Energy Consumption Speed-Based Routing for Mobile Ad Hoc Networks

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Abstract

This paper describes an adaptive routing mechanism based on the energy consumption speed of nodes for on-demand routing protocols in mobile ad-hoc networks. Our algorithm allows a fairly energy consumption during route establishment by building routes that are lower congested than other. To to this, the congestion information is obtained from a computed cost that depends mainly on the energy consumption speed. The main features of our mechanism is that it is simple, efficient and it can be applied for any on-demand routing protocol.

We evaluate through simulations the performance of the AODV routing protocol including our scheme (resulting to a new routing protocol the we call AODV-energ) and we compare it with the basic AODV routing protocol. Results show that our new concept outperforms the basic AODV. Indeed, our scheme reduces for more than 20 % the total energy consumption and decreases the mean delay specially for high load networks while achieving a good packet delivery ratio. Moreover, the simplicity of the mechanism enables the design of cheap implementations.
Keywords : Mobile ad hoc networks, On-demand routing protocols, Energy consumption.

1 Introduction

A Mobile Ad-hoc NETwork is a set of wireless mobile nodes dynamically forming a temporary network. The goal of this architecture is to provide communication facilities between end-users without any centralized infrastructure. In a such network, each mobile node operates not only as a host but also as a router. It is also possible to have an access to some hosts in a fixed infrastructure depending on the kind of mobile ad hoc network available. Some scenarios where an ad hoc network could be used are business associates sharing information during a meeting, military personnel relaying tactical and other types of information in a battlefield, and emergency disaster relief personnel coordinating efforts after a natural disaster such as a hurricane, earthquake or flooding. In fact, in such scenarios, maximizing the network lifetime is a very important deft since recharging battery is very difficult (hard) to do in such conditions. To this end, there are several works that have been presented [6]. They proposed different routing algorithms based on energy conserving mechanisms for routing in mobile ad hoc networks [5, 7].

In this paper, we discuss the most important works that have been described in this area. Then, we introduce a simple energy consumption speed-based algorithm for on-demand routing protocols. We are interested in the on-demand routing protocols since this kind of routing concept is efficient and it has the advantage to save energy consumption that is affected by the huge routing overhead comparing to data packets. There are two steps that are considered, route request and route reply broadcasting which are generated by the sources and destinations or by intermediate nodes if the required routing information are available in that nodes, respectively.

In the AODV (Ad hoc On-Demand Distance Vector) routing process, a minimum hops algorithm is applied to establish routes between sources and destinations. Our work consider another metric in the route establishment process. This parameter includes in route cost computation the speed of energy consumption. We believe that by this way we avoid nodes that participate in communications more than other and we choose nodes that participate less than the other in the communications.

We integrated our scheme in the AODV routing protocol introduced in the Draft [4]. This routing protocol consumes less energy than other on-demand routing protocols such as DSDV and TORA as shown in [7]. We studied the characteristics of route establishment algorithm in AODV protocol. The performance evaluation studied with different useful metrics and different scenarios, show the great benefits of this approach in terms of energy consumption, delay, and route establishment delay.

The remainder of this paper is organized as follows. In Section 2, we give the most important characteristics of AODV routing protocol and its main limitations. In Section 3, we describe our algorithm in detail. Simulation methodology and performance evaluation of our proposal are detailed in Section 4. We review some works related to our proposal in Section 5. Section 6 concludes the paper by summarizing results and outlining future works.

