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Dynamic Source Routing Protocol with Delay, Energy and Link quality awareness

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Abstract: **In network topology, packets are routed on the basis of shortest path but choosing the shortest path for real-time flows is insufficient. Respecting the deadline cannot be insured nor guaranteed neither with exhausted energy resource nor with overloaded intermediate mobile nodes. The traditional routing protocols in MANETs discovery routes are based on the shortest hop count metric due to which the routes selected for data transmission may be of low quality. A link on a selected route is considered as low quality link if it requires more number of re-transmissions to transmit a data packet to next hop. Therefore, a routing protocol is required which uses a route discovery process which is based on other metrics than the shortest hop count to improve the communication process in wireless MANETs. To choose the reliable, efficient and correct routing protocol to route real-time flows with respect to their deadlines within MANET constraints is the main problem. So, introducing the Enhanced Energy Delay aware protocol based on Dynamic Source Routing, EED-DSR. EED-DSR efficiently utilizes the network resources such as the intermediate node energy and load in order to balance traffic load and enhances the performance emphasizing on link quality and load balancing. In this algorithm which considers the quality of an intermediate link as a metric for its inclusion in the possible routes selected between a source-destination pair. It ensures both timeliness and energy efficiency by avoiding low-power and busy intermediate node. Simulation (NS simulator) studies shows, significant improvement in the performance of the network in terms of increased volume of delivered packets in-time shortens the end-to-end delay and energy consumption.**

Keywords: **On-demand routing, balancing, energy aware, mobile ad-hoc network, link quality, real-time flows, Quality of Service (QoS).**

1. INTRODUCTION

Mobile nodes in MANET are connected by wireless links and each node acts as a host and router in the network. They are characterized by their reduced memory, storage, power and computing capabilities. Mobile nodes are classified into two groups: Small Mobile Hosts (SMH) with reduced memory, storage, power and computing capabilities and Large Mobile Hosts (LMH) with more storage, power, communication and computing facilities than the SMHs. Here focus is especially on routing protocol for real-time applications where a number of them, including defense applications, have to respect time constraint in order to update positions of wounded soldiers or enemies, get enemy map position or find medical assistance, etc. Researches focus either on load aware for improving energy efficiency [1][5][10]without taking care of the deadline constraint, or on deadline guarantee by reserving resources [11] without considering their limited capacities. The main problem is to choose the reliable, efficient and correct routing protocol to route real-time flows with respect to their deadlines without overload intermediate mobile nodes or exhaust their batteries in MANET. Based on dynamic source routing (DSR) [3], here introducing the Energy and Delay-aware Dynamic Source Routing protocol (ED-DSR) for MANET. ED-DSR is a routing protocol which uses information from the physical layer and the MAC layer in choosing routes, focusing on the energy efficiency, load aware and deadline guarantee of intermediate nodes without disturbing the flows already in their queue. Main goal in this paper is to evaluate network load balancing proposed routing protocol and its ability to reduce energy consumption, reduce mobile node workload and guarantee timeliness. The remainder of this paper is organized as follows: in the second section, present the related work in Quality of Service (QoS) routing protocols. In the next section, describing the proposed Energy Delay-aware Dynamic Source Routing (ED-DSR) protocol and enhancement (EED-DSR). Detailed analysis of performance is performed in sections V and VI.

