

# ENERGY EFFICIENT ROUTING PROTOCOLS FOR WIRELESS AD HOC NETWORKS – A SURVEY

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## **Abstract**

*Reducing energy consumption, primarily with the goal of extending the lifetime of battery-powered devices, has emerged as a fundamental challenge in wireless communication. The performance of the medium access control (MAC) scheme not only has a fairly significant end-result on the behaviour of the routing approach employed, but also on the energy consumption of the wireless network interface card (NIC). We investigate the inadequacies of the MAC schemes designed for ad hoc wireless networks in the context of power awareness herein. The topology changes due to uncontrollable factors such as node mobility, weather, interference, noise, as well as on controllable parameters such as transmission power and antenna direction results in significant amount of energy loss. Controlling rapid topology changes by minimizing the maximum transmission power used in ad hoc wireless networks, while still maintaining networks connectivity can prolong battery life and hence network lifetime considerably. In addition, we systematically explore the potential energy consumption pitfalls of non-power-based and power based routing schemes. We suggest a thorough energy-based performance survey of energy aware routing protocols for wireless mobile ad-hoc networks. We also present the statistical performance metrics measured by our simulations.*

## **Keywords:**

*Mobile Ad Hoc Network; Energy Efficient Routing; Transmission Power Control; Routing Protocols; Performance Metrics*

## **1. INTRODUCTION**

In wireless ad-hoc networks, the nonexistence of a centralized authority compounds the problem of medium access control. The centralized medium access regulation practices endeavoured by base stations in cellular networks have to be administered in a distributed, and hence collaborative, fashion by mobile stations. Mobile stations may compete simultaneously for medium access. Consequently, transmissions of packets from distinct mobile terminals are more vulnerable to overlap, eventually resulting in packet collisions and energy losses.

In addition, the performance of the MAC scheme has an outstanding influence on the performance of the routing method employed and on the energy consumption of the wireless network interface card (NIC). Routing is one of the key issues in MANETs due to their highly dynamic and distributed nature. The on-demand routing algorithms initiate to find out the suitable route when a route is requested [1]. The pro-active routing algorithm exchanges routing information periodically and generates the routing table in advance of route request [2]. These protocols select the routes based on the metrics of minimum hop count.

The mobile nodes in wireless ad-hoc networks are typically battery powered and hence, energy efficient routing is of paramount significance in the design of such networks. Power

failure of a wireless node not only affect the node itself radically, but also its capability to forward packets on behalf of others and thus the overall network lifetime [3]. Many research efforts have been dedicated to extend the mobile node battery capacity which includes communication energy consumption and Non communication energy consumption. During communication, energy is consumed in either inactive state of communication or active communication states.

The energy consumption of active communication is more significant than the others for high-traffic environment. Energy efficient routing protocols are designed to formulate energy efficient active communications. Energy efficient active communications prolong the network life time. The network life time is defined as the time when a node runs out of its own battery power for the first time [4, 5]. The energy efficient routing protocols should consider the power consumption from the perspectives of both the network and the node.

This paper is organized as follows. Section 2 briefs background of the paper. Section 3 analyses the problems with MAC protocol for ad-hoc networks and discusses their inadequacies in the context of power awareness. Sections 4 and 5 brief the impact of topology changes and transmission power on energy conservation. Section 6 and 7 demonstrates a thorough comparative study of routing schemes for ad-hoc networks. Finally, Section 8 presents the conclusions. Recommendations for power-efficient protocol design in ad-hoc networks are also discussed.

## **2. RELATED WORK**

Main emphasis of research on routing protocols in wireless ad Hoc networks has been the energy efficiency, delivery of packets, network performance and network lifetime. There has been very less amount of work have done on energy efficient routing schemes, though it is very important aspect in route discovery, route selection, route maintenance and performance of protocol. Major impact on energy awareness needs a more detailed review of MAC scheme adopted for transceiver, transmission power control to maintain network topology, choice of routing protocols and routing algorithms. Some study has been done in this context and presented is a brief review of them.

