A Performance Analysis of Energy Efficient Routing In Mobile Ad Hoc Networks

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Abstract- **A mobile ad hoc network is characterized by constraints such as limited bandwidth, energy constraints, less memory and processing capabilities. Also MANET's are required to be deployed under scalable conditions for some applications. A routing protocol is a central to the design of such networks. In this paper we compare the energy conservation of proactive routing protocols like DSR and AODV. As DSR is a multipath source based aggressive cache routing, it has some advantages in terms of energy savings. AODV is a more robust protocol and we complement its energy conservation by integrating cross-layer energy saving extensions i.e. SPAN. Thus we would like to analyze whether energy based extensions can contribute in supporting a robust routing protocol by reducing the energy consumption of mobile nodes for improved network survivability. Also we analyze the energy conservation of nodes under scalable conditions and for different traffic patterns.**

Keywords- Ad Hoc Network; Routing Protocol;Medium Access Layer; Energy Efficiency; Scalability

I. INTRODUCTION

Mobile ad hoc networks (MANET's) consist of nodes which move arbitrarily and form dynamic topologies. MANET's exhibit characteristics like limited bandwidth, energy constraints, mobility, scalability and limited security [1]. Communication networks exhibit scale economies. That is, the average cost per user of the network declines as the network increases in size, measured by number of users, or host computers [2]. The scalability of wireless ad hoc network poses many challenges Most of these characteristics are handled by a routing protocol which is central to the design of ad hoc networks. The primary goal of a routing protocol is efficient route establishment between a pair of nodes. An equally important critical goal is to conserve energy of nodes for the survivability of network as critical nodes may finish their battery power and may become unavailable for routing, thus leading to broken links and adversely affecting routing protocol performances. Although energy awareness can be implemented as a part of routing protocol at the network layer, it is equally important to complement it with coordination from other layers such as MAC [3].

Thus in this paper we use SPAN [5] a power saving mechanism that reduces energy consumption of nodes by retaining the capacity and coordinating with the underlying MAC layer. At the network layer we use the AODV and DSR protocol for comparison. AODV an example of reactive routing protocol is suitable when traffic diversity i.e. number of active connections is more and is also a robust protocol as compared to other protocols. It is seen that AODV generally consumes more energy than DSR [4]. Thus in this paper we would like to improve the energy conserving capabilities of AODV by integrating it with SPAN, a cross layer energy saving mechanism. We would also like to measure performance based efficiency of AODV with energy related metrics.

The rest of the paper is organized as follows. In Section II we introduce SPAN and IEEE 802.11 PSM. In Section III we discuss MANET routing protocols DSR, AODV followed by the energy related metrics and mobility model used Section IV discusses about the simulation environment and the associated results. Section V discusses some of the related work. Section VI concludes the work.

II. SPAN DESIGN ISSUES

The SPAN protocol operates between the routing layer and the MAC layer. SPAN tries to exploit MAC layer's power saving features [5]. The routing layer uses information SPAN provides for energy efficient routing. The basic power saving mechanism of MAC is to power down (sleep) the radio device when it has no data to transmit or receive, thus contributing substantial saving in power consumption. The working of SPAN is as illustrated in Fig 1.

Network Layer	DSR	AODV
SPAN		
Data Link Layer	802.11	

Fig. 1 SPAN provides an interface between Network Layer and Data Link Layer

SPAN works with the underlying assumption that when a region of shared-channel wireless network has enough density of nodes, only a small number of them need to be "power on" at any time to forward traffic for active connections. It achieves this by selecting coordinators that must be awake all the time and periodically send a beacon packet to non-coordinators or slave nodes. Each non-coordinator wakes up at beacon times and if addressed receives data or else sleeps again. SPAN uses a feature of MAC where nodes asleep do not lose packets, but are buffered in an upstream neighbor

The SPAN protocol makes the information of coordinators available to the network layer, forming them as a routing backbone, routing the forward traffic in MANET. A non-coordinator node should become a coordinator if it discovers that two of its neighbors cannot reach each other directly or through other coordinators. To avoid several nodes becoming coordinator simultaneously and redundantly, a node delays announcing itself as a coordinator by a random amount of time.