2. RELATED WORK

Routing protocols in mobile ad-hoc network allow mobile nodes to search a route in order to connect to each other and share the data packets. In the literature lot of QoS aware routing protocols have been proposed [4], [6], [9]-[11] and [13]. To determine a route, QoS routing considers QoS requirements of the traffic flows (such as maximum bandwith availability, minimum end-to-end delay and so on.) and resources availability (such as maximum residual energy, etc.), too. However, the selection of path with lowest energy can imply the selection of a longer route which maximize the end-to-end delay [10][13]. The ad-hoc mobile network highly depends on the lifetime of mobile hosts. A decrease of participating nodes may result in network partition, leading to interruptions in communications. As in such networks, mobile hosts need to relay their packets through other mobile nodes toward intended destinations. Therefore, the lifetime of participating mobile nodes should be prolonged by conserving energy at each intermediate node and the total energy for each connection request. Since most mobile hosts today are powered by batteries, efficient utilization of battery power assumes importance in MANET as the ad-hoc networks nodes are power limited and require energy for computing as well as routing the packets. Several works consider both energy efficiency and load aware to improve their routing protocol [10], [13]. However, for real-time flows, these criteria are insufficient. In fact, minimizing the end-to-end delay doesn't imply the no deadline miss of real-time flows. Moreover, the deadline guarantees require often resource reservation which may lead to the battery depletion of intermediate nodes more quickly. A load balancing among mobile nodes should be provided while at the same time contribute to reduce the number of dropped packets due to the deadline miss. In next subsections, focus is especially on and critic two solutions proposed in [10] and [11].

2.1 Energy-aware Multipath Routing Protocol, EMRP:

EMRP is an energy-aware multipath source routing protocol derived from Dynamic Source Routing (DSR) [10]. It makes changes in the phases of Route Reply, Route Selection and Route Maintenance according to DSR. EMRP utilizes the energy and queuing information to select better routes. In *route response*, while an RREP packet is being sent back to the source node, each intermediate node on the traverse route will stamp its current status in the RREP packet. The status field is finally collected by the routing agent at the source node.

In *routes selection*, EMRP chooses the working set of routes from all available routes according to the following rules. With this process, it checks the route feasibility for packet transmission respecting deadline. First of all, EMRP calculates the cost of each available route according to the following equation:

$$W = \sum_{i=1}^{n} \left(\alpha \times W_{energy}^{i} + \beta \times W_{queue}^{i} \right)$$

Where W is the cost of the route and W_{energy}^{i} and W_{queue}^{i} are the costs of node i considering the energy and queue length respectively. α and β are the costing factors which normalize W_{energy}^{i} and W_{queue}^{i}. A route is selected based on minimum values of W.

W_{energy}^{i} is calculated as follows:

$$W_{energy}^{i} = \left(\frac{P_{tx}^{i}}{E_{remain}^{i}} + \frac{P_{rx}^{i+1}}{E_{remain}^{i+1}} \right) + \left(1 + N_{retrans}^{i}\right)$$

Where P_{tx}^{i} and P_{rx}^{i} are the transmitting energy cost from node i to the next-hop node i+1 and the receiving energy cost of the next-hop node i+1, respectively. W_{energy}^{i} is a function depending of the distance and remaining energy of node i and the next-hop node i+1. More remaining energy and shorter distance indicate less W_{energy}^{i} .

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W^i_{queue} is given below:

$$W^i_{queue} = \log\left(1 + N^i_{queue}\right)$$

Where N^i_{queue} is the queue length at node *i*. W^i_{queue} depends on the queue length along the current route. If there are more packets in the queues along the route, the transmission will inevitably suffer a longer delay. W^i_{queue} increases rapidly with N^i_{queue}.

Critics: The above solution proposes multi-route routing protocol. It provides redundant and alternative routes in order to assure successful data packet transmission and, at the same time, reduce the intermediate nodes power consumption. However, the exhaustible energy battery is not the only indicator for route selection and a power control scheme. The number of packets in each node's queue, along the route, doesn't reflect the local processing time. In fact, each packet has its proper execution time which varies. Thus, the packet handing will inevitably suffer a longer delay and therefore the energy exhaustion of these nodes; while there are other nodes with less energy but where the queues require less time to be treated. The route selection should be done according to energy and more queuing information, in terms of queue length and local processing time of each previous flow, too.

3. EDDSR-PROPOSED METHOD

The basic working of proposed protocol is as follows.