2 Basic AODV routing protocol

2.1 Overview

The Ad hoc On Demand Distance Vector (AODV) is a reactive routing protocol. In fact, it is self-starting, enables multi-hop routing between participating mobile nodes wishing to establish and maintain an ad hoc network. This protocol builds routes between nodes only as desired by source nodes. It discovers routes quickly for new destinations, and does not require nodes to maintain routes to non-active destinations. AODV ensures link breakages and breakdowns are handled efficiently. The AODV protocol establish routes using a Route REQuest (RREQ) / Route REPly (RREP) query cycle. So, when a node requires path to destination, it broadcasts RREQ message to its neighbors which includes latest known sequence number for that destination. This message is flooded until information required is complete by any means. Each node receiving the message creates a reverse route to the source. The destination sends back RREP message which includes number of hops traversed and the most recent sequence number for the destination of which the source node is aware. Note that if an intermediate node has a fresh route to the destination it doesn't forward the RREQ and it generates a RREP toward the source. Each node receiving the RREP message creates a forward route to the destination. Thus, each node remembers only the next hop required to reach any destinations, not the whole route.

Each node receives a duplicate of the same RREQ, it drops the packet. Moreover, AODV uses sequence numbers to ensure the freshness of routes. In fact, the routes to any destination are updated only if the new path toward that destination has greater sequence number than the old one or it has the same sequence number but with less number of hosts. So, AODV protocol builds routes between nodes regarding the shortest path parameter.

2.2 AODV Limitations

Routes, in AODV protocol, are established based on minimum hop count. This consideration might have a bad effect when the number of communications increases and so it is more likely to include other parameters that have a significant effect on network connectivity and lifetime. Furthermore, power is a very important constraint in wireless network. If a node, that participate in a route establishment, has very low energy, this later will break very soon. Moreover, this can has also a bad effect on the network lifetime: there are some nodes that will dead very faster than another ones. So, this can affect network connectivity if key nodes dead very soon. Note that, key nodes are the nodes that routes cannot be established if they dead when their energy returns to zero. To deal with these problems, the power should be taken into account in the route establishment algorithm. To this end, we propose an energy-aware routing establishment mechanism and we apply it to the AODV routing protocol. The main feature of our work compared to the related works in this area (that will be discussed in Section 5) is that is simple and efficient according to the obtained performance enhancement comparing to the results obtained with the basic protocol.

3 Our proposed mechanism

Taking in mind the different problems and constraints described above, we propose a simple energy consumption speed-based mechanism that aims to maximize the network lifetime and enhance the performance obtained by the basic AODV routing algorithm. So, the goal is routing or re-routing around nodes that we expect that they have more residual lifetime than other.

3.1 Expected residual lifetime computation

In our algorithm, we do not only consider the current energy level value of a node as the case of several mechanisms introduced in this topic. However, we observe also the speed of energy consumption at each constant period. In fact, we believe that considering energy speed consumption allows us to get information about the energy exhausted in packet transmission and reception without doing complex computation of these lasted values. Then, using the estimated speed consumption and residual energy, we compute the expected residual lifetime assuming that the node continues to consume energy with that speed. By this way, we give more real information about the battery lifetime behavior in each node. Moreover, we try to differentiate between nodes that participate in communications more than other nodes even they have the same energy level. At each period of time number j called "update period"[1] and for each node, we follow the following formula to compute energy speed consumption:

$$Speed\_consumpt^{j} = \frac{Remain\_energy^{j} - Remain\_energy^{j-1}}{Update\_period_{j}}$$

where $Remain\_energy^{j}$ is the estimated residual energy computed at update period number $j-1$ as follow:

$$Remain\_energy = Current\_energy - (Nb\_buff\_packet * Trans\_energy)$$

where $Current\_energy$ is the current energy value of the node. For more tuning of this estimated residual energy, we reduce the value of the power that will be consumed to transmit the remaining packets in the buffer noted by Nb_buff_packet. The parameter $Trans\_energy$ is the energy value that is used in our energy model to transmit one packet.

To minimize the bias against transient consumption speed, we use an estimator of Exponentially Weighted Moving Average (EWMA) to smoothen the estimated energy consumption speed values. Let $Speed\_consumpt^{j}_{avg}$ be the average energy consumption speed at step j (for each update period) computed according to the following iterative relationship:

$$Speed\_consumpt^{j}_{avg} = (1-\alpha) * Speed\_consumpt^{j}_{curr} + \alpha * Speed\_consumpt^{j-1}_{avg} \quad (1)$$

[1]The optimal value of this time period is out of the scope of this paper.