A. IEEE 802.11 Power Saving Mode

The power save mode (PSM) of IEEE 802.11 provides low-level support for buffering packets for sleeping nodes and synchronized nodes. Here all nodes are synchronized to wake up at the beginning of a beacon interval. A beacon period starts with an ad hoc traffic indication message window (ATIM window), where all node are listening and pending traffic transmission are advertised. After the ATIM window, nodes can transmit buffered broadcast or unicast packets to the nodes that are awake. Since the traffic cannot be transmitted during the ATIM window, the channel capacity is reduced.

The 802.11 PSM suffers from long packet delivery latency [5]. Also if a node cannot send an indication message to wake up a destination, it must buffer its packets until the next beacon interval. If this continues to happen, the nodes buffer eventually fills up and packets will be dropped [6].

III. MANET ROUTING PROTOCOLS

Routing protocols in mobile ad hoc networks can be classified as table-driven and on-demand. On-demand protocols include ad hoc on demand distance vector routing (AODV) and dynamic source routing (DSR).

A. DSR

This routing protocol uses packet forwarding via source routing and aggressively uses route cache to store full paths to the destination. Thus in DSR the sender knows the complete hop-by-hop route to the destination [7], [8]. DSR makes packet routing trivially loop-free. It also avoids the need for up-to date routing information at the intermediate nodes and also allows nodes to cache routes by overhearing data packets.

The main advantage of DSR is that it does not make use of periodic routing advertisements, thus saving bandwidth and reducing power consumption. Also if a link to a route is broken, the source node can check in its cache for another valid route [9].

These factors contribute to energy conservation and savings in DSR. Also the assumptions for the DSR protocol is that it operates in a network which has a relatively small diameter and the mobile nodes can enable promiscuous receive mode

B. AODV

AODV [10], [11] shares DSR's on-demand characteristics and discovers routes as needed on demand basis via similar route discovery process. AODV uses traditional routing tables and maintains one entry per destination. Being a single path protocol, it has to invoke a new route discovery, whenever the path from source to destination fails. AODV uses destination sequence numbers to prevent routing loops and to determine freshness of routing information. AODV also uses a timer-based route expiry mechanism to promptly remove stale routes. If a low value is chosen for timeout, valid routes may needlessly be discarded.

When the topology changes frequently, route discovery needs to be initiated often which can be inefficient as route discovery flooding is associated with overheads which can cause significant energy consumption. Also AODV is suitable when traffic diversity (number of active connections) increases, a condition with which DSR is not able to cope.

C. Performance Analysis Metrics

The following metrics were used to evaluate the performance analysis of routing protocols under consideration.

· Data packet delivery ratio: The data packet delivery ratio is the ratio of the number of packets generated at the source to the number of packets received actually by the destination. This metric is used so that we can analyze that network capacity is not reduced by the use of energy extensions to MAC protocol.

· Energy efficiency: is defined as total number of bits transmitted / total energy consumed, where the total bits transmitted is calculated using application layer data packets only and total energy consumption is the sum of each node's energy consumption during the simulation time. The unit of energy efficiency is bit/Joule and greater the number of bits per joule, the better the energy efficiency achieved.

D. Random Waypoint Mobility Model.

The performance analysis of routing protocol for MANET includes its evaluation under realistic conditions and this includes movements of mobile users (i.e. mobility model). In our paper we consider the random waypoint mobility model. The random waypoint mobility model is considered as one of the most widely used models for research. In a survey [12] it was concluded that 64% of simulations used random waypoint models. We have used the model as provided in the NS-2 [13] simulator. In this model, a mobile node moves from its current location to a randomly chosen new location within the simulation area, using a random speed uniformly distributed between [Vmin, Vmax]. Vmin refers to the minimum speed of simulation. Vmax refers to the maximum speed. Upon reaching the destination, the node stops for a specific duration defined by the pause time and then chooses a new destination.