Each node, before starting the transmission of real-time flows, selects a suitable route between the source and the destination. The selected route should satisfy delay requirements, preserve energy consumption and avoid overloaded intermediate nodes. Energy delay aware-dynamic source routing, ED-DSR, protocol is based on DSR. The focus in this work is on reactive routing suitable to be deployed in a network where routes are created dynamically as and when required. In DSR, multiple routes are stored in a trivial manner with no constraint on quality of services. DSR is based on three phases: route request, route response and shortest route selection. The delay requirement is not considered to ensure that packet will reach their destinations before the deadlines. Furthermore, DSR doesn't contribute to reduce the power consumption of mobile node, alleviating the network partitioning problem caused by the energy exhaustion of these nodes. However, DSR has some advantages which lead us to take it as based protocol in this study. DSR is more suitable for the real-time transfer as a reactive protocol, since it can be sure that the constructed route is up-to-date. DSR is on-demand protocol, it discovers a route between two nodes, only when required which reduce the number of packets control. DSR is simple and flexible [2] which facilitates the implementation of interested extension. Also, a route response packet, RREP, can be used to stamp the current status. The choice of the suitable route to transfer the real time data in ED-DSR is conditioned by three factors:

- The residual energy of nodes belonging to the route.

- The delay necessary of the real-time flow.

- The load of the intermediate node's queue.

A. Route request:

For a new real-time flow transmission, the source node checks its route cache first in order to check whether there are available routes to the destination node. If routes are available, the protocol starts the route selection phase, which is presented in next sub-section. Otherwise, the source node goes into the route request phase to request available routes by broadcasting a route request (RREQ) packet to all other nodes.

B. Routes reply:

A destination node sends a Route Reply (RREP) packet to the source node, when it receives a RREQ, in order to establish a route.

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In ED-DSR, while an RREP packet is being sent back to the source node (Activity 1 in Fig 1), each intermediate node on the traverse route will stamp its current status in the RREP packet (Activity 3 in Figure 1), which is finally collected by the routing agent at the source node (Activity 7 in Fig 1). This status information is shown in Table 1, in which *i* is the index for the mobile nodes.

