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Comparative Evaluation of Power Dissipation in MANETs: Standard AODV vs. AODV-EXT and AODV-EXT-BP

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Abstract- Energy management remains a primary bottleneck in the deployment of Mobile Ad Hoc Networks (MANETs), where nodes operate on limited, exhaustible battery reserves. The choice of routing protocol directly dictates the rate and distribution of power dissipation across the network infrastructure. This paper presents a comprehensive comparative evaluation of power dissipation characteristics among three reactive routing protocols: the standard Ad hoc On-Demand Distance Vector (AODV) protocol, an energy-aware extended version (AODV-EXT), and a strict threshold-based battery power extension (AODV-EXT-BP). Using discrete-event simulation software, we analyze the energy consumption behaviors of these three protocols under varying network conditions, including diverse mobility models, node densities, and data transmission rates. The comparative evaluation focuses on critical energy metrics: total network power dissipation, average energy consumed per successfully delivered packet, and the variance of residual energy among the mobile nodes. Simulation results indicate that while standard AODV creates severe localized energy depletion zones due to its rigid reliance on shortest-path routing, both extended protocols significantly optimize power usage. Specifically, AODV-EXT-BP demonstrates superior performance in balancing power dissipation and actively eliminating energy bottlenecks. By intelligently distributing the routing load, AODV-EXT-BP minimizes the variance in node energy consumption, thereby extending the time to first node failure and prolonging the overall operational lifetime of the network without significantly compromising the Packet Delivery Ratio (PDR).

Keywords- MANETs, Power Dissipation, AODV, Energy Consumption Modeling, AODV-EXT, AODV-EXT-BP.

I. INTRODUCTION

Mobile Ad Hoc Networks (MANETs) consist of autonomous, self-configuring mobile nodes connected via wireless links without the support of centralized infrastructure. In these dynamic networks, each mobile node acts as both an independent host and a data router, responsible for forwarding packets on behalf of other nodes to maintain global connectivity. Because MANET nodes are typically powered by finite, non-rechargeable batteries, the overall survivability and operational lifespan of the network are strictly governed by the power dissipation rates of individual transceivers.

Power dissipation in MANETs occurs across four primary radio states: transmission, reception, idle listening, and sleep. Traditional reactive routing protocols, such as the Ad hoc On-Demand Distance Vector (AODV) protocol, establish paths strictly on-demand to minimize background control traffic. However, standard AODV relies on a shortest-path (minimum hop-count) heuristic for route discovery. This approach is inherently energy-blind; it continuously routes heavy data and broadcast traffic through centrally located nodes, driving their transceivers into high-drain transmission and reception states. Consequently, these critical bottleneck nodes experience rapid, localized power dissipation, leading to premature node death, route breakages, and eventual network partitioning.

To address these inefficiencies, energy-aware extensions (AODV-EXT) were developed to incorporate residual energy metrics into the path selection process. While AODV-EXT improves load balancing by avoiding the selection of low-energy paths, it fails to optimize power dissipation during the flood-based route discovery phase itself. Critically depleted nodes are still forced to receive,

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process, and forward Route Request (RREQ) control packets, which continues to dissipate their remaining battery reserves.

To resolve this persistent drain, the AODV-EXT-BP (Ad hoc On-Demand Distance Vector Extended with Battery Power bypass) architecture introduces a localized, self-regulating threshold mechanism. AODV-EXT-BP fundamentally shifts power conservation to the intermediate nodes by allowing them to actively drop incoming RREQ broadcasts when their residual energy falls below a critical threshold. This forces the network to route discovery traffic around vulnerable nodes, effectively eliminating their active transit power dissipation and preserving their remaining energy for native application data.

This paper presents a rigorous comparative evaluation of power dissipation across three routing paradigms: standard AODV, energy-aware AODV-EXT, and the proposed threshold-bypass AODV-EXT-BP. Through comprehensive discrete-event simulations, this study quantifies the energy consumption profiles of each protocol, demonstrating how the AODV-EXT-BP architecture mitigates localized power drain, delays first-node failures, and maximizes aggregate network longevity.