Then, we can estimate the expected residual lifetime in each node considering $Remain\_energy$ and $Speed\_consumpt_{avg}$ values that will be defined at each update period j using the following equation:

$$Residual\_lifetime^j = \frac{Remheain\_energy^j}{Speed\_consumpt_{avg}^j} \quad (2)$$

3.2 Route establishment mechanism cost computation

Using the residual lifetime value computed using equation 2, each node computes a cost at each route request demand. This cost is defined as following:

$$cost_{res\_life} = Residual\_lifetime^j * weigth_k \quad (3)$$

where $weigth_k$ is a multiplicator factor in the interval [0, 1] defined for each energy interval k. Hence, k go from 1 to 4 referring four energy intervals: the first one is from 50% to 100% of initial energy value, the second one is from 30% to 50%, the third one is from 10% to 30% and the last one is from 0% to 10%. This yielding small value weight for small interval and a great one for the largest interval.

3.3 Integration of our scheme into the basic AODV protocol

As described in Section 2, the basic AODV routing protocol uses minimum hop parameter to establish routes between sources and destinations. However, considering the new energy-constraint metric, we follow a new route discovery scheme. Indeed, routes are established based on residual lifetime cost value ($cost_{res\_life}$) defined in 3. Each RREQ packet includes the traversed path cost. Then each node maintains for each reverse route this cost in the routing table entry and routes are built based on the maximum mean cost defined as follow:

$$cost_{mean} = \frac{\sum cost_{res\_life}}{number_{hops}} \quad (4)$$

where, $number_{hops}$is the number of traversed hops. Furthermore, this new design requires that nodes act at all duplicate RREQ packets to select the maximum cost that can be founded. However, the cost of considering routes without min hops as used in the basic algorithm, could add latency and possibly more routing packet overhead. Therefore, our algorithm should design the energy conserving concept to find a trade-off between maximum lifetime route and data-delivery quality. To this end, routes are updated regarding the extra number of hops in the new route comparing to the hops number in the old route if this later has to be changed. Moreover, RREP packet includes the minimum residual lifetime value in the reversed path. This allows the source node to avoid as feasible as possible route failure and so it sends a RREQ packet before this minimum residual lifetime of the route expires.

4 Performance evaluation

We have implemented our mechanism in the ns-2 simulator. We have extended the AODV protocol to support our energy consumption speed-based algorithm. The latest version of AODV protocol is used. We report in this section the large set of simulations we have done by various network topologies and scenarios. We also provide an analysis of performance obtained.

The energy model used bears similarities to earlier studies [3]. It is assumed that the radio interface, when powered on, consumes 1.15W when listening to the channel for any incoming packet, 1.2W while actually receiving a packet and 1.6W while transmitting a packet.

4.1 Simulation scenarios

The 50 nodes used in our simulations move in an area of 1500x300 according to a random waypoint mobility model as described in [1]. The radio model is very similar to the first generation WaveLAN radios with nominal radio range of 250m. The nominal bit rate is 2 Mbps. In this mobility model each node moves toward a random destination and pauses for certain time after reaching the destination before moving again. In our simulations, the nodes move at an average speed of 20m/sec. The pause times are varied to simulate different degrees of mobility. The traffic sources start at random times toward the beginning of the simulation and stay active throughout. The sources are CBR (constant bit rate) and generates UDP packets at 4 packets/sec, each packet being 512 bytes. Each simulation is run for 900 seconds simulated time. Each point in the plotted results represents an average of ten simulation runs with different random mobility scenarios.