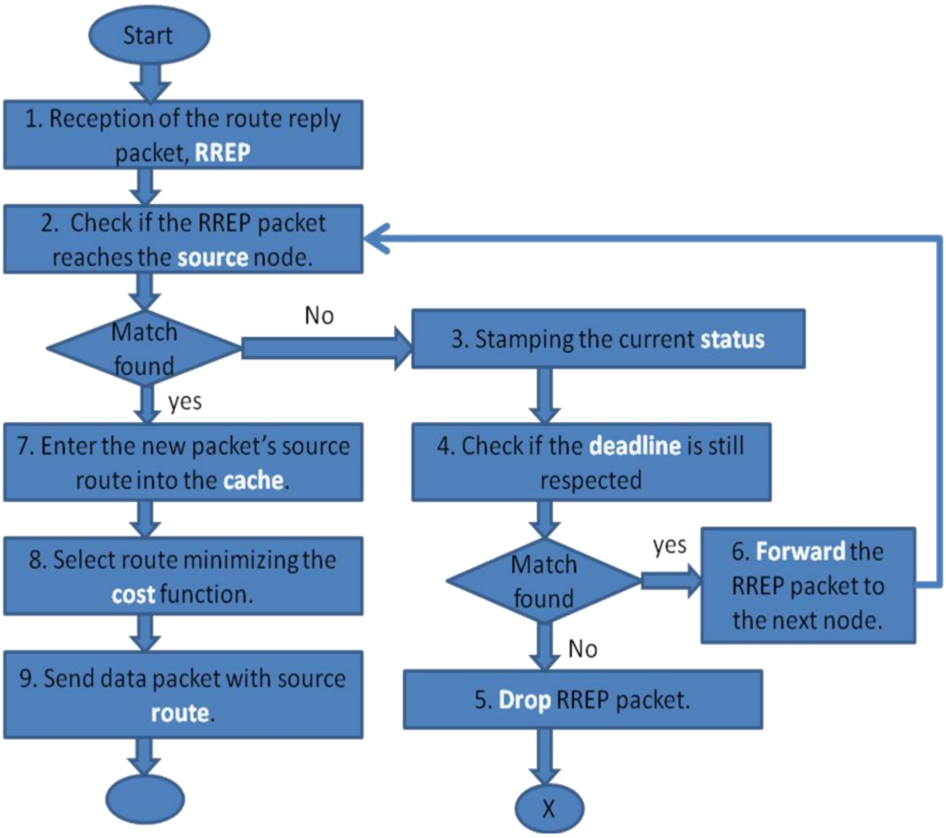

Fig 1: Activity diagram of intermediate node in route response phase

Table 1. Information fields of RREP packets

Information fields	**Contents**
d_i	Distance to this node provided by the physical layer
L^i_{queue}	Current length of queue, provided by the network layer.
E^i_{remain}	Current remaining energy of this node, provided by the physical layer.

ED-DSR calculates the cost of each available route according to the following equation:

$$C = \sum_{i=1}^{M} \left(\alpha \times C^i_{energy} + \beta \times C^i_{queue} + \gamma \times C^i_{delay} \right)$$

Where C is the cost of the route and C^i_{energy} , C^i_{queue} and C^i_{delay} are the costs of node *i* considering the energy, queue length and delay, respectively. α, β, γ are the factors which normalize , C^i_{energy} , C^i_{queue} and C^i_{delay} values between 0 and 1.

C^i_{energy} is calculated as follows:

$$C^{i}_{energy} = \left(\frac{d_i}{E^{i}_{remain}}\right)$$

C^{i}_{energy} is a function depending of the distance and remaining energy of node *i*. More remaining energy and shorter distance indicate less C^{i}_{energy}. It is more interesting to choose an intermediate node with more energy than a near node with less residual energy. C^{i}_{queue} is given below:

$$C^{i}_{queue} = \log\left(1 + L^{i}_{queue}\right)$$

Where L^{i}_{queue} is the queue length at node *i*. C^{i}_{queue} equation is calculated in the same manner as [10]. It is relative to the queue length along the current route. C^{i}_{queue} increases rapidly with L^{i}_{queue}. If there are more packets in the queues along the route, the transmission will inevitably suffer a longer delay. Thus, the application, initiated in the requestor, will deplete more energy while waiting for a response.

$$C^{i}_{delay} = L^{i}_{queue} \times T^{i}_{L} + T^{i}_{T} \times N_{hopes}$$

Where L^{i}_{queue} is the queue length at node *i*, T_L is the local processing time of any message in node *i*; T_T is the transmission time between two neighboring nodes in the worst case remaining times and N_{hopes} is the number of hops. C^{i}_{delay} depends on the queue length and the local processing time of each packet along the current route. Each packet (Activity 4 in Figure 1) should verify if it can reach the destination before the expiration delay. Otherwise, the node discards it (Activity 5 in Figure 1).

$$D_K > \sum_{i=1}^{N} C^{i}_{delay}$$

Where D_K corresponds to the worst case execution time for the packet k.

C. Route selection:

In ED-DSR, the source node waits a certain period of time to collect RREP messages from the destination nodes along various routes, which is exactly what DSR does. Different from DSR, ED-DSR chooses the set of routes from all available routes under the following rule: Among selected routes, the source node selects one based on minimum value of C (Activity 8 in Figure 1).

4. ENHANCEMENT IN PROPOSED METHOD: E-EDDSR

The proposed enhancement in ED-DSR is based on route selection criteria including the "remaining energy level" and the "sensor proximity with respect to the Base Station (BS) i.e. next hop"[14].

Cold chain monitoring application concerns the product storage in a warehouse where each pallet is handling temperature sensor. This application specifically collects rare events (alarms) to ensure the proper monitoring of the system. If the temperature is over a threshold, an alarm will be generated; this "interesting event" is then sent towards the BS. Due to the size of a warehouse which hosts large number of pallets, one upon the other, the WSN can reach several hundreds of sensors which collaborate for sending data towards the BS.