IV. SIMULATION ENVIRONMENT AND RESULTS

NS-2 Simulator ver 2.28 from [13] has been used for simulating the energy consumption of AODV and DSR protocol. The SPAN extensions to IEEE 802.11 MAC module was integrated with the NS-2 simulator. The energy model values for energy consumption where taken form [5] and are given in TABLE I.

TABLE I. Energy Consumption Model

Tx	Rx	Idle	Sleeping
1400mW	1000mW	830mW	130mW

The simulation parameters for analyzing the performance of AODV and DSR for various metrics are as given in TABLE II. Continuous bit rate (CBR) traffic sources were used and generated using cbrgen.tcl provided by NS-2.

TABLE II. SIMULATION PARAMETERS FOR ENERGY BASED PERFORMANCE ANALYSIS OF AODV AND DSR ROUTING PROTOCOLS

NS-2 Simulator Version	NS 2.28
Topology size	500 X 500
Mac Layer	802.11
MAC Layer Interfaces	SPAN
Number of Nodes	50
Protocols under test	AODV, DSR
Simulation Duration	900 sec
Initial Energy allocated to each nodes	300 Joules
Transmit Power Consumption	1400mW
Receive Power consumption	1000mW
Idle Power Consumption	830mW
Sleep Power Consumption	130mW
Mobility Model	Random Waypoint
Mobility Pause Time	0, 10, 20, 30 and 40 sec
Traffic Patterns	UDP
Data Rate	4.0 kbps
Number of Sources	20
Maximum speed of nodes	20

The different mobility scenarios was generated using the setdest tool provided by NS-2

A. *Simulation Results*

The energy conservation capabilities of DSR and AODV were simulated initially. The graph depicting the same for 10 nodes is as shown in Fig 2 (see also page 7).

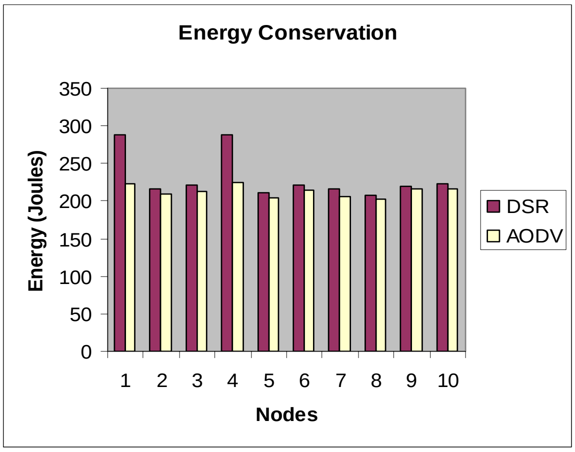

Fig.2 Energy Conservation in AODV and DSR

From Fig 2 it is clear that DSR has energy conservations advantages over AODV as it is a multipath, aggressive cached source routing protocols. Thus in order to improve the performance of AODV, we integrate SPAN to NS-2 simulator and carried out the following simulations to measure packet delivery ratio and energy efficiency.

The Fig. 3 (see also page 7) shows the packet delivery ratio of AODV over different mobility speeds and with PSM and SPAN capabilities.

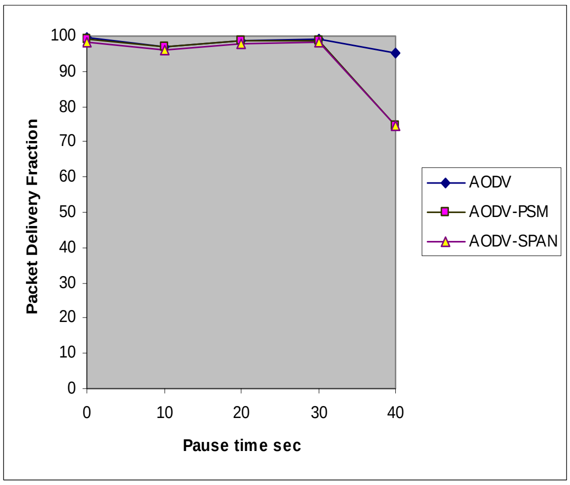

Fig.3 Packet delivery ratio for AODV.

