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OLSR vs DSR: A comparative analysis of proactive and reactive mechanisms from an energetic point of view in wireless ad hoc networks

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ABSTRACT

Untethered nodes in mobile ad hoc networks strongly depend on the efficient use of their batteries. Despite the fact that devices are getting smaller and more powerful, advances in battery technology have not yet reached the stage where devices can autonomously operate for days. At the network layer, routing protocols may balance power consumption at nodes according to their routing decisions. In this paper, an in-depth performance comparison of the DSR (Dynamic Source Routing) and the OLSR (Optimized Link State Routing) is presented in terms of energy consumption. Using the ns-2 simulator an evaluation is made of how the different approaches affect the energy use of mobile devices. It was found that a reactive protocol takes advantage of its routing policy when the traffic load is low. However, at higher traffic rates, a proactive routing protocol can perform better with an appropriate refresh parameter. Also, it is demonstrated that independently of the routing protocol selected, the overhearing activity can seriously affect performance. To the best of our knowledge, this is the first simulation study addressing the power saving issue to extensively compare the DSR and OLSR protocols under a wide variety of networking scenarios.

1. Introduction

In the last few years, thanks to the proliferation of wireless devices, the use of mobile networks is growing very fast. In particular, a very large number of recent studies focused on Mobile Ad hoc Networks (MANETs) [1,2]. A MANET is a network without fixed infrastructure, in which nodes belonging to a MANET can either be end-points of a data interchange or can act as routers when the two end-points are not directly within their radio range. This kind of network, self-organizing and self-reconfiguring, is very useful when it is not economically practical or physically possible to provide a wired networking infrastructure (battlefield scenarios, natural disasters, etc.). Performance of a mobile ad hoc network depends on the routing scheme employed, and the traditional routing protocols do not work efficiently in a MANET due to its dynamic topology (every node can move randomly and the radio propagation conditions change rapidly over time) and to the limited bandwidth (so that the control traffic overhead must be reduced to the minimum) [3].

Developing routing protocols for MANETs has been an extensive research area during the past few years, and various proactive and reactive routing protocols have been proposed [1]. However, despite the fact that advances in battery technology have not yet reached the stage where devices can autonomously operate for days, the majority of the routing proposals have not focused on the power constraints of untethered nodes. At the network layer only a few proposals have specifically focused on the design of route selection protocols that provide efficient power utilization when performing route discovery [3,4].

In this work, an in-depth performance evaluation is performed to compare the energy consumption behavior of two routing protocols: the Dynamic Source Routing (DSR) [5], which follows a reactive approach, and the Optimized Link State Routing (OLSR) [6], which uses a proactive one. In pursuit of a double objective, firstly, an evaluation of is made of how different approaches affect the energy usage of mobile devices when using two of the most promising routing protocols currently considered under IETF's MANET working group [1]. In fact, among the great variety of different proposals, DSR and OLSR have arrived at the RFC status. Secondly, a check is made of whether or not, under the IEEE 802.11 technology, some of the power-aware routing proposals in the literature might be efficiently utilized to extend the lifetime of nodes and connections. In fact, it is retained that, because of the overhearing and idle activity of a network interface card based on the

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current IEEE 802.11 technology, a majority of the proposed schemes not only are quite tricky to be implemented, but also fall short of their assumed benefits. The simulation results presented in this paper were obtained using the ns-2 simulator [7], which is a discrete event, object oriented, simulator developed by the VINT project research group at the University of California at Berkeley.

The paper is organized as follows: Section 2 gives a brief overview of energy aware routing protocols for MANET; proactive (OLSR) and reactive (DSR) routing protocol management are briefly explained in Section 3; our deep simulation analysis is presented in Section 4; Energy considerations are given in Section 5; finally, conclusions are summarized in Section 6.

2. Related work

Developing routing protocols for MANETs has been an extensive research area in recent years, and many protocols have been proposed from a variety of perspectives [4,8–11]. Those protocols can be classified into four broad categories: proactive, reactive, hybrid, and cluster-based. These protocols try to satisfy various properties to reach the best compromise in term of scalability, mobility support, and energy consumption.

The need for energy efficiency is a problem that derives from the constraints imposed by battery capacity and heat dissipation which are opposed to the desire of miniaturization and portability. The networked operation of a wireless terminal opens up additional opportunities for increasing energy efficiency. One opportunity is the possibility of dynamically offloading computation from the local terminal to remote, energy-rich nodes (e.g., fixed servers). Another opportunity comes from making various network protocols, such as link, MAC routing and transport protocols, energy aware. In recent years a number of power-aware metrics have been proposed at the network layer (like [3,4,11–19,23]). Here, a brief description of three relevant power-aware routing protocols proposed recently is presented.

The Minimum Total Transmission Power Routing (MTPR) [3] mechanism makes use of a simple energy metric representing the total energy consumed along the route.

Although MTPR can reduce the total transmission power consumed per packet, it does not reflect directly on the lifetime of each node. In other words, the remaining battery capacity of each node is a more accurate metric to describe the lifetime of each node. Let $c_i(t)$ be the battery capacity of node n_i at time t. $f_i(t)$ is defined as a battery cost function of node n_i. The less capacity a node has, the more reluctant it is to forward packets; the proposed value is $f_i(t) = 1/c_i(t)$. If only the summation of battery cost is considered, a route containing nodes with little remaining battery capacity may still be selected. The Min–Max Battery Cost Routing (MMBCR) [13] defines the route cost as: $R(r_j) = \max_{\forall n_i \in r_j} f_i(t)$. The desired route r_o is obtained so that $R(r_o) = \min_{r_j \in r_*} R(r_j)$, where r^* is the set of all possible routes. Since MMBCR considers the weakest and crucial node over the path, a route, with the best condition among paths impacted by each crucial node over each path, is selected. The Conditional Max–Min Battery Capacity Routing (CMMBCR) [3] attempts to perform a hybrid approach between MTPR and MMBCR. CMMBCR considers both the total transmission energy consumption of routes and the remaining power of nodes.

Power saving mechanisms based only on the remaining power cannot be used to establish the best route between source and destination nodes. If a node is willing to accept all route requests only because it currently has enough residual battery capacity, too much traffic load will be injected through that node. In this sense, the actual drain rate of power consumption of the node will tend to be high, resulting in an unfair sharp reduction of battery power. To address the above problem, the Minimum Drain Rate (MDR) [4,20] mechanism can be utilized with a cost function that takes into consideration the drain rate index (DR) and the residual battery power (RBP) to measure the energy dissipation rate in a given node. In this mechanism, the ratio $\frac{\mathrm{RBP}_i}{\mathrm{DR}_i}$, at node n_i, indicates when the remaining battery of node n_i, will be exhausted, i.e., how long node n_i can keep up with routing operations with current traffic conditions based on the residual energy. The corresponding cost function can be defined as: $C_i = \frac{\mathrm{RBP}_i}{\mathrm{DR}_i}$. Therefore, the maximum lifetime of a given path r_p is determined by the minimum value of C_i over the path. Finally, the MDR mechanism is based on selecting the route r_M, contained in the set of all possible routes r^* between the source and the destination nodes, which presents the highest maximum lifetime value.

The paper proposed in [24] presents an energy aware analytical approach to evaluate proactive and reactive data management but no specific protocol has been extensively tested. In [21], the authors present the results of an investigation into the power consumption performance of two contrasting ad hoc routing protocols from the IETF MANET working group, namely the proactive protocol OLSR and the reactive protocol DSR. To the best of our knowledge, this is the only paper where two important and well-known protocols such as DSR and OLSR have been compared. In [21], just some simulation results and no extensive simulations were carried out in order to evaluate protocol performance under low, medium and high mobility, under medium and high traffic load, under fixed and variable connection pattern. Contrarily to the above work, this contribution addresses this issue and an extension of the work presented in [22] is proposed. Differently from this work, a deeper simulation analysis has been carried out and some further mechanisms such as route cache reply and link failure notification at data link layer are also considered. The simulation campaigns carried out in this work permits a better knowledge of the advantages and drawbacks of proactive and reactive protocols.

