A Deep Study of a New Energy Efficient Routing Protocol for Mobile Ad-hoc Networks

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ABSTRACT- Routing in MANETs (Mobile Ad-hoc Networks) is a very hard task due to their dynamic topology and their decentralized nature. Moreover, limited-energy resources make both nodes and network lifetime among the main issues to be considered in MANETs’ routing protocols design. This paper discusses many aspects related to routing in MANETs and presents MEA-DSR, a new energy-aware routing protocol. A deep simulation study is also presented showing the efficiency of our routing-policy proposal in many challenging scenarios.

Key-words: Mobile Ad-hoc Networks, Routing Protocols, Energy efficiency.

I. INTRODUCTION

A MANET is a collection of constantly moving nodes communicating in a multi-hop fashion without a need for any central control or administrative authority. Every node runs as a router by forwarding its neighbors’ traffic. Topology changes in MANETs are too frequent due to nodes mobility and failure, but also due to the fluctuations in the wireless communication medium. Thus, traditional routing policies designed for wired networks, based on assumptions of stable topology and predictable communication medium, are absolutely inadequate for MANETs routing context. Taking into account bandwidth limitation in MANETs, many new routing protocols have been proposed in the literature. Of course, no protocol is adequate for all scenarios, since everyone is based on particular assumptions. Furthermore, performances of any routing protocol for MANETs are heavily affected by varying network conditions.

Another intrinsic characteristic of MANETs worth considering is energy–resources limitation, which has made the focus of new emerging routing protocols called energy aware routing protocols.

In fact, our present work deals with energy conservation issue in MANETs. The main contribution of this paper is the proposal of a new routing protocol: MEA-DSR (Multipath Energy Aware Dynamic Source Routing) which considers network lifetime as the first optimization criterion. In addition, we give a deep and thus an interesting simulation study concerning nodes mobility, network density and traffic-load impact on both MEA-DSR and DSR [17] protocols performances. This gives a well understanding of how network conditions may interact to influence a routing policy either positively or negatively.

The reminder of this paper is organized as follows. Section 2 deals with well known routing policies for MANETs, and discusses their limitation from an energy efficiency perspective. Section 3 summarizes the main approaches of energy efficient routing in MANETs. Section 4 presents our new protocol ‘MEA-DSR’. Section 5 illustrates simulation results. Finally, section 6 concludes the paper and highlights the future directions of our research.

II. NON-ENERGY AWARE ROUTING PROTOCOLS FOR MANETS

In order to well understand and compare routing protocols, appropriate classification criteria are indispensable. Widely accepted ones are those related to: the exploited routing information, the time when this information is acquired, the optimized metrics and nodes-rule in the routing process [1,15,20,22,24]. In what follows, we will describe shortly many routing approaches according to each classification criterion.

2.1 Evaluation of topology, destination or position for routing

By considering information exploited in routing we distinguish: topology, destination, or position based routing protocols. In a topology based routing protocol [6,27], every node maintains a full view of network topology, whereas a destination based routing protocol [25,30] maintains only next hop routing information toward every possible destination. A position based routing protocol [3,19] exploits information about source and destination nodes localizations and information about nodes mobility, either in routes discovery or in routing data phase.

2.2 Proactive, reactive or hybrid Routing

Routing protocols are different in the way they acquire and maintain routing information. Hence, we discriminate proactive, reactive and hybrid protocols. Proactive protocols [25,30] make periodic routes updates so that a data packet can be immediately transmitted when needed. In contrast, reactive protocols [17,29] initiate routes discovery on demand. A hybrid protocol [13,16] combines both reactive and proactive approaches. This is by organizing the network in a hierarchical manner, and applying appropriate approach at each hierarchy level.

2.3 Routing metrics

Number of hops is the mostly used metric, where the routing protocol looks for the shortest path [17,25,29,30]. Other routing protocols take into account link stability in routes choice[11,34]. It is also possible to consider many metrics simultaneously such as: delay, bandwidth and error rate to satisfy QoS requirement of certain applications [2,8,31].

