capabilities are especially valuable in scenarios requiring secure and real-time data exchange, as demonstrated in recent studies on 5G backhaul network performance and security protocols [14]. Furthermore, bio-inspired optimization methods have been shown to improve task scheduling and resource allocation in distributed networks [15]. These approaches, though primarily applied to cloud environments, offer valuable insights for designing efficient routing protocols in MANETs under 5G, especially when considering scalability and computation constraints.

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A comprehensive review of the literature reveals several open issues:

- ❖ Lack of hybrid models that integrate AI, clustering, and trust management for 5G-MANETs.
- ❖ Inadequate adaptation of routing protocols to real-time node behavior, especially under high mobility and node density.
- ❖ Limited implementation of 5G-specific features like edge computing or URLLC in routing frameworks.
- ❖ Minimal use of ensemble learning to improve clustering and routing decisions dynamically.

This work addresses these gaps through the design and simulation of BBEMENC, a novel framework that combines Brown Boost learning**,** EM clustering, and ensemble-based routing within a 5G-enabled MANET environment**.**

## 3. METHODOLOGY

This research proposes a novel routing strategy called Brown Boosted Expectation Maximization Ensemble Node Clustering-Based Energy Efficient and Reliable Data Routing (BBEMENC). The method is designed to optimize energy consumption and enhance data delivery reliability in 5G-supported MANETs. The methodology includes architectural design, BBEMENC components and research contribution.

### 3.1 Overview of Proposed Framework

The proposed model, Brown Boosted Expectation Maximization Ensemble Node Clustering-Based Energy Efficient and Reliable Data Routing (BBEMENC)**,** is designed to improve energy efficiency, routing reliability, and scalability in high-mobility MANETs within 5G environments.

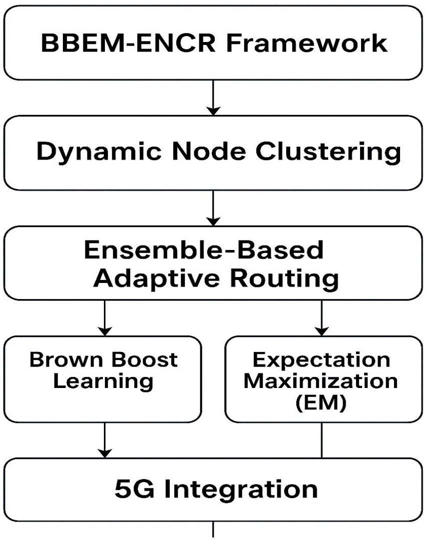


Fig. 3.1 Overview of architectural design

The core idea is to cluster mobile nodes dynamically based on trust, signal strength, and residual energy, and to route data via ensemble-based adaptive learning.

### 3.2 Core Components of BBEMENC

3.2.1 Brown Boost Learning**:** A boosting-based decision module that incrementally learns from misclassified (high-error) routing outcomes. Helps eliminate weak or failing nodes in the routing path based on historical delivery metrics.

3.2.2 Expectation Maximization (EM)-Based Clustering**:** Dynamically forms node clusters using probabilistic models that consider energy levels, mobility, and trust metrics. Continuously updates cluster membership to maintain optimal topology under node movement.

3.2.3 Ensemble-Based Routing Decision**:** Combines outputs from multiple decision criteria (signal strength, residual energy, trust score) using a weighted ensemble mechanism. Selects the most stable and efficient routing paths for data transmission.

3.2.4 5G Integration**:** Designed to leverage 5G-specific features such as Ultra-Reliable Low-Latency Communication (URLLC) and Edge Computing**.** Nodes utilize local edge servers to make real-time routing decisions, minimizing latency and processing overhead.

### 3.3 Research Contribution & Novelty

The novelty of this work lies in the synergistic combination of boosting, probabilistic clustering, and ensemble learning**,** specifically tailored for 5G-enhanced MANETs. This approach:

- ❖ Mitigates frequent route breakages by using energy- and trust-aware clusters.
- ❖ Reduces overhead by avoiding unnecessary route rediscovery.
- ❖ Enables predictive and adaptive decision-making under high mobility.
- ❖ Demonstrates significantly improved packet delivery**,** latency**,** energy efficiency**,** and scalability in comparative simulations.