So, in this environment, the link quality is a key parameter which has many effects on the network performance. In this algorithm, nodes sense and send "interesting events" to the BS. Based on the acknowledgement, a sensor decides to retransmit the data or not. If the acknowledgement fails, the sensor selects another node and routes data towards the BS.

Here local load balancing routing mechanisms [14] is proposed by comparing the following metrics: the remaining energy level and the sensor proximity with respect to the Base Station.

5. ROUTES SELECTION CRITERIA

5.1 Remaining Energy Level:

The remaining energy of sensors could be a metric for selecting routes since a node with better battery life seems to be a better candidate for the packet routing from its neighbors. Conversely, if a sensor with low power is selected as an achtophorous node, this can lead to packet losses because it might not have enough batteries to forward packets. In this paper, it is considered that each node knows its energy level.

5.2 Sensor Proximity with respect to the Base Station (BS):

Paper considers a network deployed with a Base Station where each node knows its exact position and that of the BS. As the main goal of the application is to send data towards the BS, it seems natural to look at the metric [14] defined as follows:

dist(Si,BS) = 1/d(Si,BS)

Where d(Si,BS) is the distance separating the sensor Si from the BS. Intention to choose inverse of the distance is to promote the election of the closest sensor to the BS.

6. SIMULATION MODEL

A. Energy Consumption Model:

Let ETx(k, d) the energy [14] consumed to transmit k bits message over a distance d :

$$E_{Tx}(k,d) = E_{elec} \times k + \varepsilon_{amp} \times k \times d^2$$

Let ERx the energy consumed to receive a k bits message:

$$E_{Rx}(k,d) = E_{elec} \times k$$

Eelec = 50nJ/bit and ε = 100pJ/bit/m2

7. SIMULATION ENVIRONMENT

The Network Simulator (NS-2) is used in this simulation. NS-2 is an object-oriented, event driven simulator. It is suitable to use in order to design new protocols, compare different protocols and traffic evaluations. Simulation experiments are conducted to evaluate the performance of DSR which refers to the classic DSR protocol, Energy aware- Dynamic Source Routing (E-DSR) and ED-DSR which refers to proposed QoS protocol under different traffic loads. E-DSR has the same principle as ED-DSR except that the cost function depends only to the energy function C^i_{energy}. All simulations were performed with the NS-2 simulator. A MANET is simulated with 50 mobile nodes in a 1407m×732m. With a rectangle area, longer distances between the nodes are possible than in a quadratic area, i.e. packets are sent over more hops. Each node is equipped with an IEEE 802.11 wireless interface in a priority queue of size 50 that drops packets at the queue end in case of overflow. A traffic load between pair of source-destination (SMH-LMH) is generated by varying the number of packets per second on the constant bit rate - CBR. Each packet is 512bytes in size. Two groups of mobile nodes according to their resource capacity SMH and LMH are defined. At the beginning of simulation, SMH nodes started with a starting energy of 50 joules and LMH with 100 joules. Since the problem of consumed energy in idle state is not addressed, energy consumed in transmission and reception modes is only considered. As values, 0.075 W for transmission mode and 0.075 W for reception mode have utilized. The mobile nodes move around the simulation area based on the RWP mobility model. All results reported here are the averages for at least 5 simulation runs. Each simulation runs for 1000 s.