## **3. IEEE 802.11 MAC PROTOCOL AND ENERGY EFFICIENCY**

The IEEE 802.11 protocol is widely used in wireless ad hoc networks. It is based on carrier sense multiple access (CSMA) technique with additional collision avoidance (CA) feature. When a node has data to transmit, it first senses the medium. If it

finds the medium idle, the node waits for a random back off period as a result of the CA feature. During this period, if the channel becomes busy, the node freezes its counter until the medium becomes idle again. When the counter runs out, RTS/CTS handshake takes place followed by data transmission. Medium access control (MAC) is a serious problem in ad hoc networks. Since ad hoc networks are wireless and mobile networks, their MAC protocols need more sophisticated methods in order to solve issues like the hidden terminal and the exposed node problems [7]. However, 802.11 were proposed for fully connected wireless networks and do not perform well in multi hop ad hoc networks [8]. In [6], the authors found the following problems implanted in the MAC layer:

- TCP instability - The interactions between different nodes carrying TCP-data and TCP-ACK traffic causes throughput of only one TCP connection existing in the network time and again reaching zero or was near zero. The hidden terminal stimulates collision and the exposed terminal prevents the intermediate node from sending a CTS message. Hence, the node obstructed reaching its neighbour. The link is repeatedly broken in the middle of the route and using smaller maximum window size can diminish or clear this problem.
- Neighboring Node One-hop unfairness: If two TCP connections exist in the network, one session may be entirely shut down and have no opportunity to restart in some circumstances even if it starts much earlier. This problem cannot be deciphered by balancing the window size.
- Incompatibility between two TCP sessions: Two TCP sessions cannot coexist in the network at the same time, and the turnover time is totally random, which is brought about by the exposed node problem. It cannot be solved by adjusting TCP parameters.

[9] Proposes an adaptive RTS/CTS mechanism to reduce the unfairness caused by IEEE 802.11. In an adaptive RTS/CTS scheme, a node will turn off RTS/CTS when the number of waiting for CTS timeout events exceeds a threshold. The counting number is updated in a sliding window fashion. The simulation results show that this adaptive mechanism can significantly improve the fairness both for UDP and TCP transmission. [10] Explores the RTS/CTS issue even further. At first CTS/RTS may cause a blocking problem, as illustrated in Fig.1 [10]. Node B is sending packets to node A. Node C receives both RTS and CTS, so it will stop transmitting. If at this time node D sends RTS to node C, node C cannot reply with CTS, finally node D will enter the exponential backoff mode. In this scenario, node C need not be either a hidden node or an exposed node as Fig.1 shows, because it can receive both RTS and CTS. In the current implementation of the RTS/CTS mechanism, when a node received an RTS packet not addressed to it, it is required to stop transmitting.

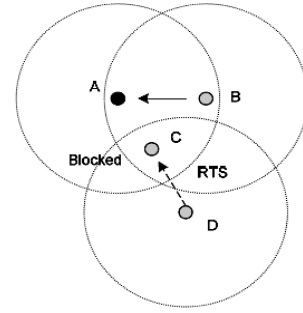


Fig.1. Node Blocking Problem

In the blocking problem scenario, these nodes neighboring to the blocked node may be falsely blocked, and even worse, the false blocking may spread through the network until some event like the packet drop breaks this kind of pseudo-deadlock. [10] Proposes a solution to the false blocking problem. The basic idea is RTS validation: when a node hears RTS, which is not addressed to it, it will defer a certain amount of time to check if there are really data packets in transmission. If the medium is still idle, which means that false blocking may happen, it will not defer any more. The simulation results show these solutions can significantly improve the battery life and throughput.

#### 4. TOPOLOGY CONTROL AND ENERGY EFFICIENCY

The topology of a multi-hop wireless network is a set of relationships between node pairs that are linked directly or via multi-hops. Transmission power, node mobility, signal attenuation, noise, climate conditions and direction of antenna stimulate rapid topology changes in wireless ad-hoc networks. Almost all the studies focus on structuring a desired topology by fine-tuning the transmission power. Topology control of ad-hoc networks preserves the network capacity, considerably improves the end-to-end packet delay, and lowers the node failure rates. For instance, if the topology is too sparse, routing requests may be deliberately obstructed due to the network partitioning. Furthermore, end-to-end delays may be very high. On the other hand, if the topology is too dense, nodes may run out of their energy quickly and may escalate interference among them. Networks that do not employ topology control are likely to be in one of these modes, which results in short battery life of nodes, and/or poor connectivity.