2.4 Uniform and non-uniform routing
We say that a routing protocol is uniform, if nodes play the same role in routing and have the same importance and functionality [11,17,25,29,30,34]. In contrast, in a non-uniform routing protocol certain nodes have extra routing and management functions. Non-uniform routing protocols can be divided, depending on nodes organization, management and routing strategies, to zone [13,16], cluster [9,28] or central nodes based protocols [14,31].

2.5 Discussion

i) Currently used metrics are inadequate with network lifetime maximization objective:

All aforementioned routing approaches try to minimize routing overhead and thus bandwidth consumption, while searching optimal routes. Most of the proposed protocols are shortest path based ones (e.g. DSR[17], DSDV[30], etc), others like ABR[34] and SSA[11] exploit links quality in routes choice. Unfortunately, all those metrics have a negative impact on nodes and, hence, network lifetime due to the overuse of energy resources of certain nodes in favor of others [37].

For example, in the network illustrated on Figure 1, a shortest path routing protocol prefers to forward packets between nodes 0-3, 1-4 and 2-5 via node 6 which exhausts its energy so quickly. Similarly, non-uniform routing protocols per their conception overuse key-nodes like: cluster-heads, gateway nodes, etc [37].

Figure 1: A network topology illustrating the problem of nodes overuse by a shortest path routing protocol.

Moreover, in reference [23], it has been demonstrated through simulations that a link-stable based routing protocol (like ABR) is less equitable in energy expenditure than a typical shortest path routing protocol (like DSR). The authors explain this by the fact that stable routes, and consequently, typical shortest path routing protocol (like DSR). The authors explain this by the fact that stable routes, and consequently, nodes belonging to those routes, are still used for longer time.

ii) Reactive and multipath routing are compatible with energy-consumption minimization objective:

It was shown in reference [5] that reactive routing protocols consume typically less energy than proactive protocols. This is because reactive protocols generate less routing overhead, since it initiates routes discovery only when there is data to be send.

Multipath routing, which consists to give a source node the choice between several routes toward a destination to be used either simultaneously or alternatively, is a compatible paradigm with energy economization(saving) goal. Traffic distribution on multiple routes balances energy expenditure among mobile nodes [21]. Also, maintaining multiple routes per destination in a reactive routing protocol has the advantage of minimization of routes discovery frequency, and hence of the global energy consumption [36].

III. ENERGY-AWARE ROUTING IN MANETS

Energy consumption is an important factor in routing protocols design for MANETs, since mobile nodes are battery powered. Also, in critical environments like battlefields or disaster areas, recharging or replacing batteries is often impossible.

Indeed, in a MANET, energy depletion of one node does not affect only its ability to send and receive, but also its ability to forward other nodes traffic. This can diminish network performances or it can cause its partition.

Actually, there are three areas of research in energy efficient routing in ad-hoc networks:

1) Power control [11,41]: increases network capacity and reduces energy consumption by allowing nodes to determine the minimum transmission power level required to maintain network connectivity and forward traffic with least energy cost.

2) Power save protocols [7,40], take care of high idle state energy consumption problem by maximizing the amount of time that nodes spend in the sleep state.

3) Maximum lifetime routing [18, 37, 39] chooses paths that maximize network lifetime by balancing energy expenditure among nodes.

The two first approaches aim to minimize energy consumption of individual nodes, whereas the later approach focalizes on balancing energy expenditure among all mobile nodes. Of course, those approaches are not exclusive, besides, works like [33,35] have combined both maximum lifetime routing and power control approaches.

As explained in a previous section, multipath routing is homogeneous with energy economization goal. In fact, many multipath energy efficient routing protocols can be found in the literature [32,38].

We believe that the most challenging issue in the design of any energy efficient routing protocol is to keep some important performances metrics such as: packet delivery ratio and end to end delay in their acceptable intervals. For this reason, we have conducted simulations of our proposed protocol in comparison to DSR, a widely accepted routing protocol for its good performances.