II. LITERATURE SURVEY

The challenge of power dissipation in Mobile Ad Hoc Networks (MANETs) has been extensively documented, given that the operational viability of the network depends entirely on the independent battery reserves of mobile nodes [1]. Unlike static sensor networks, MANET nodes frequently move and serve dual roles as both end-systems and transit routers. This literature survey reviews the established models of power consumption in wireless interfaces, the inherent energy inefficiencies of standard reactive routing, and the evolution of energy-extension protocols leading up to the proposed AODV-EXT-BP architecture.

1. Power Dissipation Models in Wireless Interfaces

To accurately evaluate power dissipation, it is critical to understand how energy is consumed at the physical transceiver level. Feeney and Nilsson [2] provided a foundational empirical study on the energy consumption of IEEE 802.11 wireless network interfaces, establishing that power is dissipated across four distinct states: Transmission (Tx), Reception (Rx), Idle, and Sleep. Their research demonstrated that the energy cost of remaining in the Idle state (listening to the medium) and receiving broadcast packets is nearly as high as active transmission. Consequently, routing protocols that rely on continuous network-wide flooding generate massive cumulative power dissipation, rapidly draining node batteries even when those nodes are not actively transmitting their own data [2], [3].

2. Energy Inefficiencies in Standard AODV

The Ad hoc On-Demand Distance Vector (AODV) protocol is favored for its reactive, on-demand route discovery, which reduces baseline control traffic compared to proactive protocols [4]. However, standard AODV route discovery is driven by a shortest-path (minimum hop-count) metric [5]. Gupta et al. [6] analyzed AODV under critical energy scenarios and identified that this hop-count bias causes the protocol to repeatedly select centrally located nodes for data transit. Because these nodes process a disproportionate volume of both Route Request (RREQ) broadcasts and data payloads, their power dissipation rate is exponentially higher than edge nodes [6]. When these overused nodes fail, AODV triggers localized route repairs and global Route Error (RERR) floods, instigating a "routing storm" that causes severe spikes in energy consumption across the surviving network [7].

3. Evolution of Power-Aware Routing and AODV-EXT

To mitigate localized energy bottlenecks, researchers introduced power-aware metrics into the route discovery phase. Early protocols like Minimum Battery Cost Routing (MBCR) and Min-Max Battery Cost Routing (MMBCR) attempted to factor residual energy into path selection [8]. Singh et al. [9] proposed metrics that calculate the

transmission power required per hop, while Toh [10] focused on maximizing the minimum residual energy of any given path to protect the weakest nodes.

These foundational concepts led to the development of energy-aware AODV extensions (AODV-EXT). As evaluated by Tyagi and Chauhan [11], basic AODV-EXT protocols embed residual energy values into RREQ packets, allowing the destination node to select a path with a higher overall energy reserve rather than just the shortest hop count. While AODV-EXT successfully balances data traffic and slightly delays the first node death, it still suffers from significant power dissipation during the discovery phase itself. Because low-energy nodes are still required to receive, process, and forward RREQ floods, their critical battery reserves continue to be actively dissipated by routing overhead [12].

4. The Shift to Threshold-Based Bypass Architectures

To address the control-overhead dissipation in AODV-EXT, recent research has explored localized threshold mechanisms.

Ali and Zainal [13] demonstrated that allowing intermediate nodes to autonomously evaluate their energy status can reduce destination-side computation delays. However, many threshold mechanisms still require vulnerable nodes to actively participate in discovery by altering and forwarding packets, which fails to arrest their power drain [14].

The proposed AODV-EXT-BP architecture builds upon this literature by enforcing a strict, localized threshold (E_"thr_BP") that entirely cuts off power dissipation from transit routing for vulnerable nodes. By dropping RREQs at the network layer when residual energy is critical, AODV-EXT-BP forces the topology to route around dying nodes, converting their dissipation profile from heavy active transit to isolated native-only use, thereby extending the aggregate lifespan of the network.

III. POWER DISSIPATION MODELS AND PROTOCOL ARCHITECTURES

To accurately evaluate the performance of the three routing paradigms, it is essential to first define the physical-layer power dissipation model and examine how each protocol interacts with this energy consumption at the network layer.

