NOAL: Node Alarming Mechanism for Energy Balancing in Mobile Ad hoc networks

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ABSTRACT

With respect to energy balance in mobile ad hoc networks, there have been active researches proposing energy-aware routing algorithms for mobile ad hoc networks. They take advantage of energy-related metrics to find the most energy-balancing route in route discovery procedure. However there have been few works touching the energy balance during data transmission that is addressed in this paper. This paper presents a new mechanism named *Node Alarming Mechanism (NOAL)* where an intermediate node having low energy alarms its status to others. With NOAL, we propose two routing algorithms: *LEAR with NOAL (LENOAL)* and *FEAR with NOAL (FENOAL)* that can balance the energy consumption among mobile nodes in ad hoc networks. The simulation study shows that LENOAL and FENOAL can balance energy consumption over networks by 21-36% depending on the network conditions.

Keywords: Mobile Ad hoc Network, Energy Balance, Power-Aware Routing, Mobile Computing, Wireless Communication

1. INTRODUCTION

Mobile wireless computing is expected to provide a large scope of applications with technological innovations and frequent utilization with a market explosion in the field of computing and wireless networking. Recently, the *infrastructureless networking*, commonly known as *ad hoc network*, has been considered as a candidate for the next generation wireless environment. A mobile ad hoc network is a collection of mobile nodes that are dynamically and arbitrarily located in such a manner that the interconnections between nodes are capable of changing on a continual basis. Without any infrastructure such as routers or switches, mobile nodes communicate with each other through intermediate nodes in their network and cooperatively maintain network connectivity. In ad hoc communication, because nodes work both as host and as router, nodes can easily consume much energy. Especially when a node is located on a *hot spot* where it supports multiple packet-relaying functions, it may consume more energy than others and deplete its energy early [5]. This can cause an unbalanced distribution of energy consumption among mobile nodes in the network.

With respect to the energy-efficient operation in wireless networks, there have been endeavors in various fields such as energy-aware links, MAC routing, and transport protocols. Energy-aware MACs [18-21] focus on managing power by turning devices on or off according to packet transmission, and on the extension of network lifetime. Protocol approaches [4, 5] take advantage of energy-related measures only when finding route paths (a route discovery procedure).

Under slow and stable link condition, however, route paths are hardly changed and intermediate nodes easily consume more energy than others. Even if the route path is too stable to be changed and data is transmitted for a long time through it, nodes along the path consume extremely high power that may result in energy depletion. This may adversely affect the distribution of energy consumption among all mobile nodes. This paper touches this issue.

The rest of the paper is organized as follows. Section 2 reviews the ad hoc routing protocols. In Section 3, several energy-balancing ad hoc routing protocols are reviewed and we propose a new algorithm in which the power-aware routing is adapted into FSR: FEAR. Section 4 proposes an energy-balancing routing mechanism: NOAL. And NOAL-adapted algorithms, LENOAL and FENOAL, are presented. Section 5 includes basic information of our simulation. Performance evaluation of the proposed schemes is presented in Section 6. Finally, we conclude this paper in Section 7.

2. AD HOC ROUTING ALGORITHMS

Routing protocols for mobile ad hoc networks have two categories: reactive and proactive. Reactive, on-demand, routing protocols tries to find routes only when needed. When a node has data to send, it starts a route discovery procedure. Then it sends data through the route path. With fewer control messages, reactive routing protocols can reduce the network overhead. On the other hand, proactive, table-driven, routing protocols take the concept of the periodic advertisement from the well-known distributed routing protocols for fixed networks: distance vector or link state routing algorithm. Ad hoc nodes periodically flood their topology information into the network, thus maintaining routes to all destinations regardless of whether they are needed. This can make a node have a consistent network view and react to dynamic changes of network topology. Many routing algorithms are proposed under the two categories in the *Internet Engineering Task Force (IETF) Mobile Ad hoc Network (MANET) Group* [10]. General overview and performance comparisons of these protocols can be found in the papers [1, 11, 12]. In this paper, we take two mobile ad hoc routing protocols, *Dynamic Source Routing (DSR)* and *Fisheye State Routing (FSR)*, which belong to different categories.

DSR [2, 3] is a reactive routing protocol using source routing rather than hop-by-hop routing. Each source/destination node exchanges a route request packet (RREQ) and route reply packet (RREP) to find a route path before transmitting data in route discovery procedure. When a node finds a change of network topology caused by mobility or energy depletion of nodes, it originates a route error packet (RRER), and sends it back to the source node. The node is notified that current data path is broken and tries to search a new route path.