IV. MEA-DSR PROTOCOL

A. Motivations

As argued in a previous section, reactive protocols are more suitable for energy efficient routing in MANETs. However, routes failure, which is a norm rather than an exception in MANETs, makes that conventional reactive routing protocols, lose a considerable amount of nodes energy due to frequent routes reconstructions.

One can say that frequent topology changes in MANETs allow some kind of load distribution by forcing nodes to discover new routes. Nevertheless, certain nodes are still overused because of their critical positions which contradict energy-expenditure (to) balancing ambition.

In MEA-DSR, we exploit multipath routing to minimize routes reconstructions. This guarantees an economization (saving) in the global energy consumption, since less routing overhead will be generated. In addition, the use of maximally node-disjoint routes makes part of our proposed load sharing strategy. This later(latter) exploits, also, information about nodes energy levels and paths lengths in making routing decisions.

B. MEA-DSR operation

In its basic functioning, MEA-DSR is somewhat similar to DSR [17], since it is a reactive, unicast, source routing...
protocol as well. In fact, DSR stores multiple routes in a trivial manner with no constraint on their number or quality. MEA-DSR limits the number of routes that a source node maintains to a destination to two routes. It was shown in [26] that using more than two alternate routes (in a typical reactive multipath protocol) presents only a minimal performances-gain. In MEA-DSR, the choice of the primary route is conditioned by two factors: residual energy of route-nodes and total transmission power required to transmit data on this route. If we consider that adjusting transmission power feature is not supported by all network interfaces cards, this factor will be equivalent to route-hops number. The primary route ‘route’ must satisfy the following condition:

\[
\text{min}_{\text{path,lev}} = \frac{\text{MSR}}{\text{remaining length}} \cdot \text{Path length},
\]

(1)

Where:
- \text{min}_{\text{path,lev}}: is the minimal residual energy of nodes traversed by a RREQ (Route Request) packet.
- \text{Route length}: measured in number of hops.
- \text{n}: is the number of candidate routes stored at the destination node.

The second route must be maximally node-disjoint than the first one. If several routes satisfy this criterion, then one will be chosen according to equation (1). Obviously, MEA-DSR does not allow intermediate nodes to respond from their caches as it is the case in DSR. This is to make choice of maximally node-disjoint routes easier.

In MEA-DSR, only one route is exploited to send data traffic until its breakage. After what, it will be substituted by the alternate route one. Note that two node-disjoint routes are less likely to break simultaneously. It is worth to notice that the use of only one route in data forwarding allows avoiding problems of routes coupling, congestion of common nodes and out-of-order arrival of data packets to destination nodes.

V. SIMULATION RESULTS

A. Simulation environment

NS-2 simulator [43] was used for MEA-DSR and DSR performances comparison. The studied network is deployed on square area of 1000mx1000m. Each node has a transmission range of 250 m. The MAC protocol was based on IEEE 802.11 with 2 Megabits per second raw capacity. For radio propagation model, a two-ray ground reflection model was used. In all simulations, we have used the RWP mobility model [4]. The duration of every simulation was 600 seconds. Communication between nodes was modelled by CBR traffic over UDP. Source nodes generate packets of 512 bytes.

Since we did not address the problem of consumed energy in idle state we have only considered energy consumed in transmission and reception modes. As values, we have used those obtained through experiments in a previous work [12] (1.4 W for transmission mode and 1 W for reception mode).

To study mobility, density and traffic impact on MEA-DSR and DSR performances we have considered several scenarios as illustrated in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Studied simulation scenarios</th>
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<tr>
<td><strong>Mobility</strong></td>
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<tr>
<td>Pause time</td>
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<tr>
<td>Maximum speed randomly</td>
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1In DSR implementation used for comparison with MEA-DSR, destination nodes reply only to the first route request arriving from a source node. Intermediate nodes are allowed to reply from their caches.