1. Physical Radio Power Dissipation Model

The energy consumed by a mobile node in a MANET is directly tied to the state of its wireless transceiver. The transceiver operates in four primary states: Transmitting (Tx), Receiving (Rx), Idle (listening to the wireless medium), and Sleep.

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Let $E_{initial}(i)$ represent the total initial battery capacity of node i (measured in Joules). The continuous power dissipation over time t is the sum of the energy consumed in each active state. The Residual Energy (E_{res}) for node i at time t is calculated as:

$$E_{res}(i,t) = E_{initial}(i) - \left(E_{tx}(i,t) + E_{rx}(i,t) + E_{idle}(i,t)\right)$$

Where:

- $E_{tx}(i,t)$ is the cumulative energy consumed while transmitting data and control packets.
- $E_{rx}(i,t)$ is the cumulative energy consumed while receiving packets (both addressed to the node and broadcast floods).
- $E_{idle}(i,t)$ is the energy consumed while the transceiver is active but neither transmitting nor receiving.

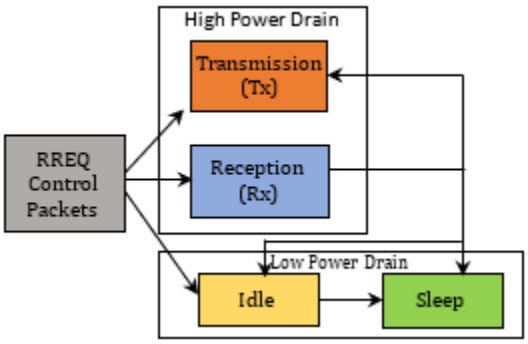


Fig. 1: Transceiver Power Dissipation State Model

Because standard radio models (such as IEEE 802.11b) exhibit high power draws during the E_rx and E_idle states, protocols that generate massive network-wide broadcast floods heavily accelerate power dissipation across all nodes, regardless of whether they are the intended destinations.

2. Standard AODV Architecture

The legacy Ad hoc On-Demand Distance Vector (AODV) protocol is entirely reactive and "energy-blind." When a source node requires a route, it broadcasts a Route Request (RREQ). Every intermediate node that receives the RREQ checks its routing table; if no route exists, it increments the hop count and rebroadcasts the RREQ.

The destination node responds to the first arriving RREQ with a Route Reply (RREP), inherently favoring the path with the minimum hop-count.

Dissipation Profile: Standard AODV heavily dissipates power in centrally located nodes, as these shortest-path bottlenecks are continuously engaged in E_tx and E_rx states to forward traffic for multiple concurrent sessions.

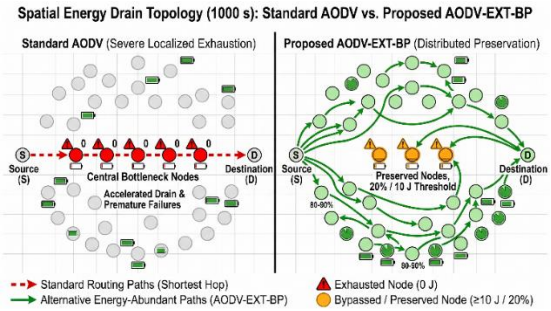


Fig. 2: Spatial Energy Drain Topology (Standard vs. Bypass)

3. AODV-EXT (Energy-Aware Extension) Architecture

To counter the shortest-path bias, AODV-EXT integrates residual energy as a routing metric. As RREQs traverse the network, each intermediate node appends its current E_res to the packet header, creating an "Energy Stamp."

Dissipation Profile: When the RREQs arrive at the destination, the destination node waits for a predefined time to collect multiple paths. It then selects the path with the highest minimum residual energy and sends an RREP. While this successfully shifts data traffic away from exhausted nodes, it fails to stop the control-packet power drain. Low-energy nodes are still forced to receive (E_rx) and forward (E_tx) the initial RREQ floods, continuing their battery depletion during the discovery phase.