3. Routing approaches for MANET

Routing protocols for mobile ad hoc networks have different features. Regarding the way to exchange routing information, the main difference is between reactive and proactive routing protocols. A reactive (or on-demand) routing protocol determines routes only when there is any data to send. If a route is unknown the source node initiates a search to find one and it is primarily interested in finding any route to a destination, not necessarily the optimal route. A proactive routing protocol, instead, attempts to maintain routes to all destinations at all time, regardless of whether they are needed. To support this, the routing protocol propagates information updates about the network's topology or connectivity through the network. From the node organization point of view, there can be a hierarchical routing system (some routers form a sort of backbone) or a flat address space (where the routers are peers of all others).

3.1. A reactive routing protocol: dynamic source routing (DSR)

The Dynamic Source Routing protocol (DSR) is a reactive protocol [5]. This generates less overhead and provides more reliable routing than proactive routing, but at the cost of finding the optimal route. Mobile hosts do not utilize periodic messages, with a consequent energetic advantage in battery consumption. DSR updates automatically only when it needs to react to changes in the routes currently in use. This protocol is simple and efficient.

DSR uses a modified version of source routing. Operation of the protocol can be divided into two functions – *route discovery* and *route maintenance* [5]. Route discovery operation is used when routes to unknown hosts are required. Route maintenance operation is used to monitor the correctness of established routes and to initiate route discovery if a route fails. When a node needs to send a packet to a destination it does not know about, the node will initiate route discovery. The node sends a route discovery request to its neighbors (Fig. 1(a)). Neighbors can either send a reply to the initiator or forward the route request message to their neighbors after having added their address to the request message (i.e., source routing) such shown in Fig. 1(b).

The route reply message can be returned to the initiator in two ways. If the host that sends reply already has the route to the initiator, it can use that route to send the reply. If not, it can use the route in the route request message to send the reply. The first case is beneficial in situations where a network might be using unidirectional links, and it might not be possible to send the reply using the same route that the route request message took.

Route maintenance is performed when there is an error with an active route. When a node that is part of some route detects that it cannot send packets to the next hop, it will create a Route Error message (RERR) and send it to the initiator of data packets. The RERR message contains the addresses of the node that sent the packet and of the next hop that is unreachable. When the RERR message reaches the initiator, the initiator removes all routes from its route cache that have the erroneous node address. It then initiates route discovery for a new route if needed.

The advantages of the DSR protocol include easily guaranteed loop-free routing and very rapid recovery when routes in the network change. The DSR protocol is designed mainly for mobile ad hoc networks of up to about 200 nodes, and is designed to work well with even very high rates of mobility.

3.2. A proactive routing protocol: Optimized Link State Routing (OLSR)

The Optimized Link State Routing (OLSR) is a proactive link state routing protocol for mobile ad hoc networks. OLSR constructs and maintains routing tables by diffusing partial link state information to all nodes in the network with the help of an optimized flooding control protocol, called MultiPoint Relaying (MPR). The Optimized Link State Routing (OLSR) protocol is an optimization of the classical link state algorithm, tailored to the requirements of a MANET [6]. Because of their quick convergence, link state algorithms are somewhat less prone to routing loops than distance vector algorithms, but they require more CPU power and memory. They can be more expensive to implement and support and are generally more scalable. OLSR operates in a hierarchical way (minimizing the organization and supporting high traffic rates). The key concept used in OLSR is that of multipoint relays (MPRs).

In order to reduce the effect of flooding messages to all nodes in the network, OLSR selects a subset of nodes, called *Multipoint Relays (MPR)*, to be part of a relaying backbone. In order to build this structure, each node gathers 2-hops neighborhood information and elects the smallest number of relays such that all 2-hops neighbors are covered by at least one relay. Nodes notify the respective relays of their decision such that each relay maintain a list of nodes, called *Multipoint Relaying Selectors (MPR Selectors)*, which have elected it as MPR. Finally, the relaying decision is made on the basis of last-hop address according to the following rule.

Definition 1. (**MPR flooding**) A node retransmits a packet only once after having received the packet the first time from an MPR selector.

Fig. 2(a) shows a node with its set of 1-hop and 2-hops neighbors. It depicts the initial full topology, while Fig. 2(b) illustrates the MPR topology, where solid circles are MPRs to the central nodes. Accordingly, the central node is part of the MPR Selector list of each solid circles node.

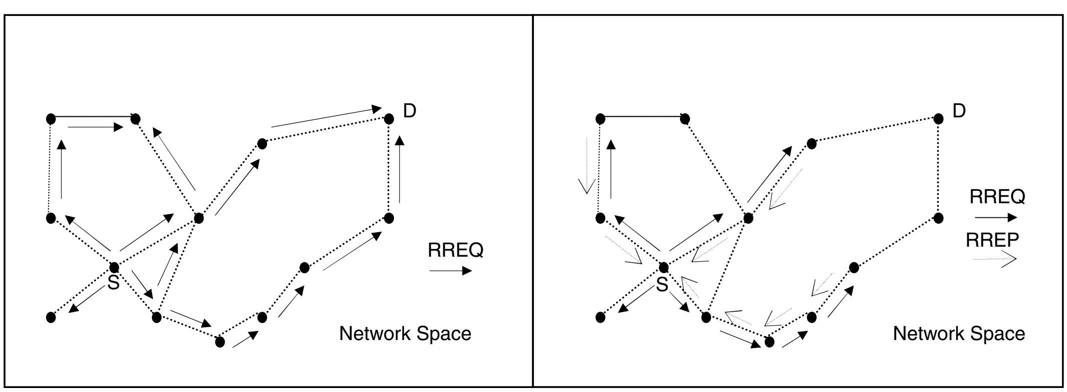

Fig. 1. (a) Route Request packets (RREQ) in DSR protocol. (b) Route cache (rc) reply.

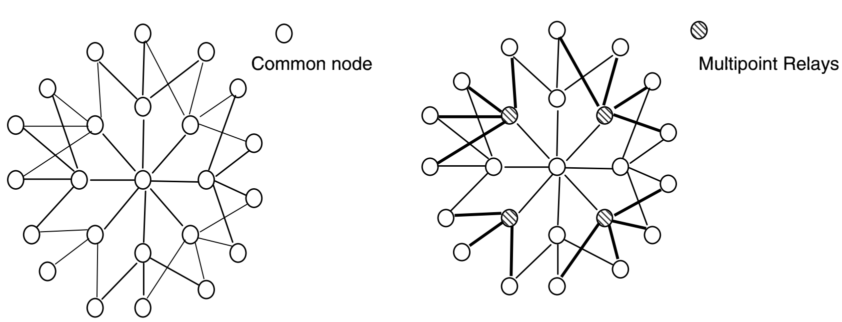

Fig. 2. Pure broadcast message propagation (left) and MPR message propagation (right).

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In order to create and maintain routing tables, OLSR generates two kinds of control traffic: HELLO packets and TC packets. Hello packets are periodically sent by each node and are never forwarded by any node. The main purpose of these packets is to gather and transmit up to 2-hops neighborhood information. Basically, a HELLO packet contains the list of a node's 1-hop neighbor. When it is received by a neighboring node, that node is able to acquire a view of its 2-hops neighborhood at no extra cost. However, OLSR requires transmission over bi-directional links only. Therefore, the set of 1-hop neighbors sent by a HELLO message is split up into four categories: a list of neighbor nodes from which control traffic has been heard, a list of neighbors with which bi-directional communication are possible, a list of neighbors that has been elected MPR, and finally, a list of neighbor nodes whose link has been lost.

Upon receiving a HELLO message, a node examines the list of addresses. If its own address is included in the MPR list, this means that the sender elected it as MPR node. Accordingly, the sender in added to the list of *MPR Selector* nodes.

In the future, if the node receives traffic from that neighbor, it will forward it. Topology Control (TC) messages are also periodically emitted. The purpose of TC messages is to transmit partial link state information on the network. A TC message can only be generated by an MPR node and contains the *MPR Selector* list.

TC messages are transmitted in the network and use the MPR protocol in order to reduce redundant transmissions. Upon reception of a TC message, a node knows that the sender is the next hop node to reach all nodes listed in the TC packet. If similar destinations are obtained, the route with the fewest hops is chosen. Further details on OLSR are discussed in [6].