4.2 Simulation metrics

We analyze several QoS metrics to evaluate the performance of our approach and we compare results with the basic AODV protocol. The following metrics are defined:

- **Gain on delivery fraction:** This metric measures the gain (in %) on the delivery fraction at the end of simulations of our new mechanism (aodv_energ), compared with the basic AODV protocol. Note that, the delivery fraction is measured as the ratio of the number of data packets delivered to the destination and the number of data packets sent by the source.

- **Route bytes:** It is the **routing overhead** which is measured as the total number of Bytes of transmitted routing packets.

- **Mean delay:** It is the average delay of all the flows that have the same priority in the different stations. The average delay is used to evaluate how well the schemes can accommodate real-time flows. However, real-time flows require both low average delay and bounded delay jitter. So we will also use the following metrics of latency distribution and delay variation.

In order to show the gain on energy and the effect on the connectivity of the network and thus the useful lifetime, we evaluate the following metrics:

- **Gain on remaining energy:** This metric stands for the gain (in %) on the total remain energy at the end of simulations of our new mechanism (aodv_energ), compared with the basic AODV protocol.
- **Behavior of the number of death nodes during simulation**: This metric allows to have an idea on how soon nodes are dying out of power and how many nodes are dead (i.e., have zero energy) during simulation.

4.3 Simulations results and analysis

We present in this subsection the performance of the basic AODV and our energy consumption speed-based routing algorithm applied to AODV (aodv-energ) for the various metrics presented above. We vary the number of traffic sources and pause times to reflect various loads and mobility[2].

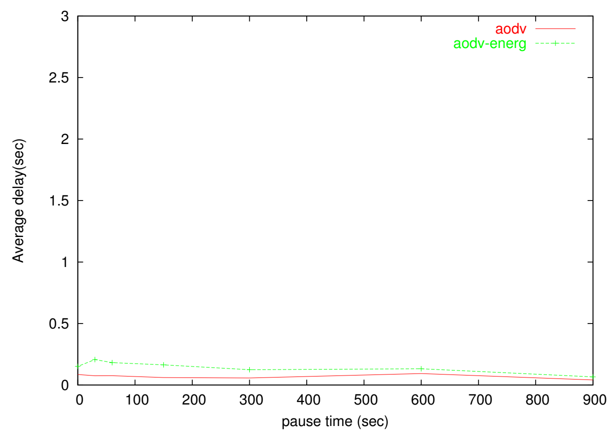

Figure 1: Average delay for 10 sources

In Figures 1, 2, and 3, we plot the mean delay of our new mechanism and the basic AODV routing protocol. This metric is improved with 20 and 30 sources which demonstrates the efficiency of re-routing based on energy consumption speed. More specifically, low energy consumption speed informs that the node does not participate a lot in communications that include sending, receiving, and forwarding packets. This lets packets follow routes that generate a high cost and so are less congested which yielding to lower delay comparing to the obtained delay with routing based on minimum hops count that does not take into account energy behavior through the time and so ignore the busy nodes. Moreover, we remark that the improvement on delay increases with low network mobility as the basic AODV does not change routes frequently in the stationary network case. However, in such scenarios, our algorithm allows re-routing and refresh routes including new nodes that have better quality than in the old routes which improves the

[2]Note that pause time = 0 means constant movement and pause time = 900 sec means stationary network.