FSR [6-8] is a proactive routing protocol. It relies on a link state protocol and has the ability of immediately providing route information when needed. The fisheye scope technique allows exchanging link state messages at different intervals for nodes within different fisheye scope distance, which reduces the size of link state message. Further optimization allows FSR to broadcast topology message only to neighbors in order to reduce the flood overhead [9]. With these optimizations, FSR significantly reduces the topology exchange overhead and scales well to large network size.

3. ENERGY-AWARE AD HOC ROUTING ALGORITHMS

In this section, we discuss the approach and the basic operation of *Global Energy-Aware Routing (GEAR)* and *Local Energy-Aware Routing (LEAR)* proposed by [4, 5]. We also propose an *Energy-Aware FSR (FEAR)*. FEAR uses energy measure and includes it into the route calculation of FSR as a metric in order to search energy-balancing route.

Global Energy-Aware Routing (GEAR)

Power-aware routing [4] introduces 5 different metrics, listed below, based on battery power consumption at nodes.

- Minimize energy consumed per packet
- Maximize time to network partition
- Minimize variance in node power levels
- Minimize cost per packet
- Minimize maximum node cost

For energy-constrained operation, it is more important to use cost per packet and maximum node cost than hop count as metrics. This can be achieved by making routing protocols power-aware. Nodes forward data packets by the method that utilizes the 5 metrics. This uses lowest-cost routing rather than shortest hop routing, which can result in reduction of the cost per packet of routing packets by 5~30%, and the energy consumption by 40~70%.

Power-aware routing is theoretically applied to DSR by [5], and named GEAR. It uses a power-related metric and tries to find an optimal energy-conserving route path with global energy information. Like the DSR, a RREQ is propagated towards a destination node. In GEAR, intermediate nodes piggyback their power-related data such as the remaining energy values as well as their identities on the RREQ. The destination node receives multiple RREQs, but chooses the best route path with respect to the given power metrics.

Local Energy-Aware Routing (LEAR)

LEAR [5] uses the energy information of intermediate nodes independently, which is different from GEAR that uses globally gathered energy information all together. The basic idea of LEAR is to consider each mobile node's willingness to participate in the routing path and to forward data packets on behalf of others. Each intermediate node determines whether to accept and forward a RREQ or not depending on its *remaining battery power* (E_r). When it is higher than a *threshold value* (Th_r), the RREQ is forwarded; otherwise, the RREQ is dropped. Therefore, the first RREQ must come to D through the energy-rich and the shortest-hop route when a destination node D receives the first arriving one. D does not need to wait for other RREQs and can immediately reply with a RREP. Fig. 1 shows the operation of LEAR.

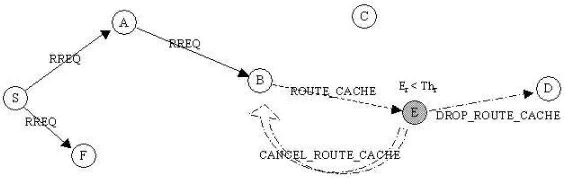

Fig. 1. Basic Operation of LEAR.

Energy-Aware FSR (FEAR)

In this Subsection, we propose FEAR; a power-aware routing adapted to FSR. In FEAR, the energy-related metrics are included in the dissemination of node information. Nodes are aware of energy information of destinations and take advantage of it for route calculation.

When a node S floods a link state message, the energy measure such as its remaining battery power is piggybacked on it. When a node N receives the message, it records/updates the energy information for node S in the topology table. Then, the topology table is flooded to neighbors again. In this way, the link state message flooded to neighbors contains complete energy information regarding the destinations in the link state list as well as the sender's energy information.

When performing the Dijkstra's algorithm, a weight function is used to compute the distance of a route. Since the original FSR considers only the shortest hop path, the weight function returns 1 if two nodes have a direct connection; otherwise, it returns 0. In FEAR, an energy aware function is added to the weight function to calculate the distance to neighbors. Therefore, even though there are neighbors that are directly connected to a node by one hop, the distances to each neighbor are different from each other based on their energy measures.