Once topology is constructed, shortest path algorithm is run to create routing tables. All routing is done through MPR nodes (i.e., they can be considered as elected routers for groups of nodes). That is because OLSR is best suited for networks where traffic is between random nodes, rather then between the same sets of nodes. In the latter case, MPRs could quickly become bottlenecks.

This way a mobile host can reduce battery consumption. OLSR provides optimal routes (in terms of number of hops). The protocol is particularly suitable for large and dense networks as the technique of MPRs works well in this context.

4. Performance evaluation

In order to test the energy consumption of mobile nodes under OLSR and DSR protocols and to evaluate the performance of MANET under mobility many simulations were carried out. In particular, the effect of overhearing, idle power, mobility and protocol mechanisms such as route cache reply and link failure notification at data link layer, were considered. Route cache reply mechanism was activated in the DSR protocols and the protocol with this mechanism was called *DSR_rc*. On the other hand, the link failure notification at data link layer has been applied to OLSR protocol and the co-respective protocol was called *OLSR_ln*.

4.1. Energy consumption model

A generic expression to calculate the energy required to transmit a packet p is: $E(p) = i^* v^* t_p$ J, where: i is the current consumption, v is the voltage used, and t_p the time required to transmit the packet. It is supposed that all mobile devices are equipped with IEEE 802.11g network interface cards (NICs). The energy consumption values were obtained by comparing commercial products with the experimental data reported in [18].

The values used for the voltage and the packet transmission time were: $v = 5$ V and $t_p = \left(\frac{p_h}{6^* 10^6} + \frac{p_d}{54^* 10^6}\right)$ s, where p_h and p_d are the packet header and payload size in bits, respectively. The energy required to transmit and receive a packet p was calculated by using: $E_{\text{tx}}(p) = 280\text{ mA}^* v^* t_p$ and $E_{\text{rx}}(p) = 240\text{ mA}^* v^* t_p$, respectively. Since receiving a packet and just being idle, i.e., when simply powered on, are energetically similar [18], it was assumed $E_{\text{idle}}(t) = 240\text{ mA}^* v^* t$ where t is the NIC idle time.

Moreover, energy spent by nodes overhearing packets is accounted for. As shown in [18], it is assumed the energy consumption caused by overhearing data transmission is the same as that consumed by actually receiving the packet.

For the purpose of evaluating the effect of overhearing, the energy model was modified to account not only for the energy consumption due to transmission and reception, but also for overhearing packet exchanges until the time t. Thus, the total amount of energy, $E(n_i,t)$, consumed at a node n_i until the time t is determined as:

$$E(n_i, t) = E_{\text{tx}}(n_i, t) + E_{\text{rx}}(n_i, t) + E_o(n_i, t) \qquad (1)$$

where E_{tx}, E_{rx}, and E_o denote the amount of energy expenditure by transmission, reception, and overhearing of a packet, respectively. Note that, as the average number of neighboring nodes affected by a transmission increases, the network is denser, and so (1) implies that the packet overhearing causes much more energy consumption.

4.2. Methodology and simulation parameters

The simulation results presented in this paper were obtained using the ns-2 simulator. ns-2 is a discrete event, object oriented simulator developed by the VINT project research group at the University of California at Berkeley. The simulator has been extended to include: node mobility, a realistic physical layer including a radio propagation model, radio network interfaces and the IEEE 802.11 MAC protocol using the Distributed Coordination Function (DCF). The radio propagation model includes collisions, propagation delay and signal attenuation. In our experiments, we have set a 54 Mbps data rate, and a radio range of 250 m.

To compare the DSR and the OLSR protocols, a dense wireless network was simulated, with 50 nodes moving in a 870×870 m area (with a density of about 33 and 66 nodes/km^2). Each node moves in this area according to the random waypoint mobility model, with a speed in the range $[0, 20]$ m/s and no pause time.

In terms of traffic, three different situations were studied: in the first case, Idle Power and Overhearing effect have been evaluated and the simulation campaign is the first (*simulation I*); then, we considered a fixed connection pattern (FCP), with 12 CBR/UDP sources generating 10 and 20 packets/s (packet size is set to 512 bytes), in a second case, a variable connection pattern (VCP) was simulated, where a single, connection between two randomly selected nodes (source and destination) of the network is created every 10 s of simulation and lasts 10 s. The duration of each simulation is 450 s, with a startup period in the first 100 s (where no traffic is generated). This means that if each connection lasts 10 s, the first connection starts at 100 s and each connection is generated after the end of the previous connection. Both VCP and FCP were carried out under the second simulation campaigns (*simulation II*). The third case is associated with the node mobility (*simulation III*). Different mobility speeds (0, 5, 10, 15 and 20 m/s) were considered and the effect of mobility on the energy dissipation of both OLSR and DSR were analyzed.

Owing to the random nature of the mobility model used, the results of each simulation were considered as IID random variables $(X_1, X_2, \ldots, X_n)$ with finite mean. The simulations were repeated, i.e., we varied to the value of n, to obtain an estimation with a 95% confidence interval, by using the following definition:

$$\overline{X}(n) \pm t_{n-1,095}\sqrt{\frac{S^2(n)}{n}} \qquad (2)$$

where $t_{n-1,0.95}$ is the upper 0.95 critical point for Student's t distribution with $n-1$ degrees of freedom, $X(n)$ is the sample mean and $S^2(n)$ is the sample variance.

The time was mainly analyzed when each node dies due to lack of remaining battery (i.e., expiration time of nodes) as well as the lifetime of connections, which captures the effects of disconnections due to lack of possible routes (i.e., expiration time of connections). The average end-to-end delay per packet was also measured, as well as the throughput. For the purpose of investigating the effect of overhearing, and according to the energy model described earlier, the ns-2 energy model was modified to allow measuring the battery energy consumed when overhearing packet exchanges, as well as the energy owing to the idle operation mode.

The simulation parameters are presented in the following tables. The first table (Table 1) presents the common parameters adopted for the different simulation tests. Tables 2–4 present, respectively, the simulation parameters adopted in simulations I–III.

4.3. Simulation results

The metrics that have been employed in the simulations are the following:

1. *Control overhead (O/H)*: It represents the number of control packets sent on the network including RREQ, RREP and RERR packets for DSR and TC, Hello packets for OLSR.
2. *Data packets received (DPR)*: It expresses the number of packet received by destinations. It gives an idea of data delivery of the network also in condition in which some nodes (included some sources) can die.
3. *Average end-to-end data packet delay (E2E delay)*: It is the average source-to-destination data packet delay including propagation and queuing delay.
4. *Throughput*: It is the number of bytes received by source in a fixed time window T (in our simulation it has been fixed to 2 s). It is a function of time and permits consideration of the capability of the protocol to send out data packets towards the destination.
5. *Connection expiration time*: It is the duration of the connection.
6. *Number of live nodes*: It expresses the network life and the network connectivity. The number of active nodes permits to observe as the energy is drain out.
7. *Energy consumption*: It is the energy consumption associated to the transmission, reception, overhearing and idle power.

