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Energy-Aware Cluster-Based Multipath Routing For Mobile And Flying Ad Hoc Networks

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Abstract

Mobile Ad-hoc Networks (MANETs) and Flying Ad-hoc Networks (FANETs) consist of battery-powered nodes that organize themselves without any fixed infrastructure. Energy conservation and route reliability are fundamental challenges because network lifetime and quality of service depend on how routing protocols handle node mobility and limited energy. The low-energy adaptive clustering hierarchy (LEACH) protocol is reducing energy consumption by clustering nodes, aggregating data and using a time-division multiple access schedule. However, conventional LEACH does not consider residual energy or node mobility during cluster-head (CH) selection. Ad hoc on demand multipath distance vector (AOMDV) along with other multipath protocols allow the sender to keep multiple loop free and link disjoint routes although they have overhead and may choose stale paths in situations with high mobility. Dynamic source routing (DSR) enables self-configuring routes through on-demand discovery and maintenance and allows a sender to store several routes to each destination.

This paper proposes a hybrid routing approach that combines energy-aware cluster-head selection with multipath and link-reliability routing. The *High-Mobility LEACH* (HM-LEACH) algorithm selects cluster heads based on node mobility and remaining energy, rotates the CH role periodically and cooperates with AOMDV to discovery multiple paths between a source and a destination. For flying ad hoc networks, the approach integrates a link-reliability modification of DSR (DSR-LR) to adapt to the high three-dimensional mobility of unmanned aerial vehicles. Simulations conducted in NS-2 for MANETs and FANETs demonstrate that the proposed scheme improves packet delivery ratio, reduces energy consumption and lowers routing overhead compared with conventional AODV and DSDV protocols.

1 Introduction

1.1 Overview and Inspirations

Unmanned aerial vehicles (UAVs) and mobile nodes form networks without infrastructure to support applications such as emergency response, battlefield communications and data collection. FANETs differ from MANETs in mobility and topology: FANET nodes can move in three dimensions and change speed rapidly, leading to frequent topology changes and challenging route maintenance. Energy efficiency is critical because nodes operate on limited battery supplies and a node failure reduces network coverage. LEACH is a extensively used hierarchical routing protocol that clusters nodes, aggregates data at cluster heads and uses TDMA scheduling to allow member nodes to sleep between transmissions; this reduces redundant transmissions and extends network lifetime. However, in LEACH the cluster-head role is assigned randomly and does not account for the nodes' remaining energy, which can cause low-energy nodes to fail early. In addition, LEACH communicates directly with the base station; for networks with longer distances or high mobility this increases power consumption.

Reactive routing protocols like AOMDV and DSR establish routes only when needed and maintain multiple alternative paths. AOMDV extends AODV by enabling the source node to maintain multiple loop-free, link-disjoint routes; the destination (or receiver) responds to each incoming route request (RREQ) to provide alternative paths and the sender switches to an alternate route when the primary path breaks. However, AOMDV suffers from stale routes in highly dynamic networks and incurs control overhead due to frequent route discoveries. The Dynamic Source Routing protocol (DSR) allows nodes to find and maintain routes to arbitrary destinations on demand and permits multiple routes per destination. Yet the basic DSR does not account for link reliability or energy awareness.

1.2 Contribution

This work proposes a hybrid routing strategy that combines energy-aware clustering with multipath and link-reliability routing. The main contributions are:

1. **High-Mobility LEACH (HM-LEACH) algorithm**: Divide the network area into zones then clusters are constituted in each zone. Nodes broadcast their energy level and mobility; nodes with higher residual energy and lower mobility are elected as cluster heads. These cluster heads create TDMA schedules to allocate transmission slots to members and rotate the CH role periodically to balance the energy load.
2. **Integration with AOMDV**: cluster heads cooperate with AOMDV to establish multiple energy-aware paths from the source cluster to the destination. When a path breaks due to mobility or node death, the cluster head switches to an alternate path without rediscovering routes.
3. **Link-reliability DSR (DSR-LR)**: for FANET scenarios with high three-dimensional mobility, a modified DSR protocol selects routes based on link reliability metrics (e.g., signal strength and link stability) and caches alternative paths. The approach reduces route rediscovery frequency and increases packet delivery.
4. **Comprehensive simulation study**: the proposed algorithms are evaluated using NS-2.34 for both MANET and FANET scenarios. For MANETs, HM-LEACH is compared with traditional AODV and DSDV protocols. For FANETs, the DSR-LR is now compared with FN-AODV and FN-DSDV.