The packet delivery ratio is more or less the same in AODV, AODV with PSM and AODV with SPAN. At pause time of 40 seconds there is a slight fall in the packet delivery ratio value for AODV-PSM and AODV-SPAN. This clearly means that there is no significant degradation in capacity with the use of PSM and SPAN extensions.

The next performance metric energy efficiency analysis is illustrated in Fig. 4 below (see also page 8).

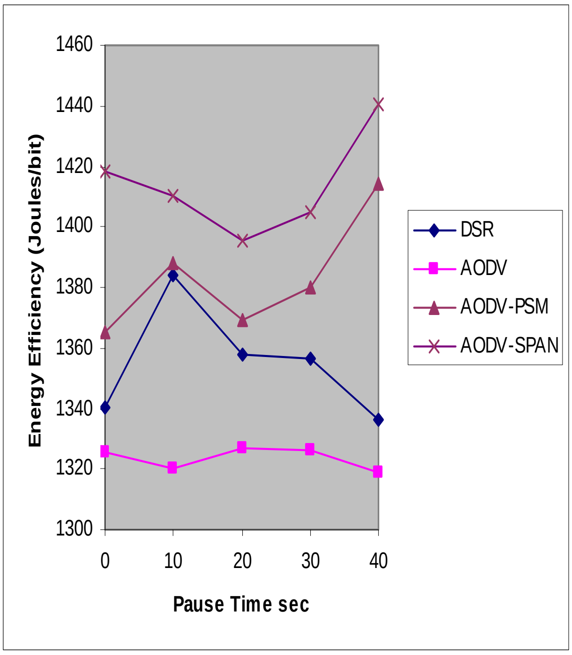

Fig. 4 Energy efficiency for DSR, AODV, AODV-PSM and AODV-SPAN

From the Fig 4 it is clear that DSR is more energy efficient as compared to AODV. But the IEEE 802.11 PSM and SPAN extensions with AODV clearly outperform DSR. It can also be noted that AODV-SPAN outperforms AODV-PSM; this is due to the fact that since traffic cannot be transmitted during the ATIM window, reducing the available capacity. It is also clearly seen that AODV-SPAN clearly outperforms DSR. We now extend the simulation for scalable conditions and for different traffic patterns. The simulation parameters for scalable conditions are as mentioned in the TABLE III. The results for corresponding energy conservation obtained for AODV and DSR protocols with PSM and SPAN interfaces are as shown in Figure 5 (see also page 9).

From the Fig. 5 it is clear that there is little difference between various protocols for energy conservation, due to scalable conditions. But we can make an observation that energy conservation is slightly higher for TCP traffic pattern as compared to UDP pattern. This is due to the fact that a lesser number of packets may be generated for tcp connections, resulting in lesser energy consumption. Also there is little difference between the energy conservation of AODV and DSR, with or without cross layer energy saving extensions like SPAN and PSM.

TABLE III. SIMULATIONS PARAMETERS FOR SCALABLE SIMULATIONS FOR ENERGY CONSERVATION OF NODES

NS-2 Simulator Version	NS 2.28
Topology size	1500 X 500
Mac Layer	802.11
MAC Layer Interfaces	SPAN
Number of Nodes	250
Protocols under test	AODV, DSR
Simulation Duration	50 sec
Initial Energy allocated to each nodes	1000 Joules
Transmit Power Consumption	1400mW
Receive Power consumption	1000mW
Idle Power Consumption	830mW
Sleep Power Consumption	130mW
Mobility Model	Random Waypoint
Mobility Pause Time	0 sec
Traffic Patterns	TCP,UDP
Data Rate	4.0 kbps
NS-2 Simulator Version	20
Topology size	NS 2.28