4.3.1. Simulation I: Idle Power and Overhearing influence

The first task is to evaluate the influence of Idle Power and Overhearing over energy consumption in a MANET. These effects reduce the network lifetime, consuming rapidly the nodes' batteries with very low differences between reactive and proactive protocols. As we can notice from Figs. 3 and 4, even with a low idle state energy consumption, all the nodes in the network tend to exhaust their battery at the same time (i.e., when idle power consumes all the device energy), no matter if one is evaluating DSR

Table 1
Common simulation parameters

Parameters	Values
Simulation area (m × m)	870 × 870
Simulation duration (s)	450
Connection type	CBR/UDP
Number of traffic source	12
Data packet size (byte)	512
Power for transmission P_{tx} (W)	1.4
Power for reception P_{rx} (W)	1.0
Routing protocols	DSR, OLSR

Table 2
simulation parameters for simulation I (Idle Power and Overhearing)

Parameters	Values
Number of mobile nodes	25, 50
Maximum node speed (m/s)	5
Connection pattern	FCP
Data packet rate for each connection (pkts/s)	20
Connection duration (expressed in seconds)	15–400
Initial node energy (J)	30.0
Idle power (W)	0.0, 0.2, 0.5, 0.9
Energy consumption for overhearing	Yes, No
Route cache reply (for DSR only)	Yes
Link layer failure notification (for OLSR only)	No

Table 3
simulation parameters for simulation II (variable and fixed connection pattern)

Parameters	Values
Number of mobile nodes	50
Node speed (m/s)	5
Connection pattern	FCP, VCP
Data packet rate for each connection (pkts/s)	10, 20
Connection duration (expressed in seconds)	100–400
Initial node energy (J)	10.0
Idle power (W)	0.0
Energy consumption for overhearing	Yes
Route cache reply (for DSR only)	Yes, No
Link layer failure notification (for OLSR only)	Yes, No

Table 4
simulation parameters for simulation III (mobility scenario)

Parameters	Values
Number of mobile nodes	50
Node speed (m/s)	0.1, 5, 10, 15, 20
Connection pattern	FCP, VCP
Data packet rate for each connection (pkts/s)	20
Connection duration (expressed in seconds)	100–400
Initial node energy (J)	2.0
Idle power (W)	0.0
Energy consumption for overhearing	No
Route cache reply (for DSR only)	Yes
Link layer failure notification (for OLSR only)	Yes

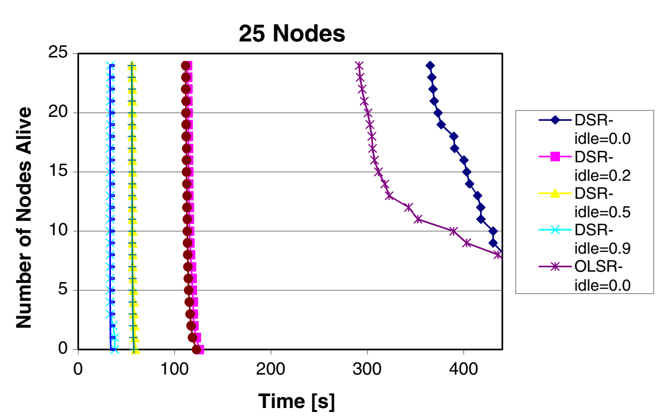

Fig. 3. Number of alive nodes vs time varying idle power with $N = 25$.

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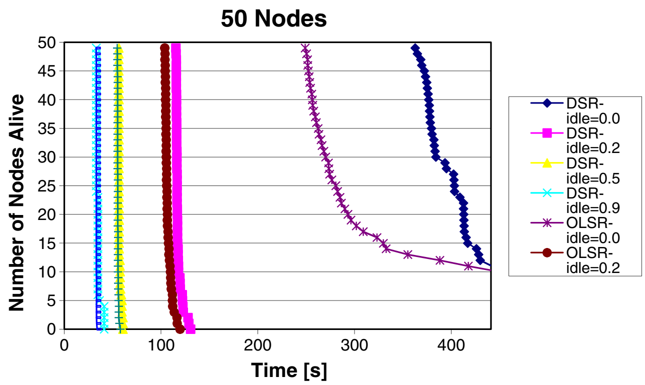

Fig. 4. Number of alive nodes vs time varying idle power with $N = 50$.

or OLSR protocol. If the ideal case of no power consumption in Idle mode is considered and just the overhearing effect is accounted for, nodes can live longer for both DSR and OLSR. It is possible to observe that nodes under OLSR die earlier than nodes under DSR. However at 440 s all nodes die for both DSR and OLSR as shown in Fig. 5. When node density increases (50 nodes for 870×870 m) without idle power, in Fig. 6 a greater impact of overhearing (>90% of dissipated energy) is observed.

To evaluate the influence of overhearing effect, we modified ns-2 code to be able to choose whether decrease or not the energy of a node when it overhears packets. Then, the DSR and OLSR protocols were simulated with and without this effect (setting the initial energy to a lower value, because the energy consumption in idle state

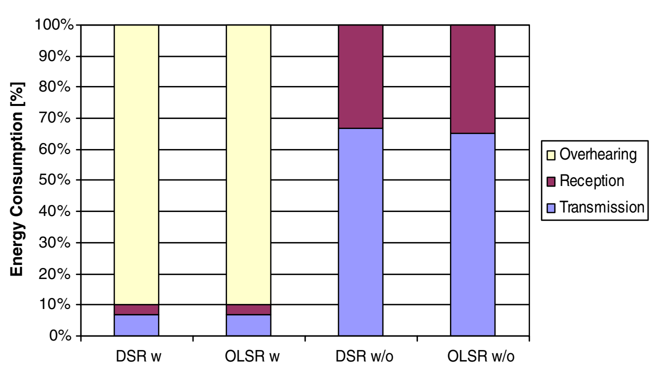

Fig. 5. Energy percentage consumption by type with (w) and without (w/o) overhearing effect for 25 nodes.

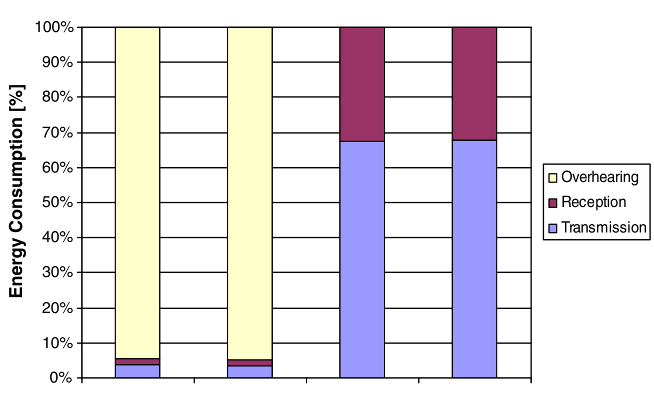

Fig. 6. Energy percentage consumption by type with (w) and without (w/o) overhearing effect for 50 nodes.

Table 5
Energy percentage consumption by type with $N = 25$: transmission (tx), reception (rx) and overhearing (ov)

	DSR w/o	OLSR w/o	DSR w	OLSR w
tx	66.97	65.10	6.87	6.69
rx	33.03	34.90	3.39	3.50
ov	0.00	0.00	89.74	89.80

was excluded). The results, from the energetic point of view, can be seen in Figs. 3 and 4. Also in this case, when node density increases the overhearing effect is predominant and a lot of energy is dissipated (around 90–95%). However, when the overhearing dissipation is not accounted for, power dissipations in transmission and reception phase maintain the same proportion and they are not affected by node density increases such as also confirmed by values listed in Tables 5 and 6.

Since Idle Power and Overhearing effects dominate the energy consumption in the simulation of a dense, high-traffic loaded network, to evaluate the actual differences between reactive and proactive protocols in a MANET from energetic point of view, both of these effects will be ignored in the rest of this work. In the implementation of DSR protocol, this last consideration leads to an important remark. When the energy consumption in overhearing packets is neglected, the promiscuous mode of the protocol must be turned off. This means that DSR cannot rescue routing information from packets directed to another node. Therefore, in the rest of this paper, the DSR protocol will be considered without the promiscuous mode operation. Moreover, concerning the DSR protocol the route cache reply effect was considered that allows an intermediate node to provide to the source the path towards the destination if it is known. In order to offer to OLSR more reactivity to topological change also the OLSR with link layer notification was considered that permits the link breakage at data link layer to be detected. Thus in the rest of the paper both mechanisms for DSR and OLSR protocols will be considered.

4.3.2. Simulation II: fixed and variable connection pattern

In these simulation campaigns the constant and variable traffic load over the MANET were considered. It was decided to adopt two connection patterns because they stress the network in different way. In particular, variable connection pattern (VCP) forces DSR to start more route discovery procedures while static connection pattern (Fixed Connection Pattern) stresses OLSR that sends a lot of control packets together with data packets, quickly exhausting the energy.

