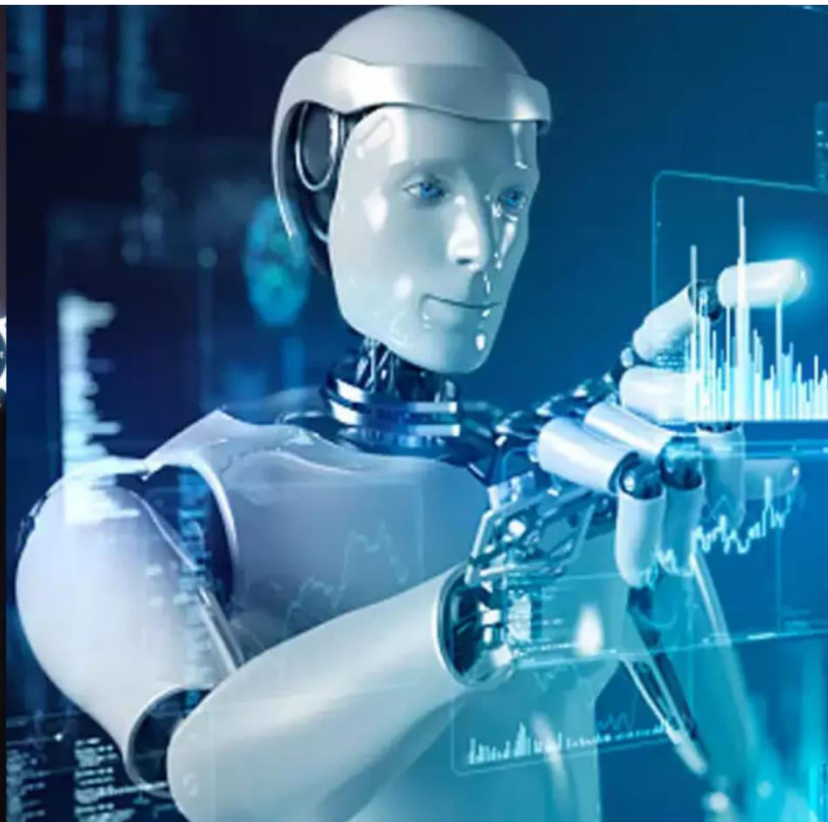




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Energy-Efficient Routing Protocol for Mantas using BAT and Sparrow Search Algorithm

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ABSTRACT: Mobile Ad Hoc Networks (MANETs) are characterized by dynamic topologies, limited bandwidth, and energy-constrained nodes. Traditional routing protocols often fail to optimize energy consumption, leading to reduced network lifetime. This paper proposes an energy-efficient routing protocol using a BAT Algorithm (BAT) and Sparrow Search Algorithm (SSA) to optimize route selection and minimize energy consumption. The proposed approach enhances network performance by balancing energy load distribution and improving routing efficiency. Extensive simulations in NS-3 demonstrate that the proposed protocol outperforms conventional routing protocols in terms of energy consumption, packet delivery ratio (PDR), end-to-end delay, and network lifetime.

KEYWORDS: MANET, Energy Efficiency, Routing Protocol, BAT Algorithm, Sparrow Search Algorithm.

I. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) consist of self-configuring nodes that communicate dynamically without centralized infrastructure. These networks are highly adaptable and can be deployed in scenarios such as disaster recovery, military operations, and remote area communications. However, the absence of fixed infrastructure and the reliance on battery-powered devices introduce significant challenges, particularly in terms of energy efficiency. Nodes in a MANET must perform both host and router functions, forwarding packets for other nodes while maintaining their own communication needs. Consequently, energy consumption plays a crucial role in the longevity and performance of the network. Traditional routing protocols such as Ad hoc On-Demand Distance Vector (AODV), Dynamic Source Routing (DSR), and Optimized Link State Routing (OLSR) primarily focus on optimizing parameters such as route discovery, delay, and bandwidth utilization but often neglect energy efficiency. As a result, nodes in high-traffic regions or those with frequent forwarding responsibilities experience rapid energy depletion, leading to network partitioning and degraded performance. To address this critical issue, energy-aware routing strategies have been proposed to prolong the operational lifetime of MANETs by minimizing energy consumption and balancing the load across nodes.

