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Energy-Efficient Routing in Mobile Ad Hoc Networks: A Review and a Conceptual Adaptive HELLO-Interval Extension for AODV

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Abstract:
Mobile ad hoc networks (MANETs) are self-organizing wireless networks whose battery-powered nodes relay traffic for one another without fixed infrastructure. Node mobility, topology changes, and control traffic drain limited energy reserves and shorten network lifetime. This paper surveys representative energy-aware routing and power-management techniques, namely MBCR, MMBCR, CMMBCR, DEAR, ONM, SPAN, sleep- and CDS-based schemes, directional-antenna routing, BECA/AFECA, and energy-aware DSR variants, and compares their objectives and limitations. Building on this survey, a conceptual extension of AODV is outlined in which the HELLO interval is adapted using two parameters: the Distance Factor (DF) and the Time Interval of Route Reply (TIRREP). The aim is to curb unnecessary beaconing while preserving connectivity and route reliability. The scheme is presented as a design proposal; its effect on energy consumption, routing overhead, packet delivery ratio, and network lifetime remains to be validated through simulation.

Index Terms: Mobile ad hoc networks, energy-efficient routing, AODV, HELLO interval, distance factor, TIRREP, network lifetime.

I. INTRODUCTION

A mobile ad hoc network (MANET) is a decentralized wireless network in which mobile devices communicate over wireless links without fixed access points or central routing equipment. Each node acts both as an end host and as a router that relays packets for others, so multi-hop cooperation is needed whenever two devices lie outside each other's radio range. Routing protocols therefore largely determine how efficient and reliable a MANET is.

Two characteristics make routing difficult. First, nodes move independently, so links break and routes must be rebuilt often, which adds control overhead. Second, nodes run on finite batteries, and transmission, reception, idle listening, and control-message processing all deplete them, shortening the lifetime of individual nodes and of the network as a whole.

MANET routing protocols are commonly grouped as proactive, reactive, or hybrid. Proactive protocols keep routes current through periodic exchanges, which shortens discovery delay but raises control traffic. Reactive protocols, such as DSR [1] and AODV [2], build routes only on demand. Hybrid protocols

combine both to trade maintenance overhead against discovery delay. No category is superior in every situation; performance depends on network size, mobility, and traffic load [1], [2].

Because energy is a first-class constraint, an energy-aware protocol must weigh residual battery capacity, communication cost, and the price of keeping the network connected, not only path length. Earlier surveys have catalogued many such protocols [3], [4]. This paper reviews the main approaches and then proposes a conceptual AODV extension that adapts the HELLO interval using a Distance Factor (DF) and the Time Interval of Route Reply (TIRREP). Section II reviews existing algorithms, Section III presents the proposal, Section IV outlines an evaluation plan, and Section V concludes.

II. Review of Energy-Efficient Routing Algorithms

Energy can be saved through battery-aware route selection, transmission-power control, topology maintenance, and node sleep scheduling. The main techniques are summarized below.

A. Battery-Cost-Based Routing

Minimum Battery Cost Routing (MBCR) assigns each node a cost that grows as its residual energy E_i falls, commonly

$$C_i = 1 / E_i \qquad (1)$$

and prefers the route with the smallest total cost. Because a sum can hide a single nearly exhausted node, Min-Max Battery Cost Routing (MMBCR) instead rates each candidate path by its weakest node and selects

$$P^* = \arg\max_P \left(\min_{i \in P} E_i \right) \qquad (2)$$

where P is a candidate route. This balances energy use but may choose longer routes that consume more total transmission energy. Conditional MMBCR (CMMBCR) combines both ideas: if some routes keep every node above a preset energy threshold, the cheapest of them is chosen; otherwise the weakest-node criterion takes over. Its behavior therefore depends on the threshold and on the extra information needed to evaluate routes.

B. Distributed and Online Max-Min Approaches

Distributed Energy-Efficient Ad Hoc Routing (DEAR) [5] seeks to cut the energy needed for delivery while avoiding heavy dependence on a few relays, using only locally available information, which suits networks without central control. Online max-min routing (ONM) pursues two goals together: minimizing transmission energy and maximizing the smallest residual battery on the path, with shortest-path methods such as Dijkstra's algorithm. Tracking several metrics at once, however, raises computation and state-maintenance costs.