B. Performance metrics

Studied performance metrics are the following:

- Normalized routing overhead (NRO) - the ratio of the number of routing protocol control packets transmitted to the number of data packets well received by destination nodes.
- Packet delivery fraction (PDF) - the ratio of data packets well received to those generated by source nodes.
- Average end to end delay (AD) - the average time that takes a data packet from the source node to the destination node.
- Consumed energy per packet (CEP) - the ratio of global consumed energy to the number of data packets well received.
- Standard deviation of consumed energy per node (SDCEN) - square root of the average of the squares of the difference between the energy consumed at each node and the average energy consumed per node.
- Minimal residual energy ratio (MRER) - the minimal of nodes residual energy to the initial energy ratio.

C. Simulation results

1. Node mobility impact on MEA-DSR and DSR performances

In all what follows, we mean by high mobility (low mobility): a high speed (low speed) and/or a frequent mobility (less frequent mobility) which is function of pause time duration.

1.1. Normalized routing overhead

\[
\text{DSR (b) MEA-DSR}
\]

(a)
Figure 2. NRO vs. pause time in a) case of low speed b) moderate speed c) high speed.

Under high mobility scenarios, DSR generates more routing overhead than MEA-DSR, because DSR reinitiates route discoveries repeatedly and consequently generates more RREQs.

In lower mobility scenarios, routes become more stable. Thus, the need to reinitiate new route discoveries is diminished for both protocols. However, MEA-DSR still generates high overhead. This is because MEA-DSR permits intermediate nodes to propagate RREQs duplicates, whereas in DSR intermediate nodes drop every duplicate RREQ. Furthermore, RREQ packets in MEA-DSR always propagate until their final destination, whereas in DSR intermediate nodes can directly reply from their caches.

1.2. Packet delivery fraction

Under high mobility scenarios, MEA-DSR presents a higher PDF than DSR. The reason is that intermediate nodes in DSR, are authorized to answer from their caches. However, in such mobility conditions stored routes are more likely to be stale.

Thus, data packets forwarded on those routes will be dropped, as soon as they reach broken links, since also salvaging mechanism becomes less efficient. In addition, data packets are more likely to expire because of the additional latency introduced by frequent retransmissions and repetitive salvaging attempts. For lower mobility scenarios, PDF of DSR increases to surpass MEA-DSR one, because routes tend to be more robust and both responding from cache and salvaging mechanisms become more efficient. In MEA-DSR, intermediate nodes are not authorized to use their caches to salvage data packets. Thus, data packets probability to be dropped is greater than it is in DSR.

1.3. Average end-to-end delay

Under high mobility scenarios, AD in DSR is always higher than it is in MEA-DSR. This is because data packets in DSR spend more time in interface queues due to frequent retransmissions and repetitive salvaging attempts. Furthermore, data packets still in wait for longer time in source-nodes -interface queues before routes construction.

Under low mobility scenario, AD of DSR is approximately the same as MEA-DSR one, since routes reconstructions become less frequent.
1.4. Consumed energy per packet

Figure 5. CEP vs Pause time in a) case of low speed b) moderate speed c) high speed.

CEP is proportional to both generated routing overhead and used routes length. For high mobility scenarios, DSR generates more overhead than MEA-DSR. Thus, it consumes more energy. For lower mobility scenarios, although DSR generates less overhead it does not neither present an important improvement in energy consumption because it tends to use longer routes (total transmission power of a packet stills high) which are replies coming from intermediate nodes (they make simple concatenations of already available route in their caches with the route from source node to the current node).

1.5. Standard deviation of consumed energy per node

Figure 6. SDCEN vs Pause time in a) case of low speed b) moderate speed c) high speed.

Under all mobility scenarios, SDCEN in MEA-DSR is always lower than that of DSR, which confirms the efficiency of load distribution policy adopted in MEA-DSR.