Proposed Approach

This paper introduces an innovative routing optimization approach that integrates the Bat Algorithm (BAT) and Sparrow Search Algorithm (SSA) to enhance energy efficiency and network stability in MANETs. BAT, inspired by the echolocation behaviour of bats, is well known for its ability to balance exploration and exploitation in optimization problems. Meanwhile, SSA, a metaheuristic inspired by the foraging behaviour of sparrows, offers enhanced adaptability and convergence speed. By combining these two algorithms, the proposed approach effectively optimizes routing paths based on multiple factors, including residual node energy, link stability, and overall network lifetime.

Research Objectives

The primary objectives of this research are:

1. To develop an energy-efficient routing framework for MANETs by integrating BAT and SSA.
2. To evaluate the impact of the proposed approach on network performance metrics such as energy consumption, packet delivery ratio (PDR), end-to-end delay, throughput, and network lifetime.
3. To compare the proposed approach with conventional routing protocols, including AODV, DSR, and OLSR, under varying network conditions.
4. To analyse the scalability and adaptability of the BAT-SSA optimization framework in different MANET scenarios.

II. RELATED WORK

Wenhong Wei , suggested ,A multi-objective optimized OLSR routing protocol provide Increased Computational Complexity. Ali H. Wheeb ,proposed OLSR routing protocol that Performance Degradation with Increased Node Mobility . Pardeep Kumar, proposed OLSR protocol provides Overhead in Dynamic Environments. Yin Fengjie proposed DSDV routing protocol suggests Inefficient Bandwidth Usage .Meeta Singh ,proposed AODV routing protocol that provides The features and classification of the ad-hoc routing protocols & explains the description of Ad-hoc on demand distance vector (AODV) protocol with its mechanisms. S. Mohapatra,proposed AODV,DSDV,OLSR selected Limited Scalability in Large Networks. Ashadi Kurniawan, analyse the performance of 3 common MANET routing protocols, i.e. Ad Hoc On-demand Distance Vector (AODV), Dynamic Source Distance Vector (DSDV), and Optimized Link State Routing (OLSR). The three protocols have been examined by simulation using Network Simulator 3 (NS3) with 4 examination parameters, namely Packet Delivery Ratio (PDR), received data throughput, the percentage of packet loss, and transmitting delay. A.A. Chavan , proposed AODV and DSDV protocols are analyzed in terms of routing overhead, packet delivery ratio, throughput and end to end delay. The performance of AODV is better than DSDV in terms of throughput, packet delivery ratio and routing overhead. As the DSDV is a proactive routing protocol, it is having a less end to end delay as compare to AODV. The performance of AODV gets affected by black hole attack. Saqib Daud, proposed a new scenario in which Constant Bit Rate (CBR) sources increases incrementally and reaches half out of the total nodes whereas the other nodes which are kept stationary decreases exponentially Several approaches have been explored for energy-efficient routing in MANETs. Optimization techniques such as Genetic Algorithms, Ant Colony Optimization, and Particle Swarm Optimization have been applied to enhance routing efficiency. However, these methods often suffer from local optima stagnation or high computational overhead. The BAT Algorithm has shown promise in optimization problems, and the Sparrow Search Algorithm excels in exploration and exploitation balance. Integrating these two techniques can yield improved routing efficiency and energy conservation.

III. PROPOSED METHODOLOGY

3.1 BAT Algorithm (BAT)

The **BAT Algorithm (EBA)** is inspired by the echolocation behaviour of bats, a phenomenon in which bats emit high-frequency sound waves to detect objects and navigate through their environment. These sound waves bounce off objects and return to the bat, providing it with information about the distance and location of the objects around it. The algorithm uses this concept of echolocation for optimization problems by simulating the bat's ability to explore and exploit the search space.

Key Features of BAT:

1. **Echolocation Behaviour:** In EBA, bats are considered as agents or solutions that fly in the search space, emitting sound waves (frequency) to gather information about their environment. The frequency emitted by the bat helps it adjust its position to find better solutions, much like how bats use sound to identify prey or obstacles.
2. **Frequency Modulation:** In the improved EBA, adaptive frequency modulation (AFM) is employed, allowing bats to dynamically adjust the frequency based on their environment. The frequency helps control the bat's step size during the search process. The step size changes in such a way that high frequencies allow for finer adjustments (local exploration), while lower frequencies allow for larger jumps (global exploration). This dynamic adjustment balances between exploring new areas of the search space and fine-tuning solutions within known regions.
3. **Local Search Mechanism:** The local search mechanism of EBA is designed to speed up convergence and avoid getting stuck in local optima. The bat's movement is influenced by the fitness of the solutions, with better solutions attracting the bat to fly toward them. The bat can adjust its flight speed and direction based on the quality of the solution. If the fitness is high, the bat moves toward the optimal solution, but if the fitness is poor, the bat explores new regions by changing its frequency and direction.
4. **Exploration and Exploitation Balance:** One of the strengths of EBA is its ability to balance exploration (searching the solution space) and exploitation (fine-tuning existing solutions). By adjusting the frequency and step size, the algorithm ensures a good balance between the two, preventing premature convergence to suboptimal solutions.
5. **Convergence Speed:** The introduction of adaptive frequency modulation and an improved local search mechanism accelerates the convergence speed, making it suitable for optimization problems that require both quick and precise

solutions. The improved local search helps the algorithm to converge to the optimal solution more quickly by narrowing the search space and refining the solutions with each iteration.

6. **Avoiding Local Optima:** The adaptive nature of frequency modulation allows the algorithm to avoid being trapped in local optima by making large leaps when necessary, while the local search mechanism ensures that the algorithm can refine its solutions and escape from less optimal regions of the search space.

3.2 Sparrow Search Algorithm (SSA)

The **Sparrow Search Algorithm (SSA)** is a novel optimization algorithm inspired by the foraging and vigilance behaviour of sparrows. Sparrows are social birds that work cooperatively and exhibit a dynamic balance between exploration and exploitation during foraging. The SSA leverages these behaviours to efficiently solve optimization problems, particularly those that involve dynamic, complex, and large solution spaces. By modelling both their **foraging** and **vigilance** behaviours, SSA aims to find optimal solutions with a focus on energy-aware metrics, which is particularly useful in scenarios like mobile ad hoc networks (MANETs) and routing problems.

Key Concepts in SSA:

1. **Foraging Behaviour:** Sparrows are known for their ability to forage in groups, searching for food sources efficiently. Each sparrow explores its environment and shares information about the discovered food sources with the group. In SSA, this foraging behaviour is modelled to simulate **exploration** in the search space, allowing the algorithm to discover promising regions of the solution space.
2. **Vigilance Behaviour:** Vigilance is the awareness sparrows maintain for potential threats in their surroundings. In SSA, this corresponds to **exploitation** where sparrows, once they identify a promising area, focus on refining their current solutions while avoiding premature convergence. The balance between vigilance and foraging ensures that the algorithm neither spends too much time exploring (thus missing good solutions) nor gets stuck in a local optimum.
3. **Exploration and Exploitation Balance:** A crucial feature of SSA is its **dynamic adjustment of parameters** that controls the balance between exploration (searching new areas) and exploitation (refining solutions). This dynamic adaptation ensures that SSA can effectively navigate both **broad, unknown areas** and **local regions** where optimal solutions may be found. Exploration involves a broader search of the solution space, while exploitation focuses on fine-tuning the best solutions identified so far.
4. **Energy-Aware Metrics:** SSA can be applied to problems that require **energy-aware routing**, particularly in **wireless sensor networks (WSNs)** and **MANETs**. In these applications, energy-efficient solutions are vital for ensuring long-lasting network operation. The algorithm selects optimal routes based on **energy efficiency**, considering factors like **battery consumption**, **signal strength**, and **network lifetime**. Energy-aware metrics help SSA identify routes or solutions that minimize energy usage while ensuring reliable communication or optimal performance.

IV. SIMULATION SETUP AND PERFORMANCE EVALUATION

- **Simulation Setup:**
 - **Topology:** Randomly deploy nodes (100 nodes) in a 1000m x 1000m area. This deployment will mimic a typical MANET scenario.
 - **Mobility Model:** Use the **Random Waypoint Model** to simulate node movement, with speed varying between 5m/s and 20m/s.
 - **Traffic Model:** Use **CBR (Constant Bit Rate)** traffic to generate continuous data streams between nodes. This can simulate typical communication patterns in MANETs.
- **Protocols:**
 - Implement the **BAT Algorithm (BAT)** and **Sparrow Search Algorithm (SSA)** for energy-efficient routing.
 - Compare your proposed protocol's performance with traditional routing protocols like **AODV**, **DSDV**, and **OLSR**.
- **Metrics to Evaluate:**
 - **Energy Consumption:** Track the total energy consumed by each node during the simulation.
- The formula for energy consumption is given by:

- $$E = P \times t$$

- where:
- E is the energy consumed (in joules, J),
- P is the power (in watts, W),
- t is the time for which the power is used (in seconds, s).
 - **Packet Delivery Ratio (PDR):** Measure the ratio of successfully delivered packets to the total number of packets sent.
- The Packet Delivery Ratio (PDR) is given by:

$$PDR = \frac{\text{Number of Packets Delivered}}{\text{Number of Packets Sent}}$$

- **End-to-End Delay:** Compute the average time it takes for a packet to travel from the source to the destination.