C. Topology Control and Sleep Scheduling

SPAN [6] keeps a small set of coordinator nodes awake to preserve connectivity and forwarding while the others conserve energy; coordinators must be rotated so that they do not drain prematurely. Connected-dominating-set (CDS) schemes follow a similar principle by concentrating forwarding on a reduced backbone [7], [8], and coordinated variants give non-coordinators variable sleep periods based on their communication history [9]. Sleep-based AODV variants let a node enter a low-power state when an energy or activity threshold is reached [10], but a node on an active route must not sleep unless an alternative path or a wake-up mechanism exists; otherwise packet loss and route failures follow. BECA and AFECA

switch nodes among active, listening, and sleep states, with AFECA adapting node activity to network conditions [11].

D. Directional Antennas

Directional antennas focus radiated power toward the intended receiver rather than in all directions, which can reduce wasted transmission, improve spatial reuse, and lessen interference [12], [13]. The benefit depends on antenna configuration, node orientation, mobility, and the availability of direction information.

E. Beacon-Interval Control

Beacons, called HELLO messages in AODV, let nodes track their neighbors. A short fixed interval detects link changes quickly but adds control traffic, whereas a long interval saves messages but delays broken-link detection. Adaptive beaconing balances the two by varying the interval with network conditions. Prior work has examined how the beacon period affects response time [14] and how useful HELLO messages are for determining link connectivity [15], [16].

F. Energy-Aware DSR Variants

DSR is a reactive protocol based on source routing. Energy-aware extensions and alternatives, including EDDSR, LEAR, and MDR, choose paths using residual energy, drain rate, or the suitability of intermediate nodes. Their results depend on mobility, routing overhead, and the energy model assumed.

G. Comparative Summary

Table I summarizes the surveyed mechanisms. No single mechanism is sufficient; route selection, control-message frequency, node activity, and topology maintenance must be considered together.

TABLE I
COMPARISON OF SURVEYED ENERGY-AWARE ROUTING MECHANISMS

Mechanism	Main objective	Key limitation
MBCR	Minimize total battery cost	Weak nodes remain at risk
MMBCR	Protect lowest-energy node	Longer routes possible
CMMBCR	Balance route cost and residual energy	Threshold selection
DEAR	Spread energy consumption	Distributed coordination
ONM	Combine energy and residual capacity	Metric-maintenance overhead
SPAN / CDS	Limit the number of active nodes	Coordinator energy balance
AODV-sleep	Save energy in sleep state	Route availability

Mechanism	Main objective	Key limitation
Directional routing	Focus transmission energy	Antenna configuration
BECA / AFECA	Reduce idle listening	Sleep scheduling
EDDSR / LEAR / MDR	Energy-aware path choice	Overhead, energy model

III. PROPOSED ADAPTIVE HELLO-INTERVAL APPROACH FOR AODV

A. Motivation

AODV discovers and maintains routes with Route Request (RREQ), Route Reply (RREP), and Route Error (RERR) messages, and may use periodic HELLO messages, typically implemented as one-hop RREPs, to confirm that neighbors remain reachable [2], [16]. These messages are useful but add control traffic that, in dense networks, can noticeably increase energy use. A fixed interval also suits all conditions poorly: a highly mobile network may need frequent updates, whereas a stable one can tolerate fewer. The proposal therefore adjusts the HELLO interval dynamically using DF and TIRREP, aiming to remove unnecessary transmissions without harming connectivity. It should not be confused with randomized interval selection between a minimum and a maximum value, which does not use network conditions.

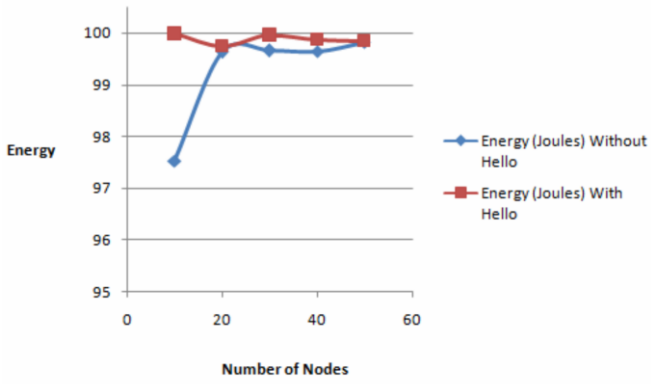


Fig. 1. Conceptual illustration of the energy associated with periodic HELLO message transmission (energy versus number of nodes).