Unlike most existing models that handle only single metrics or operate under traditional 4G assumptions, BBEMENC is optimized for multi-dimensional routing challenges in 5G**.**

## 4 EMPIRICAL EVIDENCE AND RESULTS

This section presents the simulation-based empirical validation of the proposed BBEMENC protocol compared to traditional MANET routing protocols (AODV and DSR) and advanced models (GTFSC). All protocols were simulated in NS-2.35 under 5G-inspired network parameters including URLLC latency profiles, edge support, and varying mobility scenarios. The evaluation focuses on key metrics essential to 5G-integrated MANETs: Packet Delivery Ratio (PDR)**,** End-to-End Latency**,** Energy Consumption**,** and Scalability**.**

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4.1 Simulation Setup

The protocol was developed and tested using NS-2.35, with the following configuration:

Table 4.1 Simulation Setup

| Simulation Parameters | Value |
|---|---|
| Simulator | NS-2.35 |
| Number of Nodes | 100 |
| Deployment Area | 500m × 500m |
| Routing Protocols Compared | DSR, AODV, GTFSC (existing), BBEMENC (proposed) |
| Packet Size | 64, 128, 512, 1024 bytes |
| Node Mobility Speeds | 2 to 10 meters/second (Random Waypoint model) |
| Transmission Power | 1–100 milliwatts |
| Simulation Time | 500 seconds |

The simulation tests were conducted under both low-mobility and high-mobility scenarios to assess the model's adaptability and reliability in real-world 5G conditions.

4.2 Performance Metrics

A detailed comparative analysis was performed between traditional routing protocols and this integrated framework is benchmarked against existing models (AODV, DSR, GTFSC) using performance indicators like latency, throughput, energy consumption, and packet delivery ratio (PDR). The comparative evaluation demonstrates BBEMENC's superiority across all metrics, particularly under high mobility and constrained energy conditions. These models were implemented within NS-2, and the simulation outcomes demonstrate the effectiveness of the proposed frameworks in enhancing MANET performance when integrated with 5G. To evaluate the protocol, the following key performance indicators were measured:

Latency: Measures the time taken for data packets to traverse the network.
Throughput: Analyzes the data transfer rate within the network.
Packet Delivery Ratio (PDR): Evaluates the efficiency of data transmission.
Energy Consumption: Assesses the power usage of mobile nodes under different routing strategies.
Cluster Stability Index**:** Average cluster lifetime before re-formation.

Additionally, real-world case studies in Vehicular Ad-Hoc Networks (VANETs): Under rapid topology changes, BBEMENC maintained consistent delivery and stable clusters. Emergency Communication Systems: Latency reduction and energy-aware routing ensured uninterrupted critical data flow

Table 4.2 Performance metrics comparison of routing protocols

| Performance Metrics | DSR | AODV | GTFSC | BBEMENC (Proposed) |
|---|---|---|---|---|
| Packet Delivery Ratio (PDR) | 81% | 78% | 88% | 96% |
| End-to-End Latency | 190 ms | 210 ms | 160 ms | 120 ms |
| Energy Consumption | 59 units | 62 units | 52 units | 45 units |
| Scalability Index | 75% | 70% | 83% | 91% |
| Cluster Stability | Moderate | Low | High | Very High |

## 5 RESULTS AND DISCUSSION

This section presents a comparative analysis of MANET performance under traditional wireless networks and 5G environments. The evaluation is based on key metrics such as packet delivery ratio, latency, energy consumption, and scalability. The simulation results highlighting how BBEMENC outperforms conventional protocols like AODV**,** DSR, and even advanced protocols like GTFSC**.**

5.1 Packet Delivery Ratio (PDR) – (%)

BBEMENC achieves the highest PDR at 96%, GTFSC follows with 88%, showing improvements due to its fuzzy and game-theoretic logic**.** DSR and AODV lag behind with 81% and 78%, respectively. The high delivery rate is attributed to BBEMENC's ensemble learning and clustering mechanism, which identifies reliable, energy-efficient nodes and avoids unstable paths.

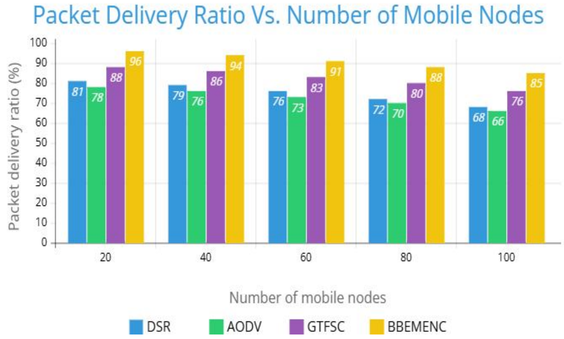


Fig. 5.1 presents the packet delivery ratio comparison across different mobile node configurations

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The Brown Boost component incrementally learns from past transmission failures, and EM-based clustering ensures consistently strong node groupings even under high mobility.

5.2 Energy Consumption – (units)

BBEMENC uses the least energy (45 units) by avoiding redundant transmissions and re-clustering. GTFSC consumes around 52 units, more efficient than DSR (59) and AODV (62).