Table 2. Simulation parameters

Propagation model	TwoRayGround
Network Type	IEEE 802.11
Transmission Range	250 m
Queue Length	50
Interface Queue	Queue/DropTail/PriQueue
Scenario Parameters	
Network dimension	1407*732
Number of nodes	50
Simulation time (secs)	1000 seconds
Energy Consumption Parameters	
Initial Energy (Joules)	100J for LMH and 50J for SMH
Transmission Power (Watt)	0.075w for LMH and SMH
Receiving Power (Watt)	0.075w for LMH and SMH
Idle Power (Watt)	0.100w for LMH and SMH

8. SIMULATION SETTINGS AND RESULTS

Four important performance metrics are evaluated. They are used to compare the performance of the routing protocols in the simulation:

Real-time packet delivery ratio: The ratio of the total number of data packets received to the destination nodes by the total number of data packets generated.

Average end-to-end delay: The average packet end-to-end delay is the time of generation of a packet by the source up to data packets delivered to destination.

Network lifetime: The network lifetime corresponds to the first time when a node has depleted its battery power.

Energy consumption per bit delivery: It is obtained by dividing the sum of the energy consumption of the network by the number of successfully delivered bits.

Several simulations are performed using NS-2 network simulator. NS-2 generates a trace files analyzed using a statistical tools developed in AWK. The performance study concerns two versions of routing protocol DSR: DSR which refers to the classic DSR protocol, EMRP which refers to extended DSR with energy and queue aware and ED-DSR which refers to proposed QoS protocol. ED-DSR is enhanced by monitoring the link quality considering real time remaining energy and sensor proximity.

A) Network performance:

The network performance is evaluated with two metrics, namely, the rate of real-time flows that are delivered in-time (the deadline constraint is respected) and the end-to-end delay. The impact of traffic load between pair of source destination (SMH-LMH) is studied by varying the number of packets per second on the CBR connection for 50 mobile nodes.

1) Real-time packet delivery:

Firstly, it is observed and compared the variation of the ratio of all delivered packets regardless of compliance with the realtime constraints and the ratio of delivered packets in-time, which respect the real-time constraint, while the data rate of the CBR flow is increased. The figure 2 proves that ED-DSR and EED-DSR provide better performance than EMRP.

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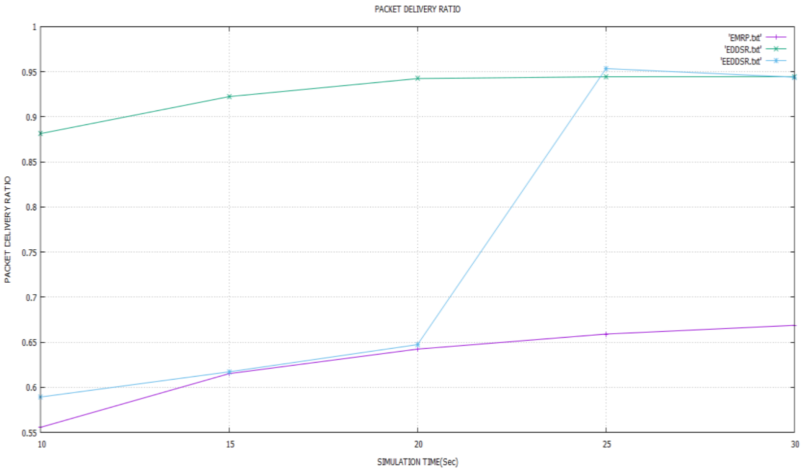

Fig 2: Comparison of packets delivery ratio

Each intermediate node verifies if the route response packet RREP respects or not the real-time constraint before reaching the source node. Thus, the MANET will avoid the network overloading with packets that have expired their deadline in order to reduce energy consumption and thus alleviate network load. However, as compared with EDDSR, in EEDDSR, the packets delivery is not guaranteed especially for the initial time duration but better than EMRP. The ratio of the packets sent within the compliance of its real-time constraint is over 50%. ED-DSR offers best performance for delivering real-time packets in time.