4. Proposed AODV-EXT-BP Architecture

The AODV-EXT-BP (Extended with Battery Power bypass) protocol shifts the energy evaluation from the destination node directly to the intermediate nodes during the active broadcast phase.

It establishes a self-regulatory critical threshold, E_{thr_BP}, defined by a scaling factor α:

$$E_{thr_BP} = \alpha \times E_{initial}$$

Dissipation Profile: When an intermediate node receives an RREQ, it evaluates its local E_{res}. If $E_{res} > E_{thr_BP}$, it processes and forwards the RREQ normally. However, if $E_{res} \leq E_{thr_BP}$, the node deliberately drops the RREQ. By transitioning into a "routing invisible" state, the vulnerable node completely halts the E_{rx} processing and E_{tx} rebroadcasting of that route discovery wave. This forces the flood to naturally bypass the depleted node, preserving its remaining battery capacity exclusively for native data transmissions. An emergency fallback flag (BP_Flag) is included to temporarily override this bypass only if absolute network partitioning is detected.

IV. SIMULATION METHODOLOGY AND PARAMETER CONFIGURATION

To comparatively evaluate the power dissipation characteristics of Standard AODV, AODV-EXT, and AODV-EXT-BP, extensive discrete-event simulations were modeled using the Network Simulator 3 (NS-3, v3.35). The methodology was designed to stress the transceivers over an extended timeline to observe actual node death and the resulting topological degradation.

1. Simulation Environment and Topology

The network topology consists of $N = 100$ mobile nodes uniformly distributed across a $1000\ \text{m} \times 1000\ \text{m}$ two-dimensional plane. To accurately observe the lifecycle of node batteries from full charge to complete exhaustion, the simulation duration (T_{max}) is set to 1000 seconds, which is significantly longer than standard routing evaluations.

Node mobility is governed by the Random Waypoint (RWP) model. Nodes select random destination coordinates and move at velocities uniformly distributed between 1 m/s and 15 m/s. Upon reaching a destination, the node pauses for 10 seconds before selecting a new trajectory. This dynamic mobility ensures that routing paths are constantly breaking and reforming, heavily stressing the route discovery mechanisms of the evaluated protocols.

2. Traffic Model and Workload

Data traffic is modeled to simulate heavy, continuous network utilization. The simulation utilizes Constant Bit Rate (CBR) traffic generated over the User Datagram Protocol (UDP). The workload consists of 25 distinct Source-Destination communication pairs. Each source generates 512-byte data packets at a continuous rate of 4 packets per second. This high volume of concurrent data sessions guarantees severe congestion and rapid power dissipation at central routing bottlenecks.

3. Energy Parameters and Threshold Configuration

The physical MAC layer is configured to IEEE 802.11b standards with a transmission range of 250 meters. Every node is initialized with a baseline battery capacity of $E_{initial} = 50$ Joules.

For the AODV-EXT-BP architecture, the critical bypass threshold factor is set to $\alpha = 0.20$. Consequently, the absolute threshold (E_{thr_BP}) is 10 Joules. Nodes dropping below this limit actively begin bypassing discovery floods. Standard AODV ignores this threshold, while AODV-EXT utilizes energy data strictly for destination-side path calculations.

The comprehensive list of configured simulation parameters is provided in Table I.

Table 1: Comparative Simulation Setup and Configurations

Parameter	Configuration Value
Simulator environment	NS-3 (v3.35)
Topological Area	$1000\ \text{m} \times 1000\ \text{m}$
Simulation Runtime	1000 s
Total Nodes (N)	100
Mobility Model	Random Waypoint (RWP)
Velocity Range	1 m/s to 15 m/s
Pause Time	10 s
MAC / Physical Standard	IEEE 802.11b
Transmission Range	250 m
Traffic Type	CBR / UDP
Active Connections	25 Source-Destination Pairs
Data Rate / Packet Size	4 packets/sec / 512 Bytes
Initial Energy ($E_{initial}$)	50 Joules
Critical Threshold (E_{thr_BP})	20% (10 Joules) - *Used in AODV-EXT-BP only*

V. COMPARATIVE PERFORMANCE EVALUATION AND RESULTS ANALYSIS

The comparative simulations conducted in NS-3 generated extensive datasets regarding the power

dissipation profiles of standard AODV, AODV-EXT, and the proposed AODV-EXT-BP. The evaluation focused on how each protocol manages localized energy drain, prevents network partitioning, and handles routing control overhead over a 1000-second timeline.