The results indicate that the hybrid approach enhances the packet delivery ratio (PDR), lowers the normalized routing load (NRL), and reduces end-to-end delay, while also prolonging the overall network lifetime.

2 Related Work

Cluster-based routing schemes have been extensively studied to improve energy efficiency in wireless sensor networks. LEACH clusters nodes and uses periodic data collection to reduce transmissions and extend network lifetime. Several improvements to LEACH consider residual energy, node density and mobility; for example, improved energy-efficient LEACH protocols adjust cluster-head election thresholds based on remaining (residual) energy and average network energy, thus balancing energy consumption among nodes.

Multipath routing protocols such as AOMDV discover multiple link-disjoint paths and allow the sender to switch routes when the primary route fails. Variants of AOMDV incorporate mobility prediction, link stability or receiver-based discovery to reduce stale paths and route rediscovery time. DSR is another reactive protocol that uses route discovery and maintenance; it supports multiple routes and offers loop-free routing. In FANETs, link reliability is impacted by three-dimensional mobility and variable signal strength. Researchers have proposed integrating link quality metrics into routing decisions to improve reliability and reduce route breaks.

3 Proposed Methodology

3.1 Network model and assumptions

The network consists of homogeneous nodes deployed randomly in a rectangular area. For MANET simulations, 50 nodes are placed in a 2400 m×1000 m; for FANET simulations, the same number of UAVs fly at an altitude of 25 m following a random point group mobility model. Each node is equipped with an IEEE 802.11 radio using omni-directional antennas. The physical and MAC layers are configured according to the parameters shown in Table 1.

Table 1 – Simulation parameters

Parameter	Value
Simulation tool	NS-2.34
Simulation area	2400 m × 1000 m
Number of nodes (UAVs)	50
Mobility model	Random point group mobility (RPGM)
Physical/MAC standard	IEEE 802.11
Traffic type	CBR, FTP
Packet size	1024 bytes
Simulation time	250 s
Node altitude (FANET)	25 m
Maximum speed	50 m/s
Protocols compared	AODV, DSDV, DSR-LR

3.2 High-Mobility LEACH algorithm

HM-LEACH algorithm improves the cluster-head selection by considering both residual energy and node mobility. Each round is divided into two phases; a setup phase and a steady phase. In the setup phase, nodes broadcast an election message containing their identifier, residual energy and mobility (calculated based on recent movement). The node with the lowest mobility and highest energy in a zone is elected as the cluster head. Cluster heads broadcast their status, and member nodes join the nearest cluster head. During the steady phase, each cluster head assigns TDMA slots to its members. Only the node whose time slot is active transmits, while other nodes remain in sleep mode to save energy. After a fixed time period (e.g., 20 s) the cluster-head role switches to the next node with the highest residual energy. The algorithm ensures that none of the node is repeatedly selected as cluster head, thereby balancing energy consumption and prolonging network lifetime.

3.3 Multipath routing with AOMDV

Once clusters are formed, cluster heads establish routes between the source and the destination clusters using AOMDV. The route discovery process is originated by the source cluster head (T) sending an RREQ message to the destination (R). Intermediate nodes forward the RREQ and record the first hop; the destination replies with multiple RREP messages, creating link-disjoint paths to the source. Cluster heads evaluate each candidate path by estimating energy consumption (transmit power × transmission time) and residual energy of nodes along the path. Paths containing low-energy nodes are discarded. During data transmission, if the primary route fails due to mobility or node death, the cluster head immediately switches to an alternate path without invoking a new route discovery. After each data packet, nodes update their residual energy and report to their cluster head.