#### 5. TRANSMISSION POWER CONTROL AND ENERGY EFFICIENCY

Many studies on topology control aim to minimize the maximum transmission power used in ad hoc wireless networks, while still maintaining network's connectivity. For static networks, optimal centralized algorithms were proposed. The basic interpretation of the algorithms is to add links one by one in non-decreasing order according to their distance. For mobile networks, two distributed heuristics called the neighbor reduction protocol and the neighbor addition protocol are used to adjust node transmission powers in response to topology changes. If a route update reveals that a link failure has occurred such that the network is no longer connected, the appropriate

nodes increase their transmission power until it is connected. This technique relies heavily on routing protocol performance, because changes in network connectivity can initiate further routing updates and hence more energy loss.

## 6. ROUTING PROTOCOLS AND ENERGY EFFICIENCY IN AD-HOC NETWORKS

A mobile Ad-Hoc network is a co-operative network of wireless nodes that communicate over a wireless medium. Topology changes of the wireless nodes in the network are rapid, and these networks are self-configuring in nature requiring de-centralized control and administration. Such networks do not surmise all the nodes to be in the direct transmission range of each other. Hence, these networks require highly specialized routing protocols that significantly contribute self-starting behavior. Energy constrained nodes, low channel bandwidth, node mobility, high channel error rates, and channel variability

are some of the limitations in an Ad-Hoc network. Under these conditions, existing wired network routing protocols would fail or perform poorly. Thus, Ad-Hoc networks necessitate special routing protocols. Ad Hoc routing protocols are conveniently categorized based on the way route tables are constructed, maintained, and updated [11]. Fig.2 shows the broad classification of MANET routing protocols.

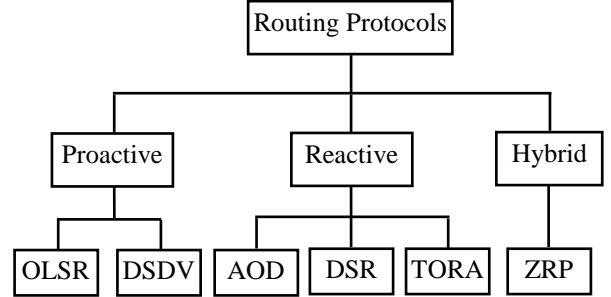


Fig.2. Classification of Routing Protocols

Table.1. Comparison of several routing protocols

Protocol	Reference	Cost Metric	Max. Network Life Time	Min. Energy Consumption
<b>Power Aware Source Routing (PSR)</b>	[14]	$\sum_{ier}^n \rho_i \left( \frac{F_i}{R_i(t)} \right) \alpha$	■	■
<b>Minimum Drain Rate (MDR)</b>	[15]	$\frac{min}{ier} = \frac{RBP_i}{DR_i}$	■	□
<b>Min-Max Battery Cost Routing (MMBCR)</b>	[16]	$R_j = \frac{max}{ieroute\_j} \frac{1}{c_i^t}$	■	□
<b>Minimal Battery Cost Routing (MBCR)</b>	[16]	$R_j = \sum_{i=0}^{D_j-1} \frac{1}{c_i^t}$	■	□
<b>Michail and Ephremides</b>	[17]	$\sum_{(i,j) \in R} W_p \frac{P_{ij}}{P_{max}} + W_e \frac{E_j^o}{E_j^R}$	■	■

### 6.1. PROACTIVE (TABLE-DRIVEN) ROUTING PROTOCOLS.

In proactive routing, each node has one or more tables that contain the latest information regarding the routes to any node in the network. Each node has the next hop for reaching to a node/subnet and the cost of this route. Various table-driven protocols differ in the way the information about change in topology is propagated through all nodes in the network. The two kinds of table updating in proactive protocols are the periodic update and the triggered update [12]. In periodic update, each node periodically broadcasts its table in the network. Each node just arriving in the network receives that table. In triggered update, as soon as a node detects a change in its neighborhood node, it broadcasts entries in its routing table that have been changed.

Examples of this class of Ad Hoc routing protocols are the Destination-Sequenced Distance-Vector (DSDV) [2] and the Wireless Routing Protocol (WRP) [13]. Proactive routing tends to waste bandwidth and power in the network because of the

need to broadcast the routing tables/updates. Furthermore, as the number of nodes in the MANET increases, the size of the table will increase; this can become a problem, in and of itself. In addition, it needs to control traffic for continual update of stale route entries. Unlike the Internet, an Ad-Hoc network may contain mobile nodes, and therefore links are continuously broken and re-established.