B. Distance Factor (DF)

Transmission requirements depend on the separation between nodes, so DF expresses the distance between a node and a neighbor. In its basic form DF_{ij} equals the estimated distance d_{ij}; a normalized form is

$$DF_{ij} = d_{ij} / R \qquad (3)$$

where R is the nominal communication range, indicating how close a neighbor lies to the edge of coverage. Distance alone cannot determine link reliability, because signal strength, interference, fading, and mobility also matter. DF is therefore used as one input to beacon scheduling and not as a complete connectivity measure.

C. Time Interval of Route Reply (TIRREP)

TIRREP is the observed time between relevant RREP events and reflects how often route discovery occurs. It must be measured over a defined observation window. Since RREPs are event-driven while HELLO messages support periodic neighbor monitoring, TIRREP cannot replace neighbor-connectivity information.

D. Adaptive Interval Formulation

The HELLO interval is modeled as $T_H = f(\text{DF, TIRREP})$, with the initial assumption that it grows with both parameters, so beacons are sent less often when distances are larger and route discovery is infrequent. A bounded formulation for further study is

$$T_H = \text{clip}(\, T_0\,(1 + \alpha \cdot \text{DF}_{ij} + \beta \cdot \tau),\, T_{min},\, T_{max}\,) \quad (4)$$

where T_0 is the reference interval, α and β weight DF and the normalized TIRREP τ, and clip(·) confines the result to $[T_{min}, T_{max}]$. Equation (4) is a proposed formulation, not an experimentally validated result; α and β must be tuned by simulation to confirm that energy is saved without additional route failures.

E. Algorithm and Connectivity Safeguard

Algorithm 1 summarizes the procedure.

Algorithm 1: Adaptive HELLO-interval selection
Input: T_{min}, T_{max}, T_0, DF, TIRREP. **Output:** updated T_H.

1. Set the HELLO interval to the reference value T0.
2. Gather neighbor information and estimate DF.
3. Record RREP events over the observation window and compute τ.
4. Assess current connectivity and routing activity.
5. Compute the candidate interval with (4) and restrict it to [Tmin, Tmax].
6. Update the HELLO schedule; repeat as conditions change.

Safeguard: a node must not enter sleep mode merely because no RREP was received within some period. RREPs are generated only in response to route discovery, so their absence does not mean that a node is unnecessary or disconnected. Sleep decisions should rely on active route participation, forwarding duties, neighbor coverage, and a reliable wake-up mechanism.

F. Expected Benefits

The scheme is expected to (i) reduce control overhead through fewer periodic beacons, (ii) improve energy utilization, (iii) adapt to distance- and routing-related conditions, and (iv) remain compatible with AODV, since it extends the existing neighbor-monitoring process. These are expectations that require experimental verification.

IV. EVALUATION PLAN

The proposal should be evaluated in a simulator such as NS-2 or NS-3 against standard AODV with a fixed HELLO interval, under identical conditions and across varied network sizes, mobility patterns, and traffic loads. The main parameters are the number of nodes, simulation area, mobility model, traffic model,

packet size, initial battery energy, HELLO interval, transmission power, and simulation duration. The following metrics are proposed.

Average energy consumption over N participating nodes is

$$E_{avg} = (1 / N) \Sigma (E_{i,init} - E_{i,final}) \quad (5)$$

Network lifetime is the time until the first node fails, until a stated fraction of nodes fail, or until the network can no longer communicate; the chosen definition must be stated. Packet delivery ratio is

$$PDR = (\text{packets received} / \text{packets generated}) \times 100\% \quad (6)$$

Routing overhead counts the control packets (HELLO, RREQ, RREP, and RERR) transmitted, and end-to-end delay is the mean source-to-destination time, which may increase if fewer beacons slow link-failure detection. The central question is whether adapting the HELLO interval through DF and TIRREP reduces control-message energy while maintaining acceptable performance. No numerical improvement is claimed here, because simulation results are not yet available.

V. CONCLUSION

Energy efficiency is a central challenge in MANETs because nodes rely on limited batteries and operate in a changing topology. This paper reviewed battery-aware route selection, topology maintenance, sleep scheduling, directional transmission, beacon control, and energy-aware DSR, showing that these techniques are complementary. It also proposed a conceptual AODV extension that adapts the HELLO interval through DF and TIRREP to reduce beacon traffic without compromising connectivity. Future work will implement the scheme in NS-2 or NS-3, compare it with standard AODV, and study its sensitivity to mobility, link stability, route-discovery frequency, traffic load, and node density. A precise definition of TIRREP and a concrete method for measuring DF (for example, GPS positions or received signal strength) must also be settled.

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