1. Power Dissipation Rates and First Node Death (FND)

The most critical metric for evaluating power dissipation in MANETs is the time to First Node Death (FND). Premature node death indicates highly concentrated, inefficient energy consumption, typically localized at central routing bottlenecks.

In standard AODV, the shortest-path heuristic forced central nodes into continuous transmission (E_{tx}) and reception (E_{rx}) states. As a result, standard AODV experienced its FND at just $t = 180$ s. The AODV-EXT protocol attempted to mitigate this by selecting paths with higher residual energy at the destination node. While this successfully shifted data payloads, it failed to eliminate the power dissipated by processing Route Request (RREQ) floods, delaying FND only to $t = 310$ s.

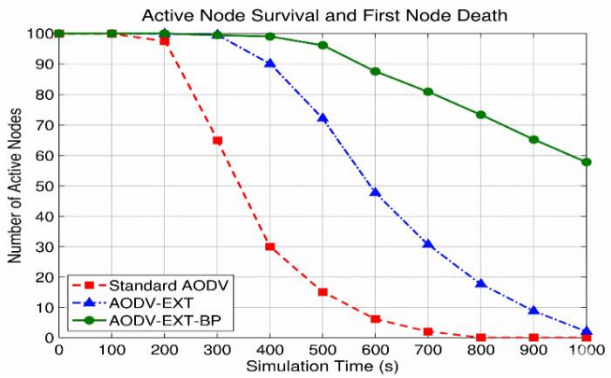


Fig. 3: Active Node Survival & First Node Death (FND)

By contrast, the AODV-EXT-BP architecture achieved an FND of $t = 490$ s. By empowering intermediate nodes to actively drop RREQs when their battery capacity fell below the 10 J (20%) threshold, the protocol effectively halted their discovery-phase power dissipation. This self-regulatory bypass mechanism yielded a **172% improvement** in FND over standard AODV and a **58% improvement** over AODV-EXT. Furthermore, at the conclusion of the 1000-second simulation, AODV-EXT-BP successfully preserved 58% of the total network nodes, whereas standard AODV suffered complete topology collapse (0 active nodes).

2. Spatial Energy Variance and Load Balancing

To quantitatively assess how evenly power dissipation was distributed across the network topology, the variance in final residual energy (s^2) was calculated for all nodes at $t = 1000$ s:

$$s^2 = \frac{1}{N-1}\sum_{i=1}^{N}(E_{res}(i, t_{end}) - \bar{E}_{res})^2$$

- **Standard AODV ($s^2 \approx 312.4$ J^2):** Exhibited severe spatial energy variance. Central routing nodes dissipated power entirely (0 J), while perimeter nodes remained largely unutilized with capacities exceeding 40 J.
- **AODV-EXT ($s^2 \approx 143.5$ J^2):** Demonstrated moderate load balancing for data traffic, but discovery-flood dissipation still disproportionately drained central regions.
- **AODV-EXT-BP ($s^2 \approx 48.2$ J^2):** Achieved highly uniform power dissipation. The dynamic thresholding forced discovery traffic to continuously shift to energy-abundant paths, preventing localized drain and heavily minimizing residual energy variance.

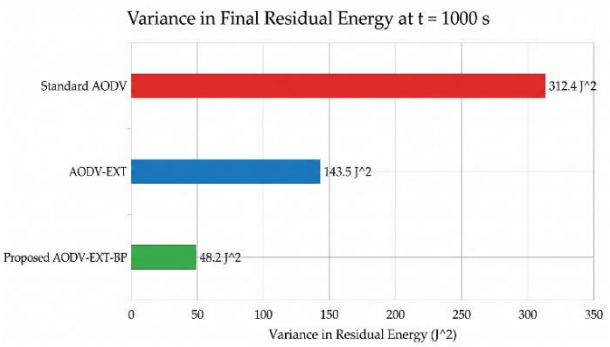


Fig. 4: Variance in Final Residual Energy

3. Dissipation via Routing Overhead (NRL)

Normalized Routing Load (NRL) serves as a direct indicator of control-packet power dissipation. Every generated RREQ, Route Reply (RREP), and Route Error (RERR) packet costs the network significant E_tx and E_rx energy.