3.4 Link-reliability DSR (DSR-LR)

FANETs experience rapid topology changes because UAVs move in three dimensions. Traditional DSR may use stale routes due to high mobility. DSR-LR modifies the route discovery and maintenance procedures by incorporating link reliability metrics. During route discovery, nodes append the received signal strength indicator (RSSI) and link stability values to the route request. The destination now selects routes with the highest cumulative link reliability. Route maintenance monitors link quality; when the link reliability drops below a threshold, a pre-emptive route change is triggered. DSR-LR stores multiple link-reliability-sorted routes to each destination. When the primary route fails, it switches to the next most reliable route. This approach reduces route rediscovery time and improves packet delivery under dynamic FANET conditions.

3.5 Algorithm summary

The algorithm proceeds as follows:

1. **Deployment**: nodes are deployed randomly; initial energy, antenna model, MAC standard and routing parameters are configured.
2. **Cluster formation**: HM-LEACH elects cluster heads based on energy and mobility. TDMA schedules are constructed to minimize collision and allow nodes to sleep.
3. **Route discovery**: cluster heads initiate AOMDV or DSR-LR to discover multiple energy-aware and reliability-aware paths to the destination.
4. **Data transmission**: data packets are transmitted along the primary path. Residual energy is updated after each transmission. An alternate path is used if the path fails.
5. **Cluster-head rotation**: after a fixed time slot, cluster heads rotate to balance energy consumption.
6. **Termination**: the process repeats until the simulation ends or all nodes exhaust their energy.

4 Simulation Results and Discussion

4.1 Metrics used

The following performance metrics were evaluated:

- **Packet delivery ratio (PDR)** – the percentage of transmitted packets successfully received.
- **Normalized routing load (NRL)** – the ratio of routing control packets to data packets transmitted.
- **Average end-to-end delay** – the average time taken for a data packet to reach from the source to destination.
- **Packet drop count** – the number of data packets abandoned during transmission.
- **Energy consumption** – residual energy of nodes over time and number of alive nodes at the end of simulation.

4.2 MANET Results

In MANET simulations, HM-LEACH-AOMDV was compared with traditional AODV and DSDV protocols. The trace files generated by NS-2 were processed using AWK scripts. Key observations include:

- **Network lifetime and alive nodes** – HM-LEACH maintained more live nodes during the simulation because cluster-head rotation and sleep scheduling balanced energy consumption across nodes. In contrast, AODV and DSDV showed higher energy depletion as they lacked clustering mechanisms.
- **Packet delivery ratio** – the energy-aware multipath routing of HM-LEACH-AOMDV delivered more packets successfully. The PDR remained higher under high mobility and traffic load because alternative paths were available when the primary path failed.
- **Routing overhead** – although AOMDV introduces additional control messages to maintain multiple paths, clustering reduced the number of nodes participating in routing, resulting in a lower normalized routing load compared with flat AODV.