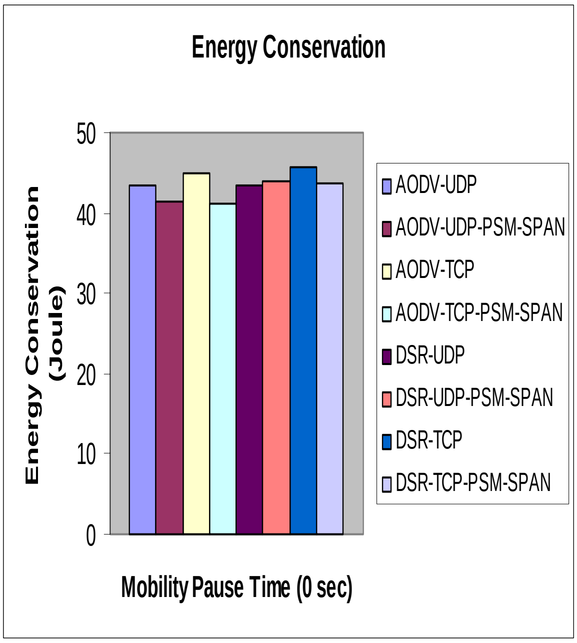

Fig. 5 Energy conservation under scalable conditions for AODV and DSR protocol with PSM and SPAN extensions

V. RELATED WORK

Geographic Adaptive Fidelity (GAF) Protocol is similar to SPAN [14], where it identifies many redundant nodes with respect to routing and turns them off without sacrificing routing reliability. In GAF nodes use GPS to associate themselves with a virtual grid. SPAN differs from GAF in that it does not use GPS and it integrates nicely with 802.11 PSM. Power management can save a significant amount of energy for nodes in ad hoc networks, provided nodes are optimally scheduled to sleeping state when they are in idle state [21].In his work Toh [17] says that beaconing is a technique that can be used to for power management in an ad hoc mobile computer. Chen and Hwa [4] in their analysis of mobility impact on energy conservation of MANET protocol conclude that AODV consumes most power in Manhattan Grid mobility model. They also claim that DSR is the best choice for low speed network, where energy conservation is the main goal. Feeney [15],[20] in experiments with network interface cards and MANET routing protocols namely AODV, DSR and DSR-np claim that AODV being a destination-oriented protocol does not maintain network-wide topology information and thus needs to initiate route discovery process more often, thus the resulting broadcast traffic gives AODV a much larger overhead energy cost than DSR-np at high mobility levels. Zeng and Kravets [16], studied the limitations of both reactive and proactive power management and claim that on-demand power management eliminates the need to maintain any nodes in active mode if there is no traffic in the network. This is achieved by treating all nodes equally. Here upon receipt of packets, a node maintains a timer and upon expiration of timer moves to power save mode. An advantage here is that on-demand power management implicitly finds routes with more awake nodes, since these routes have shorter delays. V Naumov [18] in their paper presented their results on the performance of DSR and AODV in large wireless ad hoc networks with varying number of nodes, different movement and communication models. They used only random waypoint mobility model. They concluded that with low number of traffic sources both protocols demonstrate good scalability with respect to number and density of nodes. But at high mobility rates DSR does not seem to deliver data packets effectively. They did not consider energy consumption issues. Kwak and Song [19] investigate the inherent scalability problem of ad hoc networks which originate from their multi hop nature. They concluded that the packet traffic at the center of a network is linearly related with radius of the network k.

VI. CONCLUSION

In this paper we have carried simulation based performance analysis of two major on-demand MANET routing protocols namely DSR and AODV for their energy efficiency. DSR has a slight edge over AODV because of it being multipath and alternative routes are available in its cache if it finds any broken links. But AODV is a more reliable and robust protocol when the number of sources to the network increases. In order to improve the energy conservation and its corresponding efficiency in AODV, we integrated NS-2 with SPAN, a protocol which operates between MAC layer and network layer and thus complements AODV. We also analyzed the packet delivery ratio of AODV, so that it's integration with SPAN and its performance with PSM does not degrade its packet delivery capacity. Then we measured the energy efficiency of DSR, AODV, AODV-PSM and AODV-SPAN and analyzed that AODV-PSM and AODV-SPAN outscore DSR and thus we say that cross layer optimizations leads to a overall better performance. We also studied the energy saving capabilities of protocols like AODV and DSR under scalable conditions. We could see from the results that TCP based traffic patterns for both protocols saved slightly higher energy as compared with UDP based traffic. This was primarily due to less number of packets for transmission under TCP connections. Also the underlying mobility model has no effect on the service provided by SPAN.