2) End-to-end delay guarantee:

Another commonly used metric is the end-to-end delay. It is used to evaluate the network performance. As shown in figure 3, the packet end-to-end delay results experienced by the protocols are comparable. It implies that the delay is respected when the communication load is low. When the communication load increases, a number of packets are dropped, the route discovery is restarted and the packet delay increases with EMRP. It indicates that packet delay is sensitive to the communication load and is basically dominated by queue delay. However, with ED-DSR, the end-to-end delay stills low. The network overloading is avoided by discarding the packets that have expired their deadline and thus alleviate the load of mobile node queue. Comparing with EMRP and EDDSR, EEDDSR shows great results as routes are monitored for link quality and packets are diverted through different routes if the existing route's link quality degrades. Proposed protocol EED-DSR selects different routes depending on the cost function, thereby balancing the traffic in the network. This load balancing helps to avoid overloaded nodes in the network and reduce the delay for packets. Thus, proposed protocol EEDDSR gives much improved performance. In fact, EED-DSR selects routes which reduce the transmission delay in order to respect the deadline.

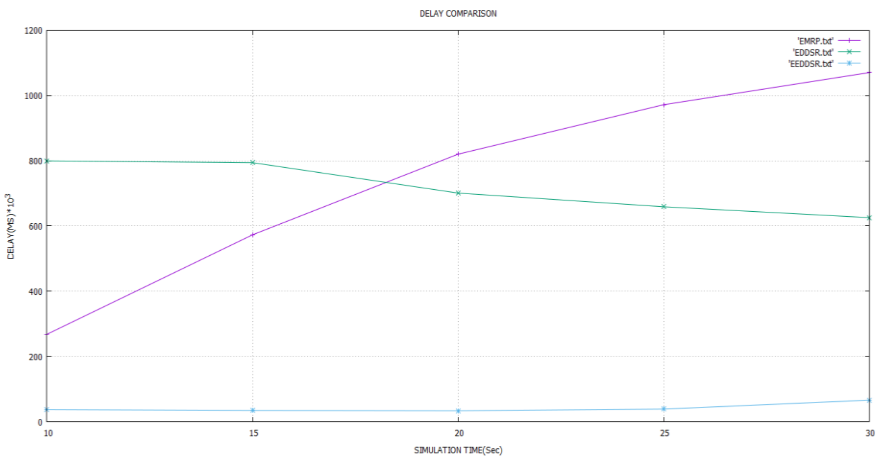

Fig 3: End-to end packet delay

B. Energy efficiency:

In this section, focus is especially on the impact of proposed protocol ED-DSR and EED-DSR on energy efficiency guarantees, compared to EMRP. Two metrics, namely, the network lifetime and the energy dissipation are used. The impact of traffic load between pair of source-destination (SMH-LMH) is studied by varying the number of packets per second on the CBR connection for 50 mobile nodes.

1) Network lifetime:

Figure 4 shows the simulation results for network lifetime comparing EMRP, ED-DSR and EED-DSR.