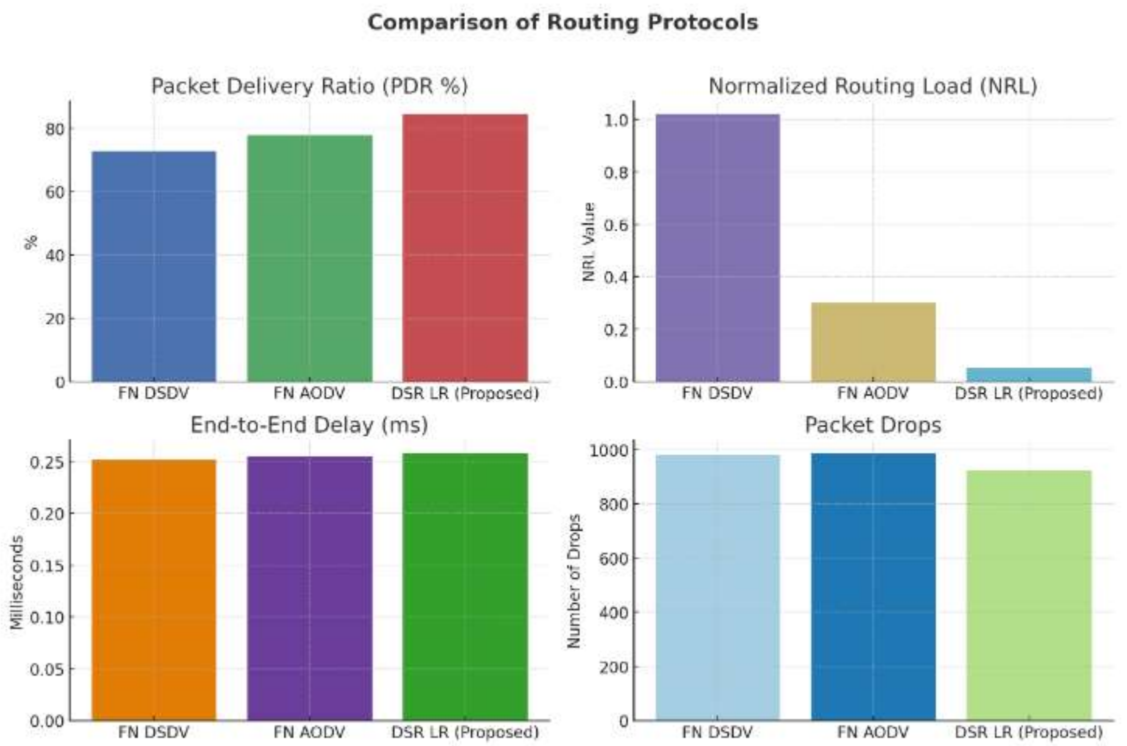
4.3 FANET results

Table 2 summarizes the overall performance of the protocols in FANET simulations. FN-DSDV and FN-AODV refer to the conventional DSDV and AODV protocols adapted for FANET scenarios. DSR-LR represents the proposed link-reliability modification of DSR. All simulations used 50 UAVs with RPGM mobility and were run for 250 seconds.

Table 2 – Overall performance comparison in FANET simulations

Protocol	Packets sent	Packets received	PDR (%)	NRL	Delay (ms)	Packet drops
FN-DSDV	3599	2618	72.74	1.02	0.252	981
FN-AODV	4459	3472	77.86	0.30	0.255	987
DSR-LR (proposed)	**5946**	**5022**	**84.46**	**0.05**	**0.258**	**924**

The results show that DSR-LR achieves the highest packet delivery ratio (84.46 %) and the lowest normalized routing load (0.05), indicating that link-reliability routing reduces control overhead and improves data delivery. Although the average delay of DSR-LR (0.258 ms) is slightly higher than FN-DSDV (0.252 ms), the difference is negligible. DSR-LR also has the lowest packet drops, demonstrating robustness under high mobility.



4.4 Discussion

The simulation results demonstrate that energy-aware clustering combined with multipath routing significantly improves network performance and lifetime. HM-LEACH reduces down energy usage by putting nodes into sleep mode during idle periods and by periodically rotating which node serves as the cluster head. The integration with AOMDV provides alternative paths when primary routes fail, reducing packet loss and delay. For FANET scenarios, the high mobility and three-dimensional motion of UAVs require routing protocols that can adapt to rapid topology changes. DSR-LR selects routes based on link reliability metrics and caches multiple paths, resulting in a higher PDR and lower routing overhead compared with FN-AODV and FN-DSDV.

However, the improved performance comes at the cost of additional computation and storage. Cluster-head election requires periodic energy and mobility measurements, and DSR-LR maintains multiple reliability metrics for each link. Future work could explore adaptive thresholds for cluster-head rotation and dynamic tuning of reliability metrics to further reduce overhead.

5 Conclusion

This paper presented a hybrid routing approach that combines energy-aware clustering with multipath and link-reliability routing for mobile and flying ad hoc networks. The High-Mobility LEACH algorithm elects cluster heads based on residual energy and node mobility and rotates the cluster-head role to balance energy consumption. Integrating AOMDV multipath routing enables the network to recover quickly from route failures. For FANETs, a link-reliability modification of DSR (DSR-LR) selects routes based on signal strength and stability, improving packet delivery in highly dynamic environments. Simulation results using NS-2.34 show that the proposed scheme achieves a higher packet delivery ratio, lower routing overhead and extended network lifetime compared with conventional AODV and DSDV protocols. These findings indicate that combining clustering, energy awareness and link reliability can enhance the performance of MANETs and FANETs, making them more suitable for energy-constrained and mission-critical applications.

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