4.3.3. Fixed connection patter (FCP)

The DSR and OLSR protocols were simulated using the minimum hop count routing policy. This is the same as using the MTPR policy (Minimum Total Transmission Power Routing, [2]), because every packet transmission costs the same energy (therefore, the protocols will search the minimum hop route, to save energy). In this first case, the network experiments a high, static traffic load, with 12 CBR/UDP traffic sources sending a constant amount of data between 100 and 400 simulation seconds and two data rates of 10 and 20 packets per seconds (pkts/s) are considered. Figs. 7 and 8

Table 6
Energy percentage consumption by type with $N = 50$: transmission (tx), reception (rx) and overhearing (ov)

	DSR w/o	OLSR w/o	DSR w	OLSR w
tx	67.34	67.78	3.64	3.51
rx	32.66	32.22	1.77	1.61
ov	0.00	0.00	94.60	94.88

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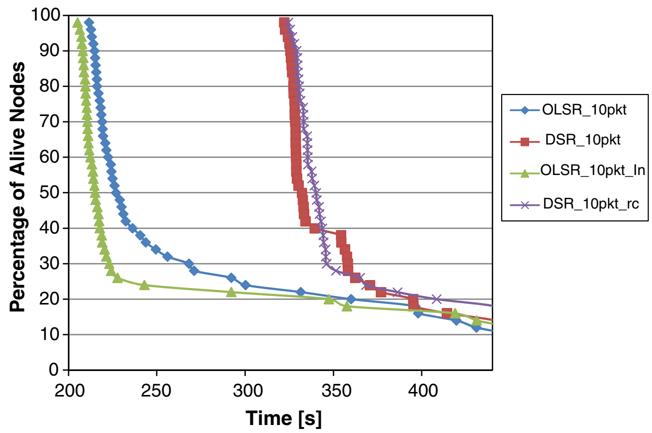

Fig. 7. Alive nodes vs time with fixed connection pattern.

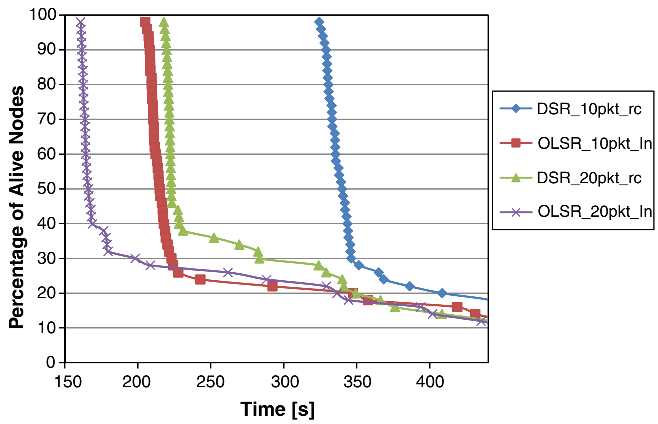

Fig. 8. Alive nodes vs time with fixed connection pattern and different data packets rate (10 and 20 pkts/s).

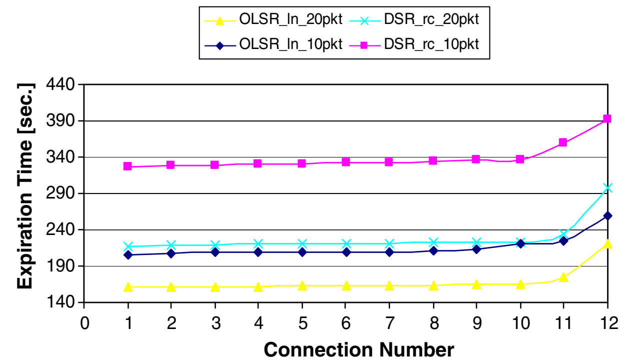

Fig. 9. Connection expiration time with a fixed connection pattern and different data packet rate (pkts/s).

Table 7
DSR vs OLSR performance evaluation with a data packet rate of 10 pkts/s and FCP

	DPR	O/H	E2E delay (ms)	Alive nodes (%)
DSR	29658.42	12.25	14.10	14
OLSR	9755.519	39.24	6.07	12
DSR rc	30354.55	12.37	28.21	20
OLSR ln	14402.58	25.89	5.53	18

Table 8
DSR vs OLSR performance evaluation with a data packet rate of 20 pkts/s and FCP

	DPR	O/H	E2E delay (ms)	Alive nodes (%)
DSR	27460.98	18.87	13.03	10
OLSR	10395.12	47.24	17.66	8.8
DSR rc	28193.32	18.47	36.32	16
OLSR ln	12556.57	36.23	11.48	15

show the percentage of remaining nodes in the network over time, plotting the halt-time of mobile nodes.

The more the curve is on the top right of the plot, the more the protocol prolongs the nodes' lifetime (thus prolonging the lifetime of the entire network). It can be seen how DSR takes advantage of its reactive nature: in the first 100 s of simulation, while OLSR spends energy to update the network topology, DSR does not generate packets (because there is no data transmission in the network). However, the gap is between 30 and 80 s for data rate of 20 pkts/s., showing the good performances of OLSR with high traffic rates. However, when data traffic rate is lower (10 pkts/s) the gap between OLSR and DSR is greater (about 140 s). To have a better vision of the behavior of the routing protocols with respect to the traffic, the lifetime of the connections of the simulated MANET can be plotted. Fig. 9 shows how the response of OLSR and DSR is very similar (but, obviously, shifted: the proactive protocol starts its periodic exchange of message at the beginning of the simulation). An increase in the data traffic rate produces a reduction in the connection lifetime.

To evaluate the performance of the protocols, some classical network metrics can be extracted from simulation, like the data packet delivered (DPR) (the number of data packets delivered to the destinations), the end-to-end delay (E2E delay) (the time interval between the moments the packet is sent and received by the source and destination nodes) or the routing overhead (O/H) (the amount of control information sent over the data traffic). These parameters are shown in Tables 7 and 8. DSR and DSR_rc present higher E2E delay in comparison with OLSR. This is due to the reactive nature of DSR that determines a high number of Route request to find a new path from source to destination. On the other hand, OLSR presents very low E2E delay due to the proactive info management that permits to have the path immediately available. However, DSR offers a higher DPR because it saves more energy in the fixed Connection Pattern scenario. OLSR, on the contrary, drains the energy faster producing the death of more nodes, such as shown in the previous graphics, and causing the network partition. Concerning the route cache reply for DSR (DSR_rc) and link failure notification at data link layer (OLSR_ln), it is possible to see an improvement, respectively, of O/H for DSR and of DPR for OLSR. Moreover, high traffic load (20 pkts/s) determines a reduction of DPR and an increase in O/H for both DSR and OLSR.

It can be seen how the overhead of OLSR is considerably higher than the one of DSR. The data packet delivery ratio is very different between the two protocols. To know the reason, the throughput of the dynamic scenario over simulation time in Figs. 10 and 11 was plotted. In Fig. 10, the data throughput of OLSR is lower than DSR, because OLSR wastes more bandwidth for control overhead (O/H) and it is not able to adapt itself faster to topological change due to mobility (5 m/s). However, if the data link notification (OLSR_ln) is applied, the data throughput increases a lot and performance similar to DSR is obtained (a data throughput of 120,000 bytes for both DSR and OLSR_ln). It is possible to see also the reduction in the duration of high throughput due to the faster node energy consumption that led to node death and network partitioning. Moreover, in Fig. 10, it is possible to see as the throughput values are coherent with the percentage of alive nodes. When around

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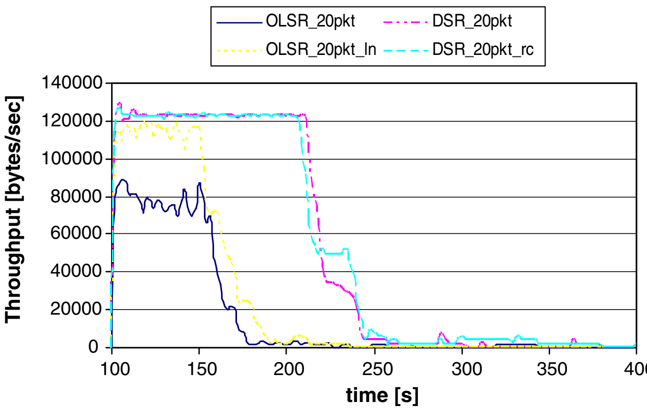

Fig. 10. Throughput vs time with fixed connection pattern.