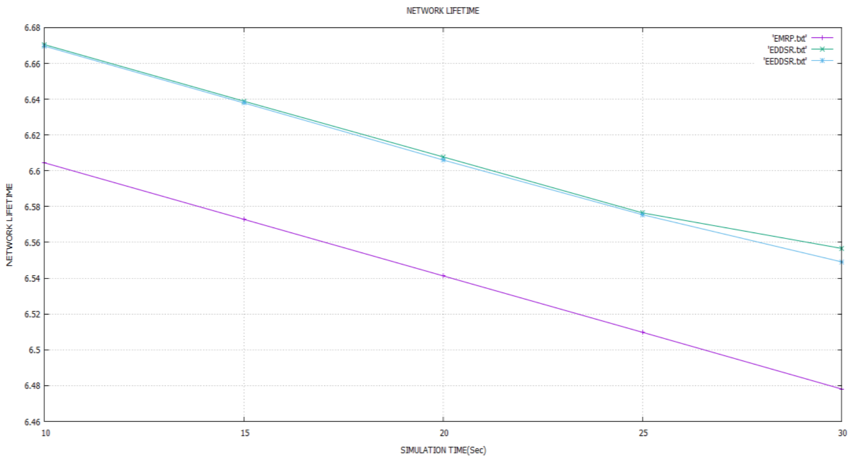

Fig 4: Comparison of network lifetime

It can seen that networks running ED-DSR and EED-DSR live longer than those running EMRP. As evident by the graph, ED-DSR and EED-DSR are much efficient as EMRP. In fact, the real-time packets are discarded by intermediate nodes once their deadline is exceeded which contributes to preserve battery resources. By avoiding the network overloading with packets that have expired their deadlines and selecting routes that minimize energy cost, ED-DSR and EED-DSR alleviates network load and reduces energy consumption, too. EMRP network lifetime was low in approximately all cases in comparison to ED-DSR and EED-DSR since EMRP generates typically more routing overhead than ED-DSR and EED-DSR.

2) Energy dissipation:

Figure 5 demonstrates the average energy consumption per bit delivery. It gives an idea about the global energy consumption in the network comparing ED-DSR, EED-DSR and EMRP. It is seen that ED-DSR and EEDDSR outperform EMRP, which is mainly due to the benefit of power control in the MAC layer.

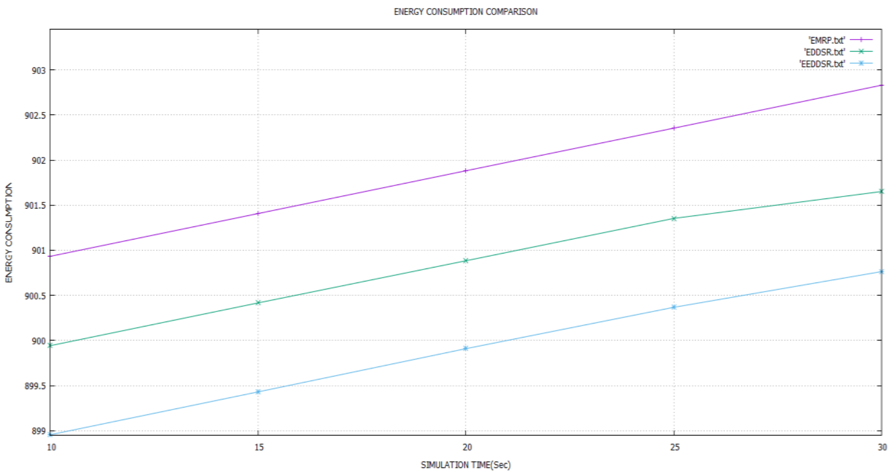

Fig 5: The average energy consumption per bit

The excess packets inevitably introduce more collisions to the network, wasting more energy. EED-DSR chooses alternative routes, avoiding the heavily burdened nodes, thus alleviating the explosion in average energy consumption. EED-DSR average energy consumption is comparable to ED-DSR. However, it is lower than ED-DSR and EMRP average energy consumption because EED-DSR and ED-DSR select path that minimize cost function.

9. CONCLUSIONS AND FUTURE WORK

There is a growing demand that mobile nodes should provide QoS to mobile users since portable devices become popular and applications require real-time services.

In this paper, an enhanced energy delay-aware routing protocol for mobile ad hoc networks with link quality monitoring is proposed. EED-DSR is a routing protocol which allows the packets of real-time flows to be routed from the sender to the receiver before the expiration delay to deadline. In addition, the route selection is done according to energy consumption and queue load of intermediate nodes, too. During the data transmission, route is monitored for link quality and based on the beacon messages (about nodes remaining energy going below threshold value) from the nodes, source selects different routes. Cost function is defined based on residual energy, queue length, processing and transmission time of intermediate nodes. The route is selected based on minimum value of cost function. Simulation results prove the performance of our proposal routing protocol. They indicate that EDD-DSR achieves lower energy dissipation per bit of data delivery and lower end-to-end delay. In the future, plan is to experiment this protocol with large number of nodes and study their effects on the system in order to appropriate QoS service to user needs: which factor to privilege (energy, delay or node load).

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