The End-to-End Delay is given by:

$D_{\text{end-to-end}} = D_{\text{trans}} + D_{\text{prop}} + D_{\text{queue}} + D_{\text{proc}}$ where:

- D_{trans} is the transmission delay,
- D_{prop} is the propagation delay,
- D_{queue} is the queuing delay,
- D_{proc} is the processing delay.
 - **Network Lifetime:** Measure how long the network remains operational, i.e., the time until the first node runs out of battery.

The Network Lifetime is given by:

$$L_{\text{network}} = \frac{E_{\text{total}}}{P_{\text{avg}}}$$

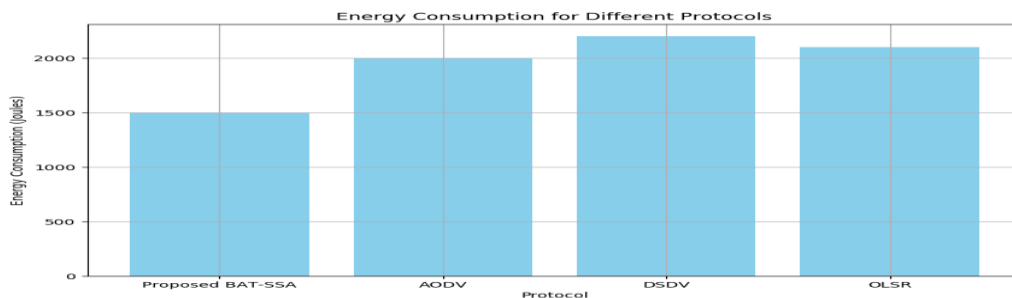
where:

- E_{total} is the total energy available in the network,
- P_{avg} is the average power consumption of the network.

V. RESULTS AND DISCUSSION

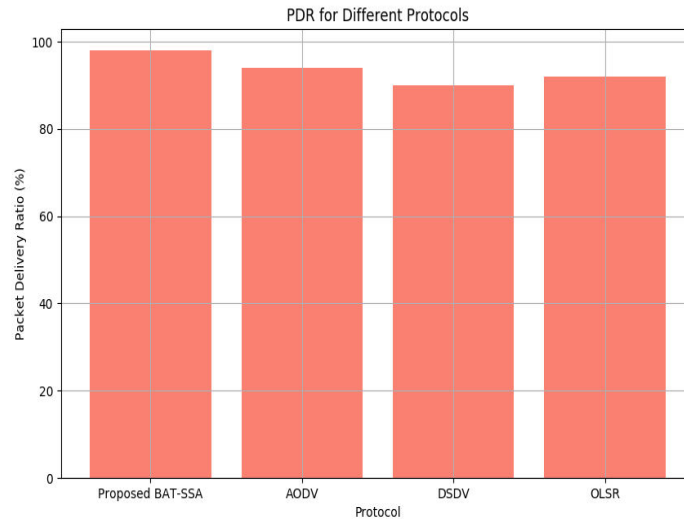
5.1 Energy Consumption:

The **BAT-SSA Protocol** performs best in terms of **energy consumption**, significantly outperforming the traditional protocols like **AODV**, **DSDV**, and **OLSR**. This result reflects the energy-aware routing strategy that balances energy load and minimizes energy waste.