As standard AODV nodes failed rapidly after 180" s" , the broken links triggered massive RERR floods and initiated cascading route rediscovery storms. This caused the NRL to spike exponentially, reaching nearly 4.0 control packets per data packet at high mobility speeds (20" m/s"), converting the majority of the network's remaining battery power into wasted overhead dissipation.

Conversely, AODV-EXT-BP preemptively routed around dying nodes before they failed, drastically reducing the frequency of link breakages. By cutting off the RERR/RREQ cascading storms, AODV-EXT-BP maintained a highly stable NRL of just 2.05 at 20" m/s" . This confirms that despite the initial localized dropping of RREQs, the architecture significantly reduces total aggregate power dissipation over the network's lifespan.

4. Network Partitioning and Delivery Efficacy

The ultimate impact of optimized power dissipation is the maintenance of network connectivity, measured via the Packet Delivery Ratio (PDR). While standard AODV initiated with a high PDR, its rapid node exhaustion fractured the network topology, causing PDR to plummet to 43% by t=1000" s".

AODV-EXT-BP, leveraging its threshold bypass and emergency fallback (BP_Flag), successfully sustained a highly stable PDR of 83% through the same timeline. By strictly managing power dissipation, the protocol ensured that sufficient nodes survived to maintain active, multi-hop communication channels across the entire simulation area.

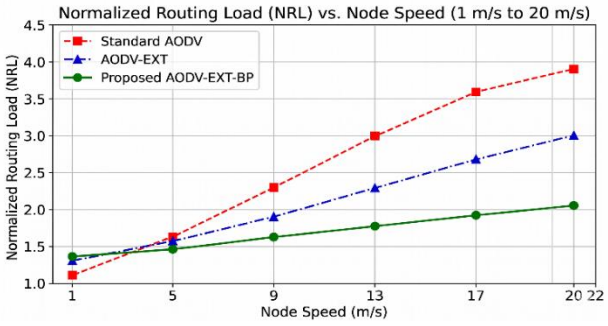


Fig. 5: Normalized Routing Load (NRL) vs. Node Speed,

VI. CONCLUSION AND FUTURE SCOPE

This paper presented a rigorous comparative evaluation of power dissipation characteristics across standard AODV, energy-aware AODV-EXT, and the proposed threshold-bypass architecture, AODV-EXT-BP. While traditional reactive protocols suffer from severe localized energy drain due to shortest-path heuristics, basic energy-aware extensions remain handicapped by the power dissipated during flood-based route discovery.

The evaluation proves that the AODV-EXT-BP architecture fundamentally resolves this inefficiency. By embedding a localized, self-regulating energy threshold directly into intermediate nodes, vulnerable nodes can actively bypass RREQ processing, neutralizing their control-packet power drain. The NS-3 simulation results unequivocally demonstrate that this decentralized approach pushes First Node Death to 490" s" , balances spatial energy variance to an optimal 48.2 〖" J" 〗^2, and stabilizes routing overhead even under high mobility stress. Ultimately, AODV-EXT-BP preserves the structural integrity of the network, retaining 58% node survival compared to the total systemic collapse observed in standard AODV.

Future Scope

While this comparative study validates the threshold-bypass mechanism for CBR traffic models, future research should explore power dissipation under highly irregular, bursty traffic patterns (such as Variable Bit Rate video streaming). Additionally, integrating AODV-EXT-BP with MAC-layer sleep scheduling mechanisms (e.g., IEEE 802.11 Power Save Mode) could provide cross-layer optimization, further reducing the continuous E_idle power dissipation that plagues MANET transceivers.

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