4. PROPOSED ALGORITHMS

Even though energy-balancing algorithms described in section 3 can find the energy-balancing route in route discovery procedure, it does not care about energy balance during data transmission. In order to address the issue, this paper proposes *Node Alarming Mechanism (NOAL)*, in which a node forwarding data packet alarms its energy status to others when it has low energy. The basic idea of NOAL is to protect node against consuming much energy. By notifying its energy status to others, it can prevent others from sending more data to itself, which stops consuming more energy by forwarding data packets. Subsections contain the proposed algorithms adapting NOAL to energy-aware algorithms, called *LEAR with NOAL (LENOAL)* and *FEAR with NOAL (FENOAL)*, which can achieve an energy balancing even after route discovery.

LEAR with NOAL (LENOAL)

LENOAL is based on LEAR. In LEAR, energy-balancing route can be found by making energy-rich nodes participate in route path in a route discovery procedure. LENOAL exploits the route selection process from LEAR. Therefore LENOAL can also keep energy balance in route discovery procedure.

In addition, LENOAL utilizes *Route Warn Message (RWAR)* in order to achieve the energy balance during data transmission. On transmitting data, intermediate nodes check their remaining battery power (E_r). When a node (node E in Fig. 2) finds its energy level is lower than a *warning value* ($E_r < Th_w$), it originates RWAR and sends the message back to the data sender (node S in Fig. 2). Along the unicast of RWAR, related nodes (E, B, and A) calculate a *waiting time for link breakage* (T_{wait}) based on the distance to S. After T_{wait}, they delete the entry to destination D in their route cache and data are not forwarded through it any more. T_{wait} is determined for intermediate nodes to forward data packets that are already sent from S. Therefore, without T_{wait}, data already on the way to D may be lost in the network. When S finally finds the route path is unavailable and has more data to send, it searches for *Alternative Path Route (APR)* in its route cache. If one is found, it is used; otherwise, it restarts the route discovery procedure by flooding RREQ into the network.

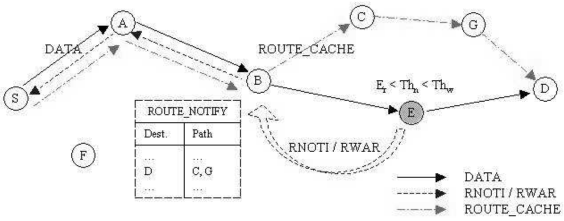

Fig. 2. LENOAL.

A source node in LEAR hardly has APR in its route cache, because corresponding destination node sends a RREP as a reaction only for the first-arriving RREQ and ignores next RREQs. In LENOAL, an APR mechanism is adapted by utilizing *Route Notify Message (RNOTI)*. The basic operation of RNOTI is the same as that of RWAR. Intermediate nodes check their energy level. If it is lower than a threshold value, then they originate RNOTI and send the message back to S as in Fig. 2. The difference is the threshold value and the operation of nodes relaying the message. Intuitively, RNOTI is originated before RWAR to inform that this route path may be broken in the near future, and APR should be searched. The node E (in Fig. 2) originates and sends the message back to S when its remaining energy is lower than a *notifying value* (Th_n) and is greater than warning value ($Th_w < E_r < Th_n$). Nodes relaying the RNOTI examine whether they have other routes to D in their route cache. If found along the unicast of RNOTI, the new APR is piggybacked on it. When S receives the RNOTI piggybacking the APR, it sends ROUTE_CACHE control message towards D in order to confirm the APR is still energy-rich. If confirmed, it records the APR in its route cache. When it receives RWAR, it deletes its previous route to D out its route cache and uses the new APR to send data. Otherwise APR is not found along the RNOTI, S does nothing until it receives RWAR. When S receives RWAR, it recognizes the route path is going to be broken, and tries to find APR. If it finds another route path in its route cache, it uses the route. Otherwise, S restarts route discovery procedure by flooding RREQ into the network. And data can be protected due to the waiting time on intermediate nodes. On receiving the next RREQs, E does not accept and forward the message because it has low energy level, thus does not consume more energy. As destination in LEAR do, D may receive multiple RREQs or ROUTE_CACHEs and choose the first arriving one to reply with a RREP to S. LENOAL can protect nodes from consuming much energy by forwarding others' data packet. It also makes LEAR exploit more efficiently the optimization based on route cache, and it can actualize APR due to energy depletion of nodes.