For both protocols, network stability provokes SDCEN increase. This was expected, since routes are still in use in a communication session while they are valid.

1.6. Minimal residual energy ratio
Since MEA-DSR was fairer than DSR, under all mobility scenarios, its MRER was the highest. Under high mobility scenarios, the gain in residual energy was more important thanks to its lower global energy consumption.

2. Load traffic impact on MEA-DSR and DSR performances

2.1. Normalized Routing Overhead

If we increase data send rate, more routes breaks will occur involving more routes reconstructions. If we increase number of data sessions more protocol operations will be initiated. In either case, this will increase the generated routing overhead. When augmenting data send rate, NRO of MEA-DSR was less important than DSR one. This is because DSR needs to reinitiate routes discoveries more frequently than MEA-DSR per data session. When augmenting number of data sessions, NRO of MEA-DSR was more important than DSR one. This is normal since the number of exchanged RREQs per route discovery cycle in MEA-DSR is greater than in DSR.

2.2. Packet delivery fraction

The augmentation of traffic load increases the risk of congestion and interferences which provokes more packets loss. This explains why the PDF of both protocols have decreased while increasing number of data sessions and data send rate. When increasing data send rate, MEA-DSR outperformed DSR. This is because MEA-DSR suffers less from queue congestion since it generates less overhead per data session than DSR. Although increasing number of data sessions has provoked an increase of the generated overhead by MEA-DSR, but DSR still drops more data packets than MEA-DSR due to queue congestion. This behavior can be explained by the fact that DSR spends more time before liberating an interface-queue entry corresponding to a non-acknowledged packet by making several salvaging attempts (under high mobility conditions cached routes are more likely to be stale). During this time, new arriving data packets will be dropped. Particularly, this is problematic when packets transmitters do not maintain alternate routes or do not maintain valid ones.

2.3. Average end-to-end delay
The increase of traffic load leads to more collisions and congestion. Thus, in both protocols data packets spend more time in interface queues due to frequent retransmissions attempts. In approximately all cases, AD of MEA-DSR was smaller than DSR one. This can be obviously explained by the fact that data packets in DSR spend more time in senders’ buffers waiting for routes establishment, and at intermediate nodes’ interface-queues due to frequent retransmission and salvaging attempts.

### 2.4. Consumed energy per packet

![Figure 11. CEP vs a) data send rate b) number of data sessions](image)

When increasing data send rate, CEP of MEA-DSR was inferior from DSR one. This is because MEA-DSR generates less routing overhead than DSR. Although when increasing number of data sessions, the routing overhead generated by DSR was less important than that generated by MEA-DSR, but this did not yield to DSR outperformance. This can be explained by the fact that DSR consumes more energy than MEA-DSR due to its ineffective salvaging attempts.

### 2.5. Standard deviation of consumed energy per node

![Figure 12. SDCEN vs a) data send rate b) number of data sessions](image)

The efficiency of load distribution strategy implemented in MEA-DSR was clear in cases of 2 and 4 pkts/s send rates. In all other cases (data send rate from 8 to 12 pkts/s and number of data sessions from 15 to 40), SDCEN of MEA-DSR was the worst. This can be explained by the reduction in number of RREQS received at destination nodes due to interferences and congestion provoked by traffic load augmentation. When increasing data send rate from low to moderate values (2 to 6 pkts/s), SDCEN of both protocols have increased since more traffic is injected between same source-destination pairs. Hence, same nodes are used more frequently. When increasing the number of data sessions, both protocols have marked an enhancement in their SDCEN. This is because more nodes initiate communications, and thus will have very similar energy-consumption profiles.

### 2.6. Minimal residual energy ratio

![Figure 13. MRER vs a) data send rate b) number of data sessions](image)

When increasing data sent rate, MRER of MEA-DSR was more important than DSR since the global energy consumption in MEA-DSR was lower than DSR one. This was also true in cases of 10 and 15 data sessions. From 20 to 40 data sessions, the MRER of DSR was somewhat enhanced thanks to its nodes usage fairness mitigation.