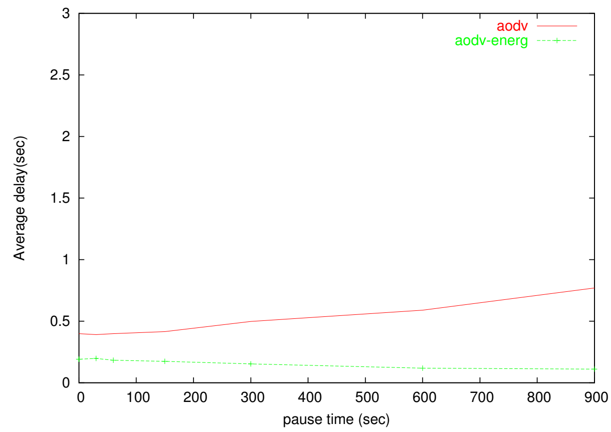

Figure 2: Average delay for 20 sources

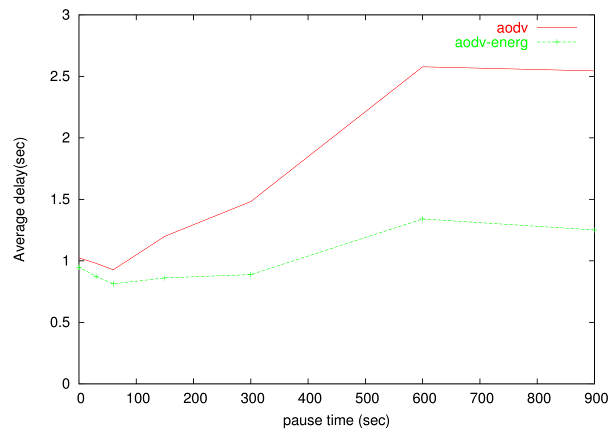

Figure 3: Average delay for 30 sources

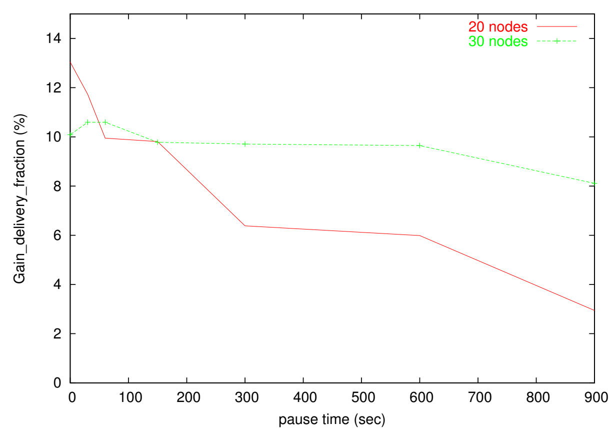

Figure 4: Gain on delivery fraction for 20 and 30 sources

end to end delay. Note that we mean by a good quality node, the node that is less busy and have more energy than other nodes in the some other alternative route possibilities. Furthermore, we follow the RREQ broadcasting mechanism by source nodes since the minimum residual lifetime in the route will turn to zero soon. By this way, route failures are more avoided than in the basic AODV protocol. There are no improvement in the obtained average delay with low loads (10 sources). Indeed, the obtained results with our mechanism are a little greater than those of the basic AODV which could be explained by the fact that we use routing packet broadcasting in the research of other alternative routes more than in the basic AODV which might be high comparing to the low total load. The plot shown in Figure 5 enforces this claim given that the obtained route bytes of our mechanism is larger than in the original protocol. Moreover, this affects the packet delivery fraction which presents the same little difference between our algorithm and the basic one for the same reasons presented above. However, we obtain a good performance enhancement using 20 and 30 sources as shown in Figure 4[3]. The improvement attempts more than 10 % for 30 sources and 13 % for 20 sources. These results are proved by the fact that routing overhead is low with our new mechanism as shown in Figures 6 and 7.

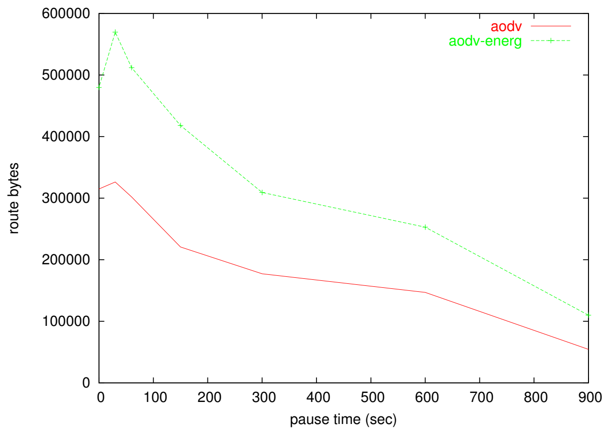

Figure 5: route bytes for 10 sources

To demonstrate the efficiency of our scheme regarding to the energy consumption, we plot in Figure 8 the gain in the total remaining energy that is obtained at the end of simulation. Our algorithm presents an improvement for more than 26 % for 30 sources, more than 17 % for 20 sources, and for more than 10 % for 10 sources.