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Appendix: Larger Versions of Figures 2, 3, 4 and 5

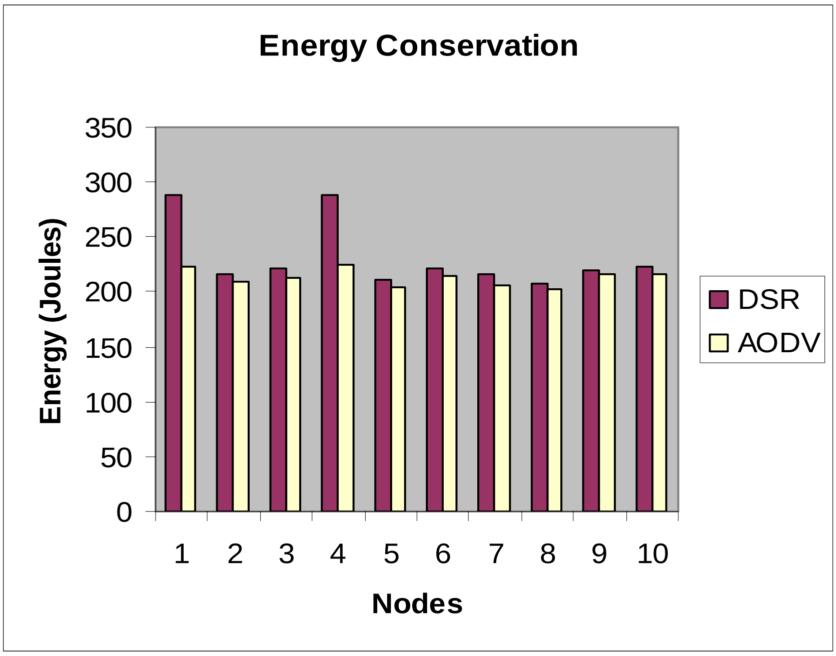

Fig.2 Energy Conservation in AODV and DSR

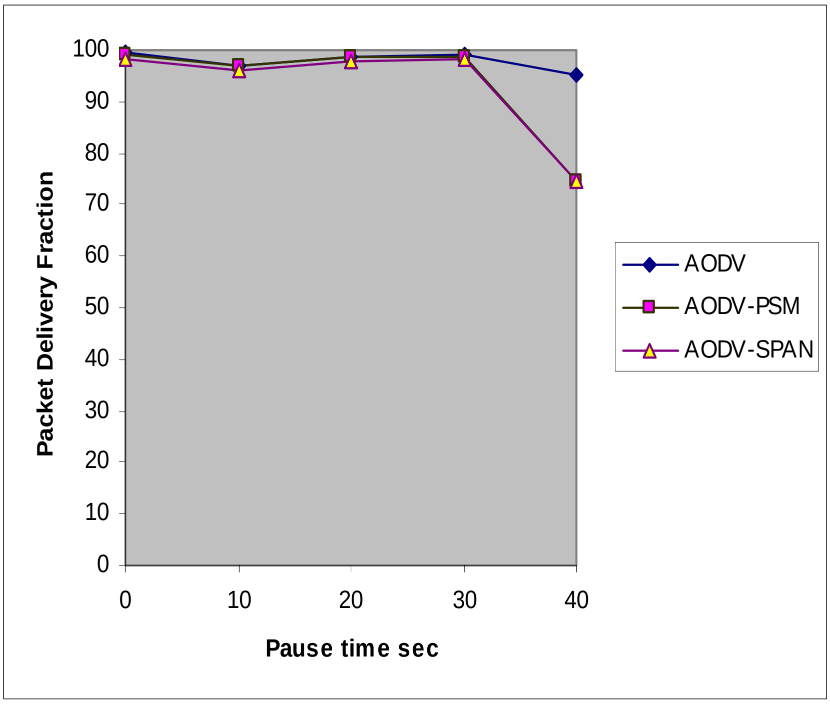

Fig.3 Packet delivery ratio for AODV.