### 6.2 REACTIVE (ON-DEMAND) ROUTING PROTOCOLS

Reactive routing protocols take a sluggish approach to routing. They do not maintain or constantly update their route tables with the latest network topology changes. Instead, when a source node wants to transmit a message, it floods a query into the network to discover the route to the destination. This discovery packet is called the Route Request (RREQ) packet, and the mechanism is termed Route Discovery. The destination replies with a Route Reply (RREP) packet. As a result, the source dynamically finds the route to the destination. Discovered route is maintained until the destination node becomes unreachable or

until the route is no longer needed. This class of protocol differ in handling cache routes, and in the way route discoveries and route replies are handled. Reactive protocols are generally considered efficient when the route discovery is employed rather infrequently in comparison with the data transfer. Although the network topology changes dynamically, the network traffic caused by the route discovery process is low compared to the total communication bandwidth.

Table.2. Comparison of several routing protocols

Properties	AODV	DSR	DSDV	TORA /IMEP
<b>Reactive</b>	Yes	Yes	No	Yes
<b>Multiple Routes</b>	No	Yes	No	Yes
<b>Power Conservation</b>	No	No	No	No
<b>Unidirectional Link Support</b>	No	Yes	No	No
<b>Multicast</b>	Yes	No	No	No
<b>Periodic Broadcast</b>	Yes	No	Yes	Yes

Examples of Reactive routing protocols are the Dynamic Source Routing (DSR) [9, 1], the Ad Hoc on-demand Distance Vector Routing (AODV) [18] and the Temporally-Ordered Routing Algorithm (TORA) [19]. Since the route to destination will have to be acquired just before communication begins, the latency period for most applications is likely to increase drastically.

### 6.3 HYBRID ROUTING PROTOCOLS

Both the proactive and reactive protocols work well for networks with a relatively small number of nodes. As the number of nodes increases, hybrid protocols are used to attain higher performance. The key idea is to use a reactive routing procedure at the global network level while operating a proactive routing procedure in a node's local neighbourhood. Zone Routing Protocol (ZRP) [9] is an example of the hybrid routing protocols. Table.2 presents a comprehensive comparison of various routing protocols properties for the wireless ad-hoc networks.

### 6.4 ENERGY EFFICIENCY OF TABLE-RIVEN vs. SOURCE-INITIATED PROTOCOLS

Table-driven protocols have the overhead of route updates with no consideration to the frequency of forwarding packets that take place in the Ad-Hoc network. The routing information is constantly propagated within the network. With on-demand protocols, routing information is exchanged only when the source wishes to send some information to the destination and has no information about the destination in its route cache. On the other hand, since routing information is constantly propagated and updated in table-driven protocols, information about a particular source-destination route is always available regardless of whether or not this information is required. This feature leads to significant signalling overhead and power consumption. Since both battery and bandwidth are scarce resources in Ad-Hoc networks, this becomes a serious limitation. Table.1 presents some of the metrics for power-aware routing that addresses maximizing the lifetime of wireless networks and minimizing power consumption for packet delivery. From the discussion of table-based protocols provided in Section 6.1 and

on-demand protocols demonstrated in Section 6.2, table-based protocols incur significantly high routing overhead and hence lead to increase the energy consumption compared to the on-demand protocols.

## 7. SIMULATION RESULTS

Following are the simulation results of our work with a network simulator. Fig.3 and Fig.4 shows the amount of data dropped of the three routing protocols when applied in a mobile 15-node and 30-node network topology. Low data drop shows that both DSR and TORA routing protocols maintain many routes to the same destination.