### 3. Node density impact on MEA-DSR and DSR performances

#### 3.1. Normalized routing overhead

![Figure 14. NRO vs number of nodes](image)

As expected, the NRO of both protocols increased with node density growth. It is clear that under all density conditions MEA-DSR NRO was inferior from DSR one. This is because MEA-DSR reinitiates routes discoveries less frequently than DSR thanks to the use of maximally node-disjoint routes, and thus generates less control packets.
3.2. Packet delivery fraction

Under all density conditions (except for the case of 50 nodes where PDF of both protocols was approximately the same) the PDF of MEA-DSR was higher than DSR one. This can be explained by the fact that DSR suffers more than MEA-DSR from queue congestion problem since it generates more overhead. Furthermore, routing overhead for both protocols increases with node density which had aggravated queue congestion problem. This explains the reduction of both protocols PDF according to node density augmentation.

By examining trace files of simulations, we found out that MEA-DSR tends to use longer routes when node density increases which lead to an augmentation of routes failure probability. This is another reason for MEA-DSR PDF decrease.

3.3. Average end-to-end delay

The augmentation of node density leads to the occurrence of more collisions. Thus, in both protocols data packets spend more time in interface queues due to frequent retransmissions attempts. In all cases, AD of MEA-DSR was smaller than DSR one. This can be obviously explained by the fact that data packets with DSR spend more time in senders’ buffers waiting for routes establishment.

3.4. Consumed energy per packet

Increasing node density leads to an augmentation of collisions risk (consequently to more retransmission attempts) and to a growth in number of exchanged control packets. All those factors cause more energy dissipation for both protocols. MEA-DSR CEP was lower than DSR CEP under all density conditions because MEA-DSR always generates less overhead than DSR. Thus, its global energy consumption remains lower than DSR one.

3.5. Standard deviation of consumed energy per node

The efficiency of load distribution policy implemented in MEA-DSR was clear in cases of 50 and 60 nodes, where the SDCEN of MEA-DSR was inferior from DSR one. Changing node density had not a significant impact on SDCEN of MEA-DSR; it was still varying from 30 to 33. The load distribution in DSR was enhanced with node density increase. This is due to the variety of routes replies received from intermediate nodes.

3.6. Minimal residual energy ratio

Since the SDCEN and thus fairness of MEA-DSR was approximately the same under all density conditions MEA-DSR MRER diminution according to node density augmentation is justified by the increase of generated routing overhead.

Although the generated routing overhead had also increased in DSR, but this did not lead to a reduction of its MRER. In fact, under all density conditions DSR MRER was nearly the same and it varied between 51% and 54%. This result can be explained by the enhancement of nodes usage fairness of DSR. Nevertheless, DSR MRER was low in approximately all cases in comparison to MEA-DSR since DSR generates typically more routing overhead than MEA-DSR.

VI. CONCLUSIONS AND FUTURE WORKS

Maximally node-disjoint routes are exploited in MEA-DSR to 1) achieve a global energy gain by minimizing routes discoveries frequency; and to 2) balance energy consumption between mobile nodes. The choice of the primary route in MEA-DSR is dictated by minimal residual node energy to route length ratio, whereas disjunction ratio from primary route comes in first order in alternate route choice. Simulation results have shown energy efficiency of the proposed protocol, under many difficult scenarios characterized by high mobility and/or high node density. Unfortunately, the benefit of the proposed load sharing strategy becomes negligible under high traffic load.

Although the global efficiency of the proposed schema, it still remains best-effort service based. In fact, success of MANETs is conditioned by their ability to support both error and time-sensitive applications which have specific quality of service requirements. Hence, we plan to extend the presented protocol by addressing quality of service issue.

Another serious critic which can be made about the proposed routing-schema is its lack of adaptability. To take care of this problem we propose to adopt a powerful learning technique like reinforcement learning one. This makes the main focus
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