FEAR with NOAL (FENOAL)

FENOAL is a new energy-balancing algorithm where NOAL is applied to FEAR. It uses *Link Warning message (LWAR)* and is for protecting nodes against consuming much energy by preventing data from being routed through them. An intermediate node (node E in Fig. 3) that consumes more energy than a *warning value* ($E_r < Th_w$) originates and floods LWAR to neighbors. A neighbor receiving LWAR recognizes that E has low energy and updates the weight of the connection to E to high value. This can make it difficult to include E in route path to other destinations, which prevents E from consuming energy by forwarding others' data. After E floods LWAR, it stops flooding link state message any more. This can save the energy of E from being consumed by control messages when it has low energy. In FENOAL, the energy status of a node can be immediately notified to the whole network. This can make data be routed through another path resulting in energy balance in the network. In addition, reduction of link state message after LWAR can help protecting nodes against consuming much energy, which make the lifetime of the network longer.

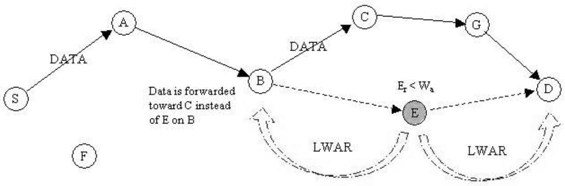

Fig. 3. FENOAL.

5. SIMULATION ENVIRONMENTS

We used *GloMoSim 2.0* simulator [13] developed from UCLA. GloMoSim supports a wide range of ad hoc routing protocols as well as realistic physical layers based on *Parsec* [14]. Our evaluations are based on the simulation of 40 mobile nodes moving around over a regular rectangular area of 1,500 meters by 300 meters for 500 seconds of simulated time.

We make two assumptions associated with energy. The first one is that we ignore the energy consumed during idle mode, and the second one is that we exclude the promiscuous mode in our simulation. In general, a node stays in sleep mode for the most of its lifetime, and putting the node in sleep node is a general idea to conserve energy. In this mode, a node consumes negligible energy. From [16, 17], emerging wireless LANs such as *IEEE 802.11* and *Bluetooth* provides a mechanism for each node to know when to wake up and receive packets and to sleep again. This means that time delay due to data receiving is almost similar to that due to data transmission for an intermediate node.

6. SIMULATION RESULTS

Comparison Summary

Throughout this paper, we focus on the balance of energy consumption among mobile nodes in mobile ad hoc networks. We introduce NOAL, adapt it to previously proposed routing algorithms, and propose two algorithms: LENOAL and FENOAL. In order to evaluate their performance, we compare them with DSR and FSR. In addition, GEAR is taken for the performance comparison because it can give us an upper bound in terms of power-aware routing. With these algorithms, three parameters are compared: *the average energy consumption, the energy balance, and the energy performances.*

Average Energy Consumption

In terms of the average energy consumption, LENOAL consumes a little more energy than DSR, because LENOAL uses more control packet such as DROP_ROUTE_REQ and RWAR for energy balancing and node protection. However the increasing rate is small (about 4%). In the case of GEAR, it consumes more energy than DSR and LENOAL. In GEAR, control packets contain the energy information piggybacked on intermediate nodes, which increases the size of control packets resulting in consuming much energy. In addition, GEAR does not use the optimization based on the route cache, which increases the number of control packets flooded into the network In proactive routing protocols, FENOAL consumes much more energy than the original FSR due to the overhead of piggybacking energy information on link state messages.

When comparing the average energy consumption between the reactive and proactive routing protocols, Fig. 4 clearly shows the difference.

Energy Balance

At first, Fig. 5 depicts the standard deviation of energy consumption in simulated routing algorithms. The result shows that under various network conditions, LENOAL improves the energy balance compared to DSR (24-36% with different pause time of nodes) and GEAR. It also shows that FENOAL balances the energy consumption among mobile nodes better compared to FSR (increased by 21~26%). As LENOAL does, the energy balance in FENOAL is getting better as the pause time becomes longer.

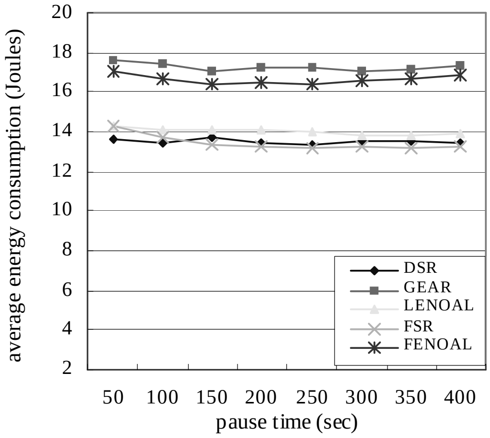

Fig. 4. Average Energy Consumption.