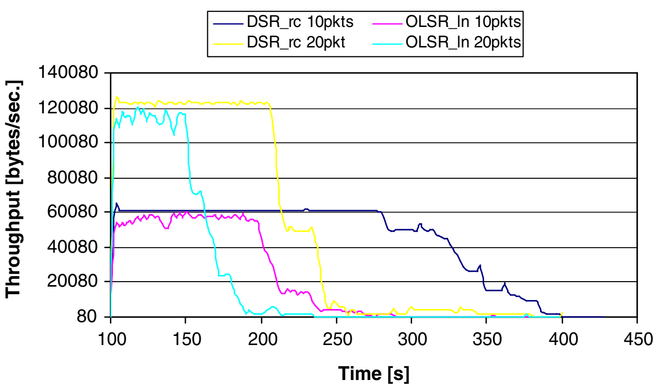

Fig. 11. Throughput vs time with fixed connection pattern and data packet rate of 10 and 20 pkts/s.

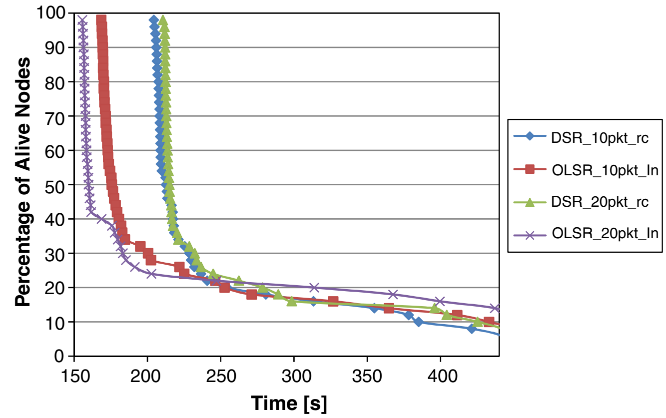

Fig. 12. Alive node vs time with variable connection pattern.

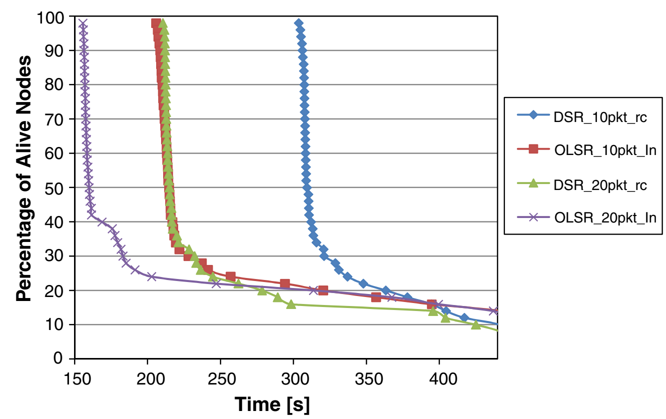

Fig. 13. Alive node vs time with variable connection pattern and different data packet rate (10 and 20 pkts/s).

150 s a lot of nodes die under the OLSR protocol, the data throughout decreases. In the same way, the throughput of DSR is reduced around 250 s when the greater number of nodes die (40 nodes).

When data rate is reduced, a stable throughput can be supported by both OLSR and DSR for a longer time in comparison to 20 pkts/s of data rate. This is due to the energy saving in the transmission and receiving power of mobile nodes. Also in this case DSR outperforms the OLSR in terms of longer duration of data throughput.

Before the expiration of connections, DSR presents a stable throughput, while the one of OLSR varies a lot. This is why DSR, being reactive, rapidly reacts to path changes, while these changes lead to packet losses in OLSR. This could be repaired updating the routing tables of OLSR more frequently, but this could lead to very high values of routing overhead.

4.3.4. Variable connection pattern (VCP)

In a second phase, the same, dynamic network topology was simulated to have a variable connection pattern: in this case, a random connection (512 bytes packets, sent at a rate of 10 and 20 pkts/s) is generated every 10 simulation seconds. Every connection lasts exactly 100 s. In this scenario, the reactive protocol will have to work a little more, to continuously find new routes to the destinations added by the connection pattern. Figs. 12 and 13 show nodes' lifetime, for the simulated network.

DSR without cache reply and with cache reply (DSR_rc) presents similar performance in terms of node lifetime. When data rate decreases (10 pkts/s) the node lifetime increases by 100 s. When simulation reaches 300 s, 40 nodes die for both DSR and OLSR. OLSR consumes more energy than DSR and this determines a shorter node lifetime such as shown in Figs. 12 and 13 where, for 150–180 s, 50% of nodes die. When data rate decreases (10 pkts/s) the lifetime of nodes increases of 80 s under OLSR protocol. It is possible also to see as there is no difference in terms of number of alive nodes if we apply route cache reply in DSR or not. This behavior will be explained in the following through results in Tables 9 and 10. Moreover OLSR for high data rate (20 pkts/s) show a higher number of alive nodes after 270 s. Also this behavior is attributed to the cache reply use of DSR that determines a slightly higher en-

Table 9
DSR vs OLSR performance evaluation with a data packet rate of 10 pkts/s and VCP

	DPR	E2E delay (ms)	O/H	Alive nodes (%)
DSR	25840.83	41.14	3.64	7
OLSR	10481.31	27.36	46.16	10
DSR rc	25393.49	62.19	3.70	9
OLSR ln	12975.73	11.01	34.50	13,6

Table 10
DSR vs OLSR performance evaluation with a data packet rate of 20 pkts/s and VCP

	DPR	E2E delay (ms)	O/H	Alive nodes (%)
DSR	27182.65	81.35	2.22	6
OLSR	13146.21	7.78	27.19	9
DSR rc	28459.62	77.53	1.87	10
OLSR ln	14619.54	4.51	23.81	14

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ergy consumption. For heavy traffic load (20 pkts/s) also DSR degrades its performance and a lot of nodes die (more than 80% after 260 s). This is due to the DSR activity that causes many simultaneous lacks of energy, corresponding to RREQ broadcast storms.

To see the protocol performance in terms of connections lifetime, the simulation was repeated providing the nodes with enough energy to survive all simulation time. So, a linear plot of connections expirations over time can be expected, according to (3) below. This equation models expected expiration time ($ET_{\exp}$) for every connection i. Under the assumption in which each connection lasts t_{con}, the first connection starts at t_{start} and each connection is generated after the end of the previous connection the Eq. (3) is:

$$ET_{\exp}(i) = t_{\text{start}} + t_{\text{con}} \cdot i \tag{3}$$

Then, the Connection Expiration Delay (ED(i)) can be plotted as the difference between the expected value and the measured one, as shown in (4), where $\text{ET}_{\text{sim}}(i)$ is the expiration time of connection i, taken from the simulations.

$$\text{ED}(i) = \text{ET}_{\text{sim}}(i) - \text{ET}_{\exp}(i) \tag{4}$$

Figs. 14 and 15 plot the values of ED(i) for DSR and OLSR protocols; in the specific simulated scenario the first connection starts after the first 100 s of simulation, then each other connection starts after the end of the previous one (each connection lasts 10 s); in the graphics (Figs. 14 and 15) a positive value corresponds to a delay in the delivery of the last connection packets, while a negative value represents an early expiration (due to an unrecovered path loss).

The delay in the connection expiration is present on both protocols, but it is lower for DSR at the end of connection. In this case the data packet delivery is not delayed by route request propagation thanks to the route cache reply use. On the other hand, OLSR is slower in the topological change reaction because of the timers that determine a slower propagation of topology control information.

If data packets rate is 20 pkts/s (high traffic load condition), the behaviour previously explained is exacerbated and OLSR presents higher delay.