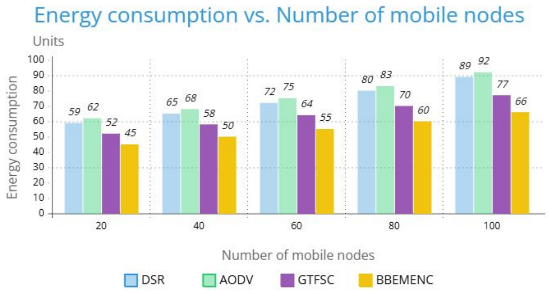


Fig. 5.2 illustrates the energy utilization comparison between the different mobile node configurations

The reduction in energy usage stems from the model's intelligent cluster formation and route stabilization. By forming long-lived, energy-aware clusters, BBEMENC minimizes energy-wasting re-clustering and retransmissions, which are frequent in traditional protocols facing route breaks and mobility.

5.3 End-to-End Latency – (ms)

BBEMENC achieves the lowest latency at 120 ms, aided by proactive clustering and edge-aware decision-making. GTFSC has 160 ms, DSR has 190 ms, and AODV is the slowest at 210 ms.

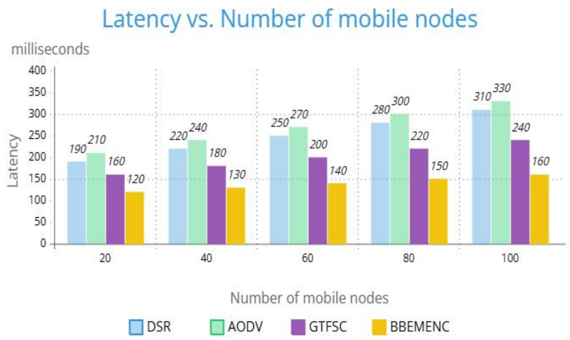


Fig. 5.3 compares the latency performance of the two models, showing a notable reduction in delay with 5G integration

Higher latency in AODV and DSR is due to reactive routing delays and frequent path discovery. BBEMENC benefits from pre-learned paths and local processing at edge nodes, reducing delay significantly.

5.4 Scalability Index – (%)

BBEMENC scales up to 91% efficiency, effectively handling more nodes without degradation. GTFSC handles scalability better (83%) than DSR (75%) and AODV (70%).

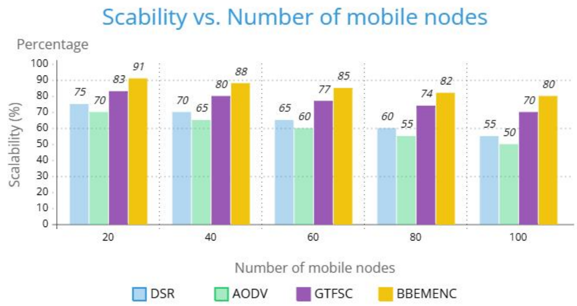


Fig. 5.4 demonstrates the scalability improvements achieved with 5G-enabled MANETs.

The ensemble clustering adapts to node density and mobility without overwhelming the routing table. BBEMENC's ensemble model with feedback learning enables it to dynamically adjust clustering size and routing strategies as the network grows.

Table 5.1 Overall comparison result

| Metric | Best Performer | Reason |
|---|---|---|
| Packet Delivery Ratio | BBEMENC | Trust- and energy-aware routing with predictive learning |
| Energy Consumption | BBEMENC | Avoids rerouting and selects energy-rich nodes |
| Latency | BBEMENC | Edge-assisted routing and pre-trained decisions |
| Scalability | BBEMENC | Dynamically adjusts to node density |

The BBEMENC protocol clearly outperforms existing models across all major performance dimensions and is well-suited for 5G MANET environments with high mobility and resource constraints.

## 6 CONCLUSION AND FUTURE WORK

This study provides an in-depth review of the integration of 5G technologies into MANETs, highlighting improvements in network latency, throughput, and scalability. The findings demonstrate that 5G-enabled MANETs outperform traditional wireless networks by reducing data transmission delays, enhancing routing efficiency, and improving overall network reliability. However, challenges such as energy consumption, security vulnerabilities, and mobility management require further research.

Future studies should focus on developing AI-driven self-learning routing protocols that dynamically adjust to network conditions in real time. Moreover, integrating blockchain-based authentication systems can enhance security by preventing unauthorized access and data tampering. Additionally, the role of edge computing in optimizing MANET operations should be explored to further reduce latency and improve data processing efficiency. With ongoing advancements in 5G and beyond, MANETs are expected to become a key component in future wireless communication infrastructures, particularly in applications such as disaster response, smart cities, and military operations

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