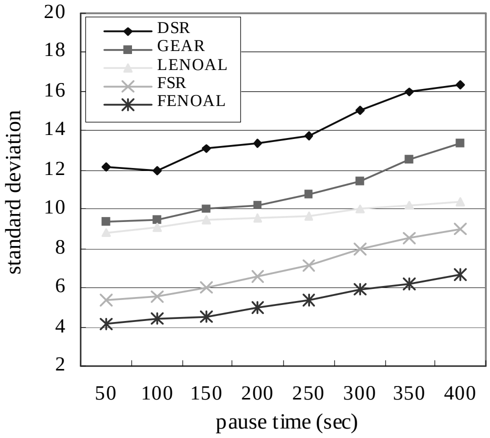

Fig. 5. Energy Balance: Standard Deviation.

On comparing between reactive and proactive routing protocols (see the non-NOAL algorithms: DSR and FSR), they have differences with each other (almost 2 times). FSR has better performance than DSR because of the flood of link state messages. In proactive routing algorithm, the energy consumption due to control packet is so large, and every node floods the message periodically. Therefore the difference in energy consumption among mobile nodes is not so large. On the other hand, nodes just along the data path handle control packets such as RREP and RERR in DSR. Therefore mobile nodes consume their energy only when they participate in the data path – if not, they don’t consume energy.

Fig. 6 and 7 depict results of energy balance in more detail. They belong to reactive and proactive routing algorithms, respectively. The results are taken under the network condition of 400 seconds of pause time. In Fig. 6 and 7, we measure the differences between the energy consumed by a node and the total average value and count the number of nodes according to the results. In Fig. 6, the distributions of energy consumption in DSR, GEAR, and LENOAL are compared. GEAR gets better performance than DSR because intermediate nodes in GEAR consume more energy due to relaying control packets containing energy information. LENOAL shows that an efficient distribution of energy consumption is accomplished, which there are fewer nodes consuming little or much energy than DSR and GEAR. In Fig. 7, two proactive routing protocols (FSR and FENOAL) are compared for the same parameter. It clearly shows that FENOAL can balance energy efficiently: there are few nodes consuming little or much energy comparing to the average value.

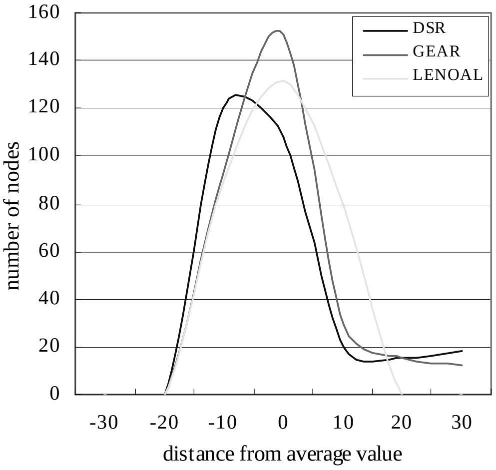

Fig. 6. Energy Balance: Distribution in Reactive.

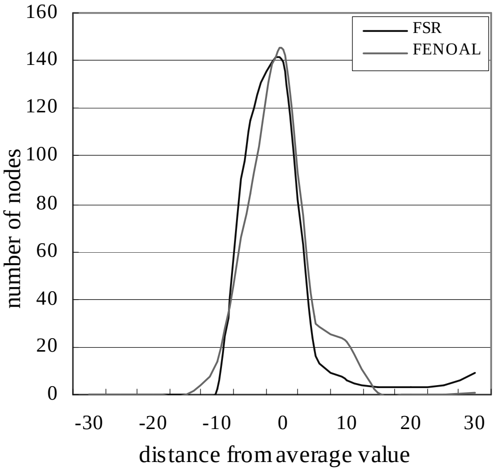

Fig. 7. Energy Balance: Distribution in Proactive.

As mentioned with Fig. 5, proactive routing protocols get better performance in energy balance. Fig. 6 and 7 depict the difference. In proactive routing protocols (Fig. 7), there are more nodes whose distance from the average value is close to 0 and fewer nodes consuming little or much energy.