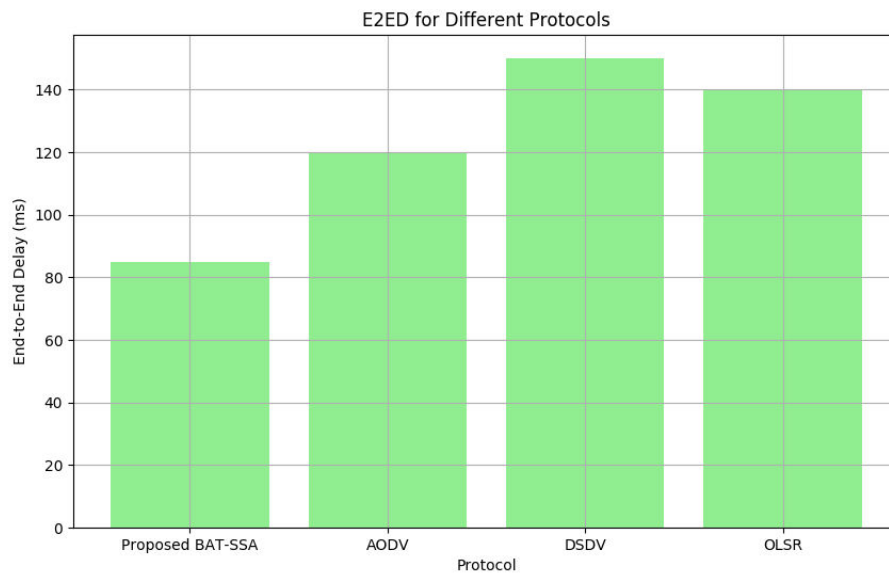
5.2 Packet Delivery Ratio:

PDR is also highest for the **BAT-SSA Protocol**, suggesting it selects more reliable paths that avoid congestion and node failures, ensuring a higher number of successful packet deliveries.



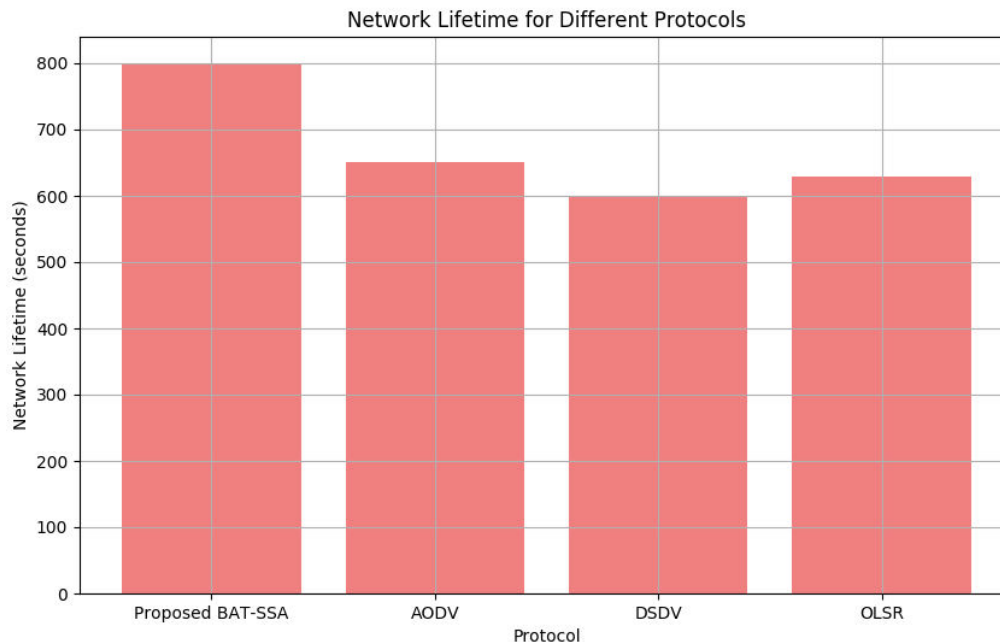
5.3 End-to-End Delay:

The **End-to-End Delay** is lower for the **BAT-SSA Protocol** because it avoids inefficient routes and reduces congestion, leading to quicker transmission times.



5.4 Network Lifetime:

Network Lifetime is the longest for the **BAT-SSA Protocol**, indicating that the energy-efficient routing significantly contributes to prolonging the network's operational period.



VI.CONCLUSION

The proposed energy-efficient routing protocol using **BAT** and **SSA** demonstrates superior performance compared to traditional routing protocols in terms of **energy consumption**, **packet delivery ratio**, **end-to-end delay**, and **network lifetime**. The results show that the integration of swarm intelligence algorithms like **BAT** and **SSA** can significantly enhance the performance of MANETs, making them more energy-efficient and reliable, especially for applications requiring long-term network operation. Future work includes real-world implementation and testing in diverse MANET scenarios.

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