In Figure 9, we investigate the behavior of the number of death nodes during simulation. The plot presents how many nodes are dying as a function of simulation time for 20 sources and pause time equal to zero. Indeed, this number has a great importance since it informs about network connectivity. The more the large number of survived nodes it is, the more routes could be established. On the other hand, when this number is small communications between some nodes might be impossible. The experiment that we have done shows that our mecha-

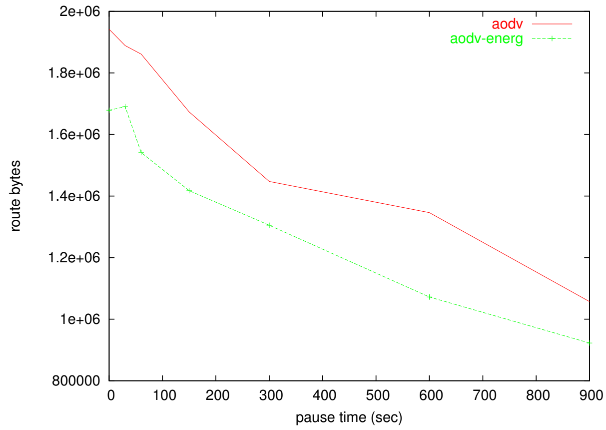

Figure 6: Route bytes for 20 sources

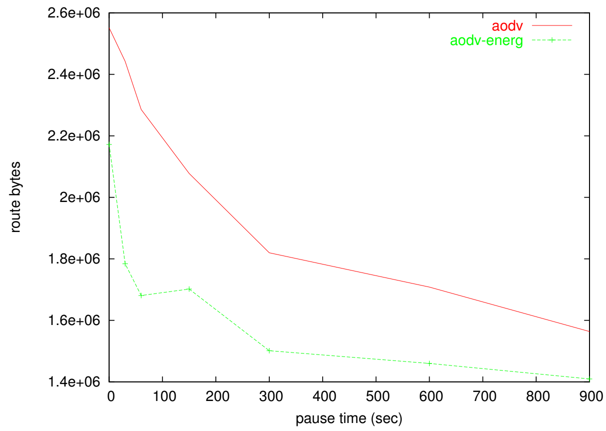

Figure 7: Route bytes for 30 sources

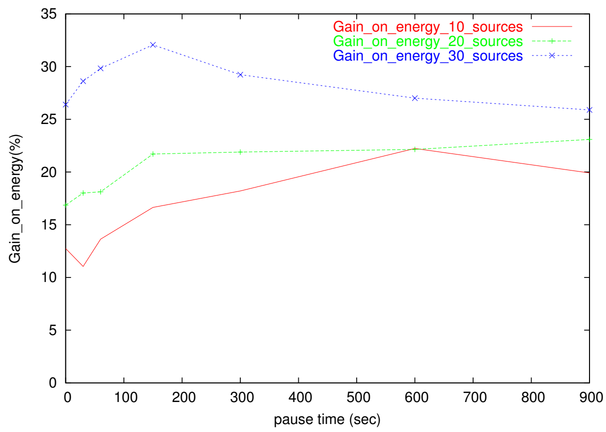

Figure 8: Gain on total remaining energy

[3]We did not show the results for 10 sources because it has no gain value.

nism is able to keep more survived nodes than the basic AODV protocol. Indeed, there is about 100 second difference between the first died node in the two mechanisms. Moreover, we can see that our algorithm always outperforms the basic protocol during all simulation time. For example, at 500 second, there are only five nodes that are dead for our mechanism, however the basic AODV protocol leads to more than 15 dead nodes. This result shows the efficiency of our scheme that aims to have as smaller as possible a number of congested nodes participating in communications and which allows load balancing in the network. This is the effect of including energy consumption speed in routing process.