Energy Performances

In this Subsection, we compare energy performances among the implemented algorithms: *the normalized standard deviation* and *the energy consumed per one data packet.*

Fig. 8 shows the normalized standard deviation. In reactive routing protocols, GEAR gets the best performance. Even though GEAR consumes much energy than the others, it distributes traffic over a network. This is because it uses the global energy information received form intermediate nodes. LENOAL gets a little higher result than GEAR because it consumes energy by additional control packets. DSR shows the worst performance. In proactive routing protocols, FENOAL shows better performance than FSR. Even though it consumes more energy than FSR because of piggybacking energy information, it efficiently balances energy in a network. When comparing the two categories, proactive routing protocols result in better performance. This is because mobile nodes in them consume similar amount of energy with each other due to processing similar amount of control packets. The longer the pause time becomes the worse the result gets. In low mobility, the route paths are stable enough for data to be routed for a long time through themselves. This makes unbalanced energy distribution because nodes along the paths consume more energy than others, which increases the results.

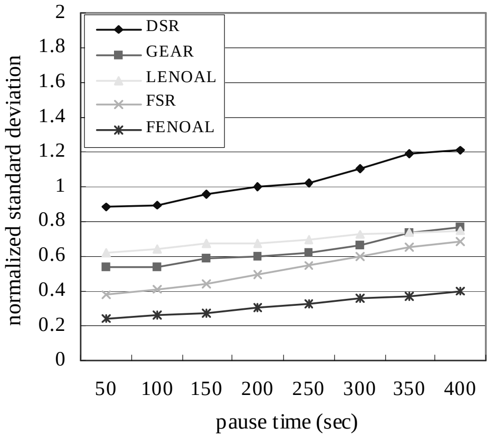

Fig. 8. Normalized Standard Deviation.

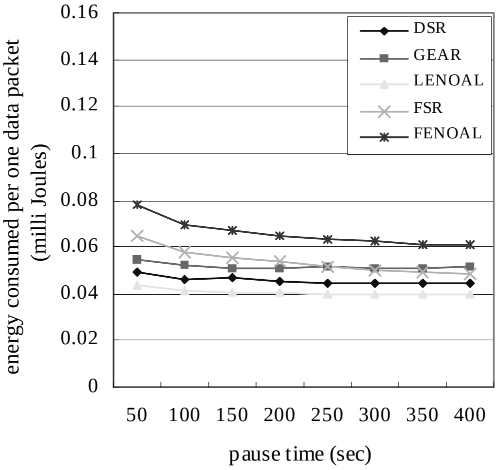

Fig. 9. Energy Consumption per One Data Packet.

The energy for an intermediate node to transmit a data packet is shown in Fig. 9. Only data packets successfully received on destinations are considered here. Among reactive routing protocols, LENOAL shows the best performance and GEAR shows the worst. LENOAL can transmit data without consuming much energy. Even though GEAR successfully transmits data well, it consumes energy due to piggybacking the energy information and not using route cache. In proactive, FENOAL shows worse performance than FSR. It is expected that the energy information piggybacked on control messages contributes to the energy consumption.

7. CONCLUSTION AND FUTURE WORKS

In this paper, we presented *Node Alarming Mechanism (NOAL)* that could protect node by avoiding energy depletion. It was adapted into LEAR and FEAR that are energy-aware routing protocols, and then *LEAR with NOAL (LENOAL)* and *FEAR with NOAL (FENOAL)* were introduced. Throughout this paper we measured the energy consumption, the energy balance, the network performances, and the energy performances. From the evaluation, LENOAL and FENOAL were shown to achieve balanced energy consumption in mobile ad hoc networks. They balance energy consumption in route discovery procedure where LEAR and FEAR begin their energy-balancing mechanism. They also consider energy balance during data transmission by adapting NOAL. Simulation results showed that energy usage was better distributed with the proposed LENOAL and FENOAL algorithms by 21-36% compared to DSR and FSR algorithms.

Current focus in energy-aware routing is to know the energy level of nodes and to include the value into route optimization process. However mobile devices in ad hoc network are required to do multiple tasks, such as internal computation, data sending/receiving, and data forwarding. Therefore the absolute value of energy on a node has different meaning for each node. [22] addresses this issue achieving fair energy balance among mobile nodes. We would like to adapt the style of energy consumption to LENOAL and FENOAL. We leave this as our future work.

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