In Tables 9 and 10, DPR, E2E Delay and protocol control overhead (O/H) are listed for all protocols and for both data rates (10 and 20 pkts/s). DSR delivers more data packets than OLSR because its lower energy consumption determines a longer node lifetime in comparison to mobile nodes under the OLSR protocol. Concerning the mechanisms of OLSR (link layer notification) and route cache reply, it is possible to observe an improvement in the DPR. Also O/H is reduced especially for lower data rate (10 pkts/s) and for

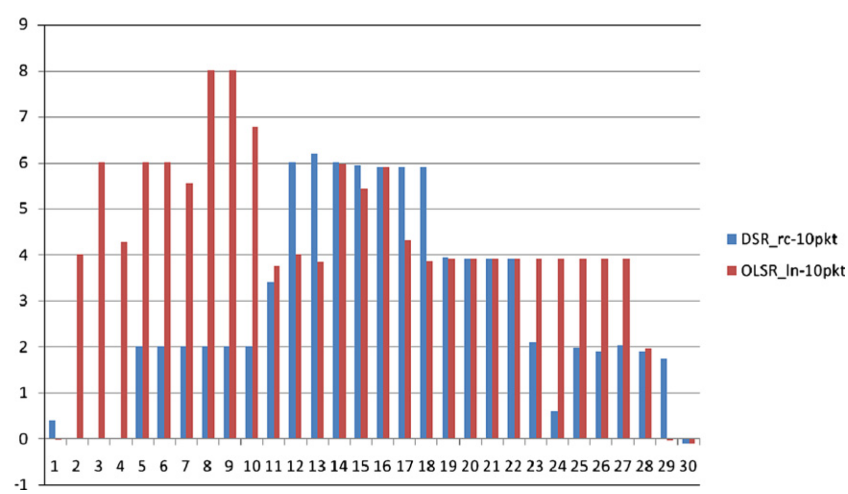

Fig. 14. Connection expiration delay with a variable connection pattern and different data packet rate of 10 pkts/s.

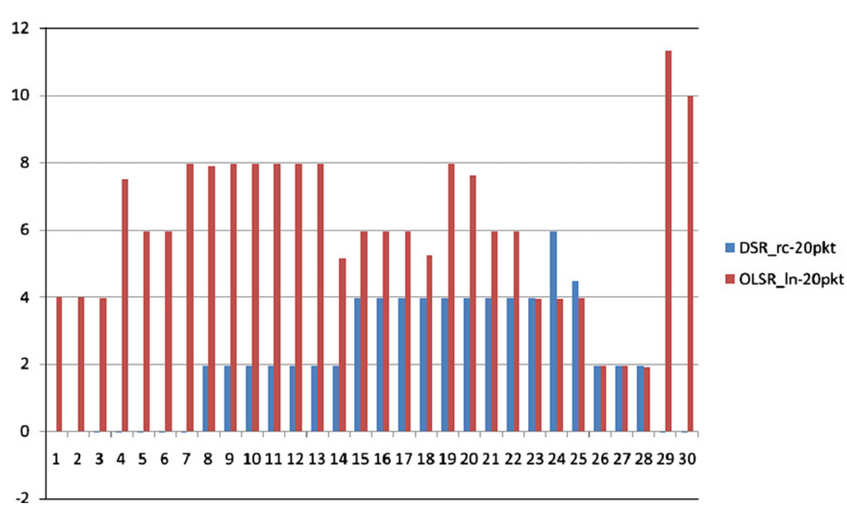

Fig. 15. Connection expiration delay with a variable connection pattern and different data packet rate of 20 pkts/s.

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OLSR with link layer notification (OLSR_ln). However, through the route cache reply a longer route data packet detour. This could appear strange but this behaviour is due to the reply of intermediate nodes. If an updated path (shortest path) is not stored in the route cache, often a longer route to reach the destination could be adopted. The effect of this longer route is not only an increase in the E2E delay but also a dissipation of more energy due to the higher number of nodes involved in the data packet transmission and reception. This is testified by the higher number of nodes that die in the DSR_rc protocol in comparison with simple DSR protocol.

As expected, OLSR has a high average end-to-end delay value (influenced by the delay values previously seen), while the average end-to-end delay of DSR has to cope with the path construction delay. With respect to the previous simulation, the higher value of overhearing percentage is mostly due to the lower amount of data sent (remember that the normalized control protocol overhead is given by the ratio between routing packets sent and data packets received). To better justify the low value of OLSR data packets delivery ratio, we plotted the throughput over time for this simulation in Fig. 16.

As in the previous case (fixed connection pattern), the DSR throughput over time shows an almost stable behavior, while OLSR value changes frequently with time. A light stabilization in the data throughput of OLSR is observed in the case of lower traffic load (10 pkts/s) and link layer notification (OLSR_ln) (Fig. 17).

If the route cache reply in DSR is considered, a light data throughput improvement is observed. Moreover, DSR and DSR_rc present a more stable throughput and this is due to a greater capacity of DSR to react to link breakage caused by node mobility (5 m/s). It is interesting to observe also the improvement of OLSR when link layer notification is adopted (OLSR_ln) such as testified also by increasing in the DPR (see Tables 9 and 10). In this case, OLSR_ln is able to adapt faster to topology change and to offer a throughout comparable with DSR. However, the duration of high throughput of OLSR is shorter than DSR and DSR_rc because more energy is consumed and more nodes die reducing the network connectivity.

4.3.5. Simulation III: influence of mobility over performance

Figs. 18 and 19 present the number of live nodes under mobility scenarios where $v = 0$, 5 and 20 m/s have been considered. It is possible to observe the good performance of OLSR when no nodes mobility is considered. This is due to the reduction in TC packets sent on the network that allows a longer node lifetime. DSR outperforms OLSR in terms of energy consumption during the simulation because more nodes under DSR are alive. For node mobility of 5 and 20 m/s also DSR degrades its performance because 75% of nodes die in the first 220 s for $v = 20$ m/s and 80% of nodes die in the first 200 s. For a speed of 20 m/s DSR and OLSR consume similar energy and the number of nodes alive is the same. This is due to the high node mobility that forces DSR to start more route discovery procedure consuming energy resources and reducing the benefits of the reactive data management approach.

To better see the slow reaction of OLSR to path changes in the network, the throughput with time with different nodes speeds was plotted, in Figs. 20 and 21. OLSR throughput is maintained for a shorter time than DSR throughput. This is due to higher energy dissipation and nodes death that reduces the network connectivity. Both DSR and OLSR decrease throughput maintenance time for increasing nodes speed because higher speeds imply higher O/

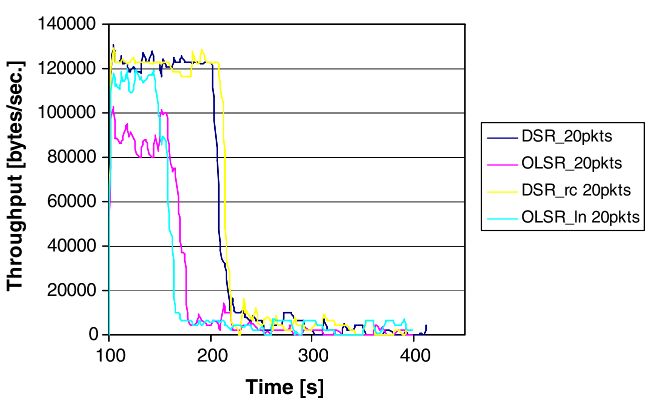

Fig. 16. Throughput vs time with variable connection pattern.

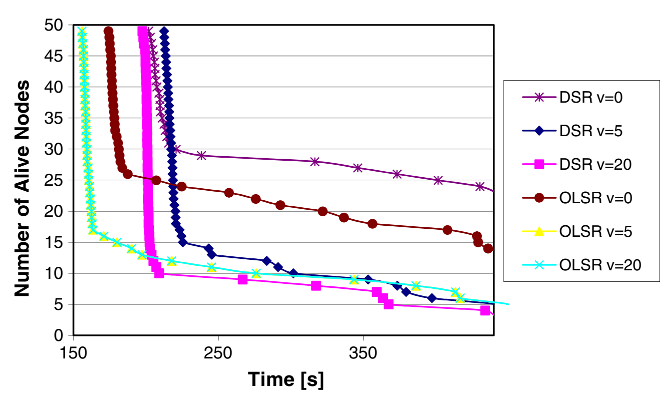

Fig. 18. Alive node vs time with fixed connection pattern and different nodes mobility ($v = 0$, 5 and 20 m/s).