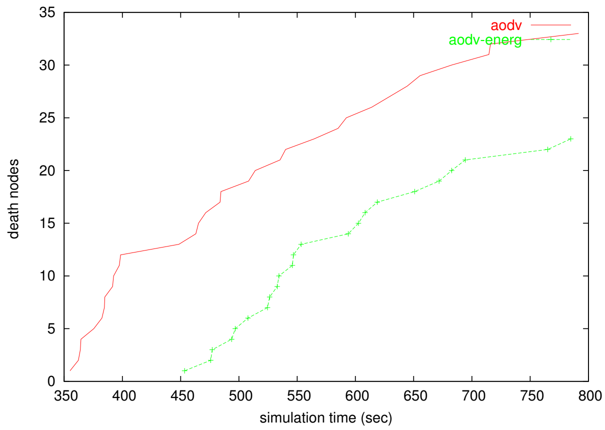

Figure 9: Number of death nodes for 20 sources (pause time = 0)

5 Related work

Energy coming to be constraining factor for many mobile systems. There are several works that have been addressed to deal with battery usage conservation problem. Due to limited spaces, we analyze here only some works most closely related to our proposal. In [8], an energy-aware routing algorithm that follows a new route discovery scheme, is described. This scheme is based on the remaining energy value, number of neighbors and mainly a sleep-active node model. Using current energy level in the route establishment algorithm, it is not sufficient to achieve a maximum route lifetime since the behavior of energy consumption is very important to a better estimatimatrion of the residual lifetime of nodes.

This sleep-active node model switches off the radio interfaces when nodes are idle. Our algorithm does not apply this model which has been investigated in several works. Switching off radio interface can interfer with routing, as routes cannot be formed via sleeping nodes. This also can result in longer routes or in failure of route discovery. The latter may result in longer delays or lost packets due to buffer overflows at the source. To find a good tradeoff between energy conservation and good performance, it requires more energy consumption in order to compute the requested paths. Moreover, improvement performance remains restricted to some limited scenarios. The proposal in [5], called span, presents a conserving energy scheme based on sleep-active model. A local election is used to elect coordinators. The elected coordinators are connected by paths in such communication can be possible between large number of nodes. Each node has at least one coordinator neighbor. The coordinators remain awake at all times and therefore form a low latency routing backbone for the network. The Span coordinator election algorithm is intended to approximate a minimal capacity-preserving set of coordinators.

In [2], the authors proposed an algorithmic approach that aims to reduce the battery consumption. This approach defines a class of flow augmentation algorithms coupled with flow redirection. Unlike the conventional approach of minimizing the cost of the route from a source to a given destination, the strategy here was geared toward balancing the battery usage among the nodes in the network in proportion to their energy reserves. The presented algorithms are only centralized and there is no solution for distributed network.

6 Conclusion

On-demand routing protocols are useful for mobile ad hoc network environment for their low routing overheads. However, if battery energy is not taken into consideration in their design, it may lead to premature depletion of some nodes' battery leading to early network partitioning. Since computing complexity consumes power as well as communications, we proposed in this paper a simple and efficient energy consumption speed based algorithm to establish routes between sources and destinations.

Performance evaluation using ns-2 simulator shows that the longevity of the network can be extended by a significant amount. Overall, we conclude that our mechanism demonstrates significant benefits at high traffic and high mobility scenarios. We expect that these scenarios will be common in ad hoc networking applications. Even though we implemented the algorithm on AODV, the technique used is very generic and can be used with any on-demand protocol.

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