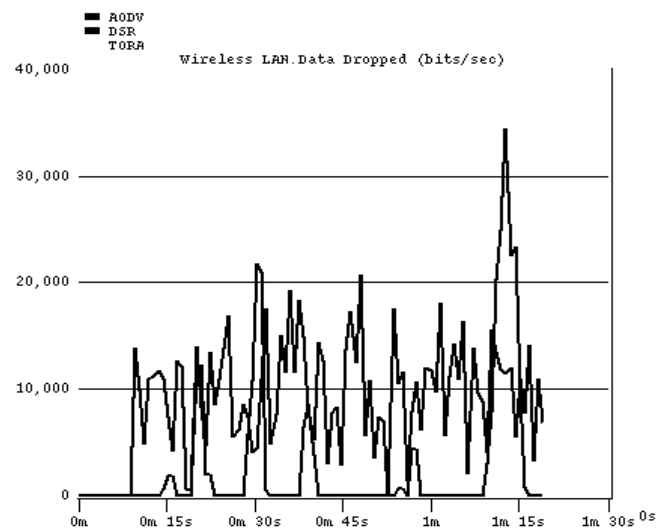


Fig.3. Data dropped with 15 Nodes

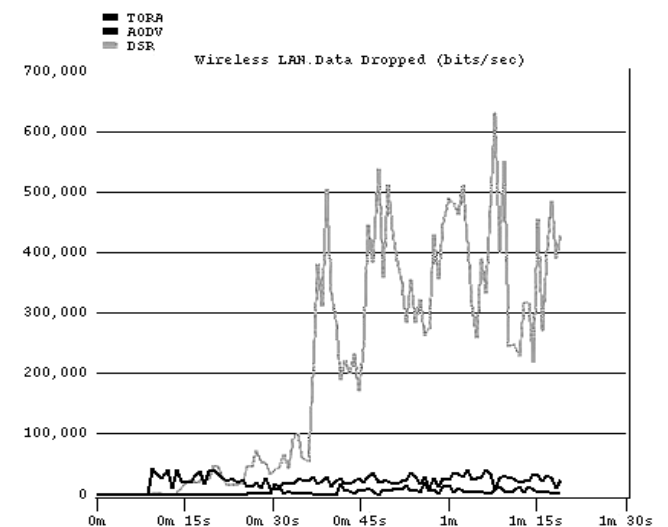


Fig.4. Data dropped with 30 Nodes

The packet can still be delivered to its destination, in the event of a link failure. On the other hand, AODV keeps only one route to a destination and therefore, a link failure must initiate route discovery to the destination node. While the route discovery process is underway, an increasing number of nodes are being dropped.

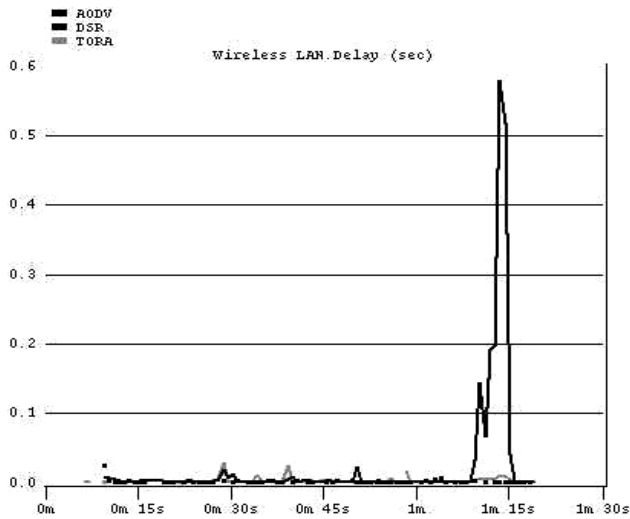


Fig.5. Delay for 15 Nodes

TORA routing protocol has the lowest level of data dropped (bits / second) followed by DSR, which is almost near the performance of TORA protocol. AODV has the greatest level of data dropped because it does not support several routes for destination nodes as DSR and TORA routing protocols do. Therefore, with node mobility, a lot of routes will be broken, and some packets will be dropped until the route is rediscovered.

Fig.5 presents the delay encountered by the three routing protocols during the simulation period in a 15-node mobile topology. DSR routing protocol encounters most of the delay during the simulation than AODV and TORA. As the number of mobiles is increasing DSR protocol performs worst than AODV and TORA as shown in Fig.6.

general, TORA routing protocol performed moderately because the TORA routing protocol does not scale well with relatively large networks, and it is designed for networks with mobile nodes moving at a moderate speed.