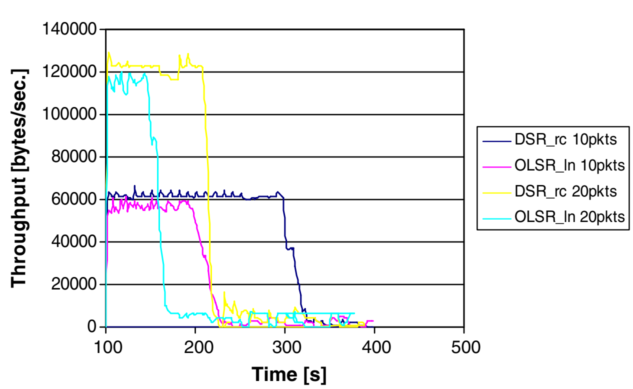

Fig. 17. Throughput vs time with variable connection pattern and different data rates (10 and 20 pkts/s).

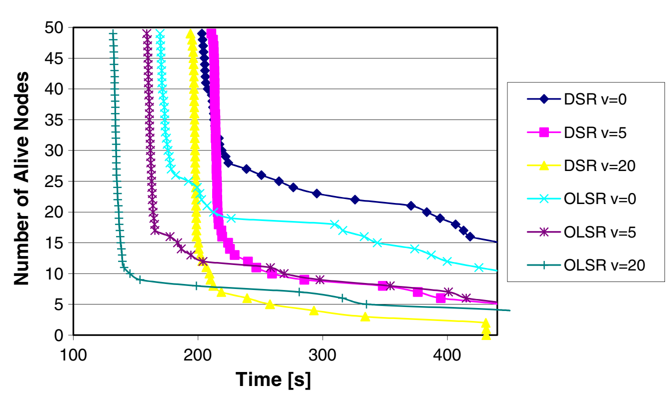

Fig. 19. Alive node vs time with variable connection pattern and different nodes mobility ($v = 0$, 5 and 20 m/s).

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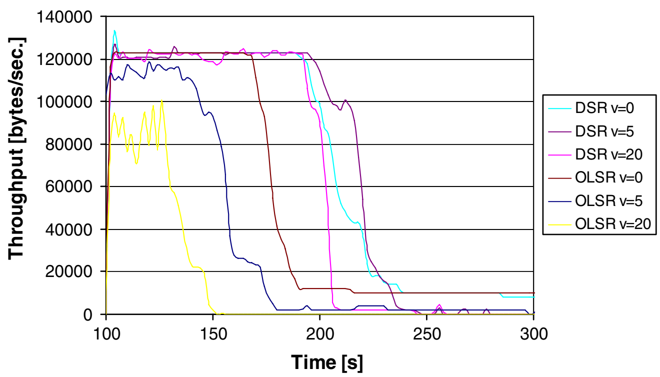

Fig. 20. Data throughput vs time with fixed connection pattern and different nodes mobility (*v* = 0,5 and 20 m/s).

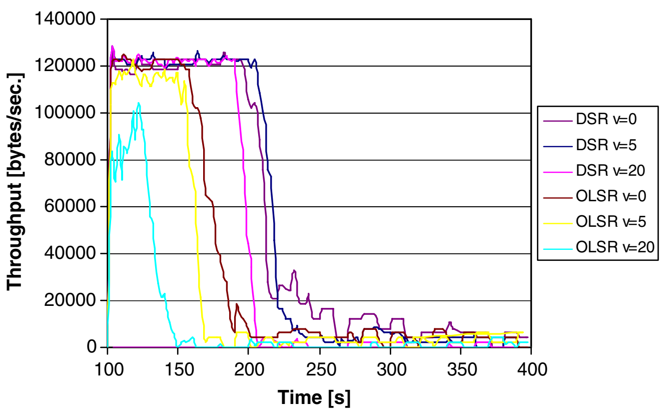

Fig. 21. Data throughput vs time with variable connection pattern and different nodes mobility (*v* = 0, 5 and 20 m/s).

H and greater energy dissipation. When node mobility is high (20 m/s) data throughput is more variable for the slower topology change adaptation of OLSR in comparison with DSR.

From the figures above, it is clear how DSR rapidly reacts to topology changes, while OLSR cannot reach the same performance values. DSR increases its O/H for higher nodes speed such as OLSR such shown in Tables 11 and 12. However, DPR of OLSR significantly decreases when node mobility is considered because a high data throughput is supported for a shorter time in comparison with the throughout supported by DSR. Moreover, a lot of nodes die and some network partition occurs reducing the DPR. However, in terms of E2E delay, OLSR performs better than DSR and for high mobility (15–20 m/s) there is a reduction of 15–20 ms in comparison with DSR. The proactive data management gives the possibility of immediately having a path towards destination. In the DSR protocol a greater route discovery latency determines higher E2E data packet delay.

Table 11
OLSR Performance evaluation under different node mobility

m/s	O/H	E2E delay (ms)	DPR
0	15.61	3.82	24466.15
5	27.31	5.97	13962.43
10	34.53	5.78	10871.79
15	57.14	10.45	7586.69
20	68.71	13.68	6279.92

Table 12
DSR performance evaluation under different node mobility

m/s	O/H	E2E delay (ms)	DPR
0	0.84	6.76	29561.22
5	1.59	10.91	28031.21
10	2.61	23.42	25679.15
15	3.25	20.07	24361.45
20	3.72	30.32	24392.46

5. Energy considerations about DSR and OLSR

A lot of work needs to be carried out on proactive and reactive routing protocols concerning the energy consumption. Reactive protocols present higher efficiency when node mobility is low-medium (0–10 m/s) and continuous traffic load (FCP). If traffic is intermittent producing higher route discovery procedures the reactive protocols lose their advantage on proactive ones. On the other hand, proactive protocols permit reduction of the latency time and they could be good for applications that are willing lose more energy to reduce the end-to-end data packet delay. When mobility is high (10–20 m/s) they do not perform well due to the high energy consumption and more nodes die reducing the network connectivity and DPR.

Two mechanisms such as link failure notification at data link layer and route cache reply were, respectively, considered for OLSR and DSR. The first mechanism permits a high increase in the data throughout without reducing the nodes' lifetime and improving also DPR. On the other hand, Route cache reply determines an increase in the DPR and an O/H reduction without increasing the energy dissipation. It could be strange how the route cache reply, which allows intermediate nodes to answer to path request, do not reduce the energy consumption. However, it has been shown in the paper how this mechanism determines a longer route to be selected increasing the E2E delay and increasing the energy dissipation associated with a longer path travelled by data. Thus, in the route cache adoption two effects are encountered: the reduction of route requests propagation and the increase in the traversed path. These two opposite effects maintain the similar the performance of DSR with and without route cache reply mechanism from an energetic point of view. This does not mean that route cache reply is not effective on DSR protocol, but just some extensions should be included in route cache maintenance procedures where obsolete route should be timely erased and energy metrics should be adopted.

This work shows how OLSR degrades a lot its performance when node mobility increases. This is due to the proactive data management of the protocol that is more energy consuming. Moreover, the MPR selection mechanisms of OLSR does not account for energy metric producing a fast energy consumption of nodes that could be important for the network connectivity. This is confirmed by the lower DPR also in situation of lower mobility and higher traffic load. Thus, as future contributions, it could be interesting to adopt energy aware metrics in the MPR selection mechanism to see whether OLSR performance continues to be lower than DSR. Proactive data management presents some drawbacks in terms of control packets sent on the network; however, a better traffic distribution and energy aware mechanism such as Minimum Drain Rate and the like, could improve OLSR performance also in situations of high traffic load and node mobility.

6. Conclusions

In this paper, some routing protocols such as OLSR and DSR have been analyzed from the energetic point of view. Simulations show that a reactive protocol takes advantage of its routing policy,

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but a proactive routing protocol can perform well with high traffic load and a variable traffic pattern. If the mobile network is very dense, the problem of overhearing seriously affects the lifetime of nodes, independently of the routing protocol. This problem must be investigated at different network layers, i.e., introducing a good sleep mode policy for the devices. At the routing layer, it can be noticed that new power-aware metrics are required for protocols, especially to OLSR, to improve its performance in MANETs. Route cache reply mechanisms activated on DSR can increase the data packet delivery and protocol control overhead. However, the drawback of this approach is the increasing end-to-end data packet delay. Concerning the OLSR protocol, the link failure notification at data link layer permits the delivered data packets to be considerably increased and the data throughout to be increased without expending more energy. Future work will focus on new energy saving policies for OLSR and DSR and on comparing the effectiveness of these new policies.

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