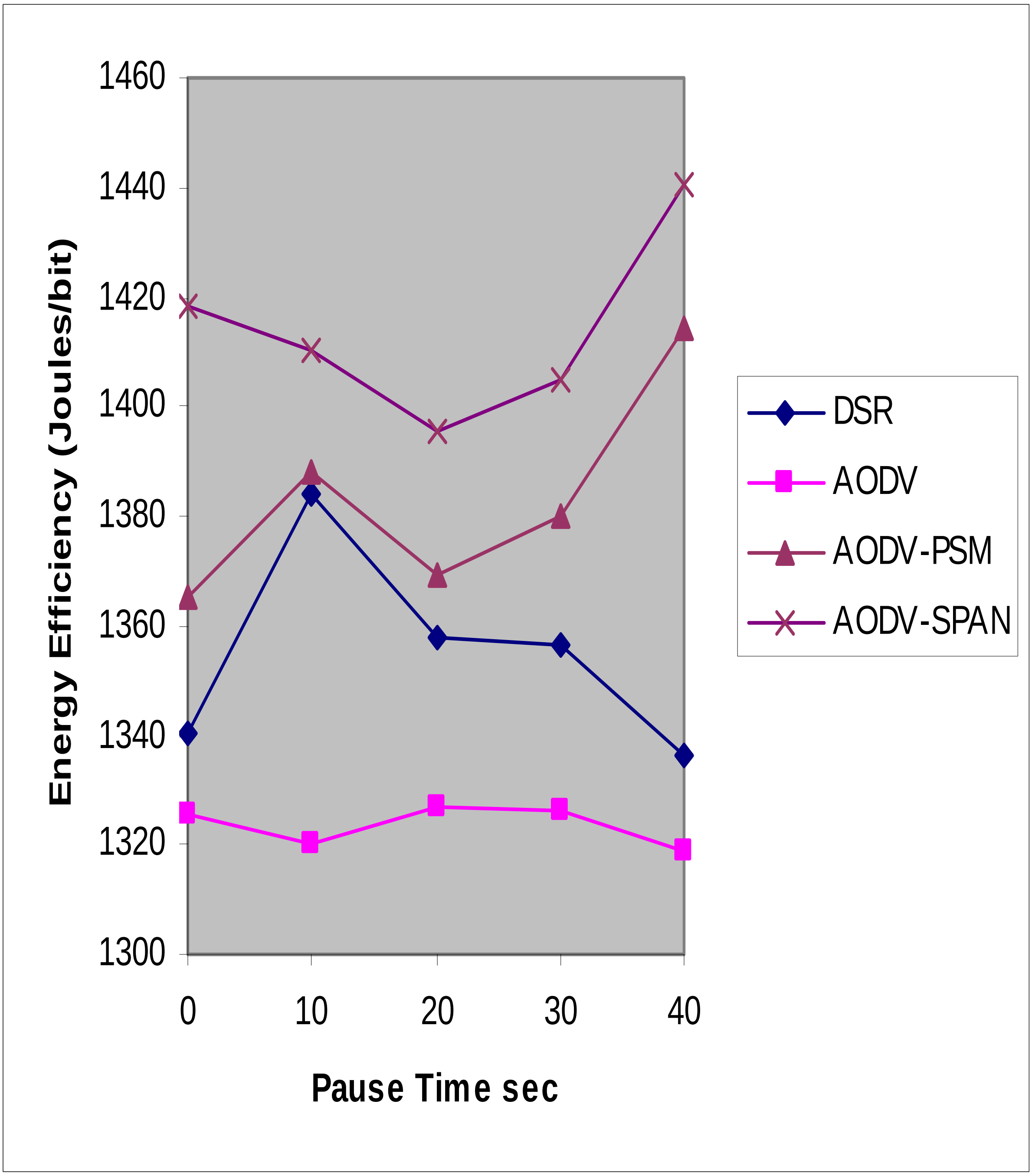

Fig. 4 Energy efficiency for DSR, AODV, AODV-PSM and AODV-SPAN

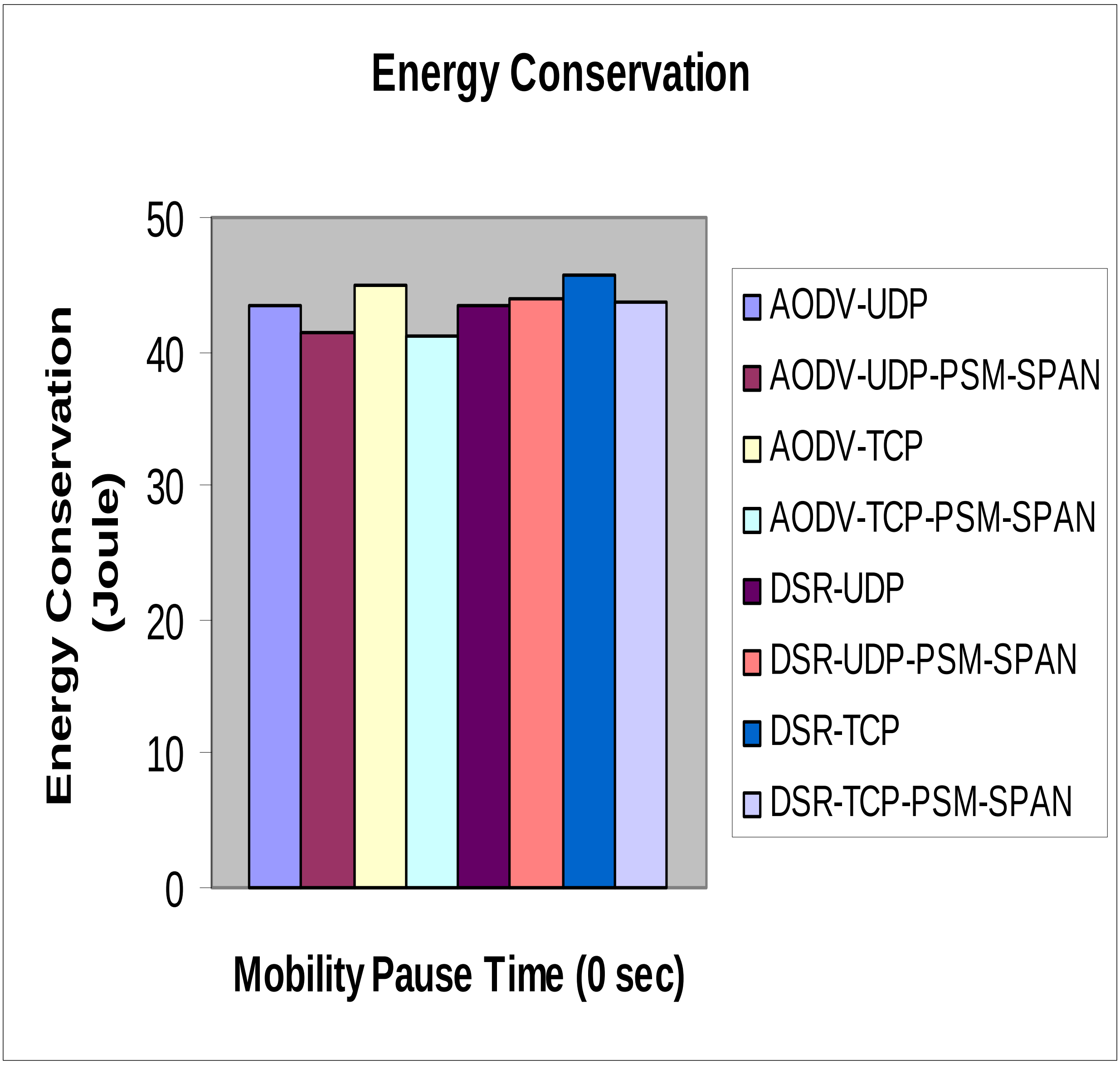

Fig. 5 Energy conservation under scalable conditions for AODV and DSR protocol with PSM and SPAN extensions