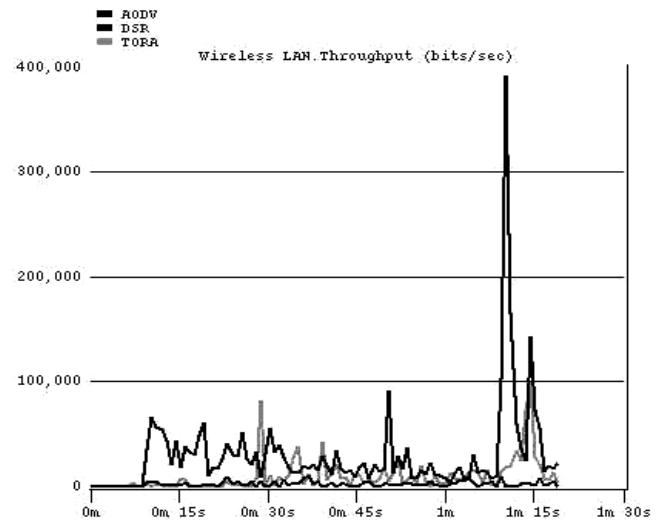


Fig.7. Throughput 15 Nodes

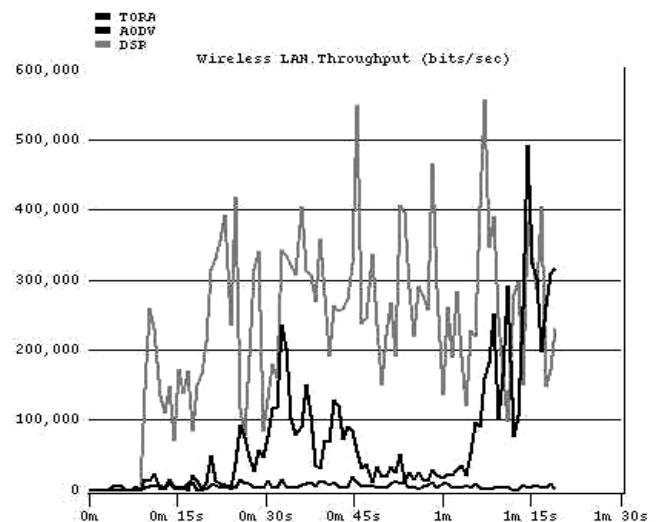


Fig.8. Throughput 30 Nodes

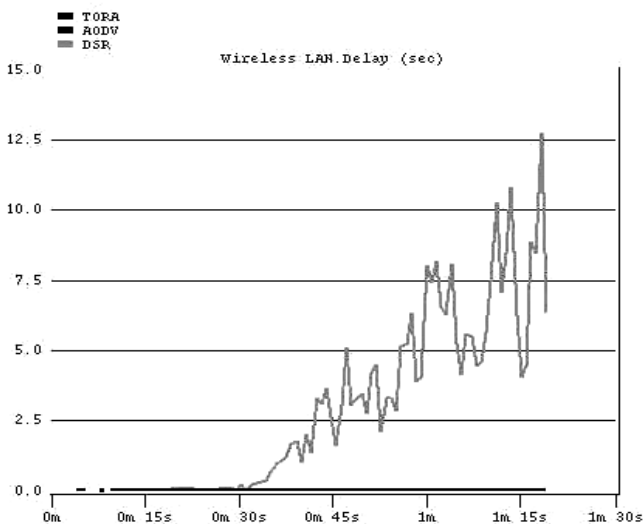


Fig.6. Delay for 30 Nodes

Fig.7 and Fig.8 represents the throughput of the routing protocols across the simulation time. As shown AODV experiences the lowest throughput since, it requires discovering the route to the destination, especially in a mobile network. However, packets can be easily delivered in the case of DSR and TORA, as more than one route to the destination present either in route tables of TORA or in the cache of DSR. In

## 8. CONCLUSION

The performance of three source-initiated routing protocols that are AODV, DSR and TORA routing protocols were closely examined. Even if energy efficiency is not the design targets of these routing protocols, each routing protocol behaved in a different way with energy aware metrics. This is due to the route discovery and maintenance mechanisms of the routing protocols. The simulation results revealed that TORA exceeds AODV and DSR in energy per packet consumption. The network lifetime of TORA is also better than DSR and AODV. This indicates that less energy consumption does not prolong the network lifetime by itself. So, it is an indication that energy efficient routing protocols must include battery energy level aware load balancing. Each routing protocol exhibited better performance in specific scenarios and metrics. In general, TORA

outperforms in the majority of scenarios and metrics. Hence we conclude that TORA is more energy-efficient than DSR and AODV with better performance.

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