Ad Hoc Networks Routing Protocols and Mobility

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Abstract: *An ad hoc network is a temporary infrastructureless network, formed dynamically by mobile devices without turning to any existing centralized administration. To send packets to remote nodes, a node uses other intermediate nodes as relays, and ask them to forward its packets. For this purpose, a distributed routing protocol is required. Because the devices used are mobile, the network topology is unpredictable, and it may change at any time. These topology changes along with other intrinsic features related to mobile devices, such as the energy resource limitation, make ad hoc networks challenging to implement efficient routing protocols. In this paper, we drive a GloMoSim based simulation study, to investigate the mobility effects on the performance of several mobile ad hoc routing protocols.*

Keywords: *Ad hoc mobile networks, wireless networks, routing protocols, simulation, GloMoSim.*

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1. Introduction

A Mobile Ad hoc Network (MANET) is a collection of mobile nodes, that forms on the fly a temporary wireless multi-hop network in a self-organizing way, without relying on any established infrastructure. This kind of networks can be used in different applications, such as emergency search and rescue operations, communication between soldiers on a battlefield, sharing information in a conference, and data acquisition operations in inhospitable terrains. In MANET, a pair of nodes exchange messages either over a direct wireless link, or over a sequence of wireless links including one or more intermediate nodes. For this purpose, an adaptive routing protocol is required. An efficient MANET's routing protocol must cope with many limitations, related to intrinsic feature of nodes and wireless links, such as: low battery capacity, low bandwidth, high error rates, and time varying channels. Moreover, it must cope with the frequent topology changes engendered by nodes mobility. Therefore, implementing an efficient routing protocol is one of the challenges facing MANETs.

Many routing protocols have been proposed, but just few comparison studies have been performed. Almost all the available comparative studies use the absolute mobility, i. e., the absolute speed or the pause time. However, this kind of mobility does not faithfully reflect the topology change as we will see later.

In this paper, we present some parameters and metrics that we have added to GloMoSim, and we study the mobility effects on the performance of six protocols; four reactive (ABR, AODV, DSR, LAR), and two proactive (FSR, WRP). This study is performed by measuring different quantitative metrics at different mobility levels. We use a rigorous definition of mobility that reflects the topology change.

The remainder of the paper is organized as follows. After presenting the related work in section 2, section 3 presents an overview of the simulated routing protocols. Section 4 presents the metrics and the parameters used in the simulation. The results of our simulation are analyzed in section 5. Finally, section 6 concludes the paper.

2. Related Work

The problem of routing in MANETs has received attention among researchers, and many routing protocols devoted to MANETs have been proposed. According to their approaches for creating and maintaining routes, these protocols can be divided into two main categories; proactive protocols and reactive ones.

The proactive protocols, also called table driven, establish routes in advance, and permanently maintain them, basing on the periodic routing table exchange. Whereas, the reactive protocols, also called on demand protocols, don't establish a route between a pair of nodes until the source one asks for it.

In [7], Das *et al.*, have compared two on demand protocols, DSR [9] and AODV [18]. In their further work [2], they have studied more protocols, including TORA [15] and DSDV [17], with respect to three key performance metrics: fraction of packets delivery (reliability), the average end-to-end delay, and the routing overhead. Broch *et al*. [6] have compared four routing protocols; DSDV [17], TORA [15], DSR [9], and AODV [18], by measuring the overhead and the reliability of each one in different situations. Iwata *et* *al.* [8] have evaluated HSR [8], FSR [16], and DSDV [17], and have measured the overhead, the average end-to-end delay, and the average path length. Camp *et al.* [3] have compared the two locations routing protocols; LAR [12] and DREAM [1] with DSR [9]. The comparison has considered three metrics: overhead, end-to-end delay, and data packet delivery ratio. In [19], Sesay *et al.* have compared DSDV [17], DSR [9], TORA [15] and AODV [18] with respect to end-to-end throughput, delay, control packet overhead and route acquisition time. In [4], the author compares OLSR [5] with AODV [18] and DSR [9] by evaluating packet delivery rate, packet delay, control traffic overhead, and route length.

However, all these studies represent the mobility either by the pause time or by the nodes speed. As we will see later, this representation may be meaningless and it does not reflect the topology change. Larsson *et al.* [10, 13] have proposed a new definition of the mobility, based on the relative movement of nodes. They have compared three routing protocols; namely DSDV [17], AODV [18], and DSR [9] according to the end-to-end delay, the throughput, and the routing overhead. In this paper, we use this mobility definition to compare more protocols with respect to more metrics. We also test the protocols performance in higher mobility situations than those used in all the previous studies.

3. Protocols in a Nutshell

In the following, we give general descriptions of the protocols involved in this study. We have chosen these protocols among those proposed because they are largely used, and they are based on approaches different from each other. This allows us to make an in deep comparison between these protocols by focusing on their basic approaches.

3.1. Wireless Routing Protocol

Wireless Routing Protocol (WRP) is based on the vector distance algorithm [14]. To avoid counting to infinity problem, WRP introduces the shortest path predecessor node for each destination. Each node maintains 4 tables: distance table, routing table, link cost table, and Message Retransmission List (MRL). When a node either detects a neighbor link state change, or receives an update message from its neighbors, it sends another update message. Nodes included in response list of the update message (formed using MRL), have to acknowledge the message reception. If there is no routing table change compared with the last update, a hello message has to be sent in order to ensure the connection. At the time of update message reception, the recipient modifies its distance and seeks the best routes basing on the received information. MRL list must be updated after each ACK reception.

3.2. Fisheye State Routing

Fisheye State Routing (FSR) [16] is based on the fisheye technique [11], it aims at reducing the topological information size. Intuitively, this technique gives a great precision at a focal point, then this precision regarding a given node decreases when the distance between this node and the focal one increases. FSR is similar to the Link State (LS) approach, as each node saves the whole topology. The main difference is the manner in which routing information is exchanged between nodes. In FSR there is no message flooding, control messages are merely exchanged between neighbors.

3.3. Dynamic Source Routing

Dynamic Source Routing (DSR) is a reactive protocol based on the source route approach [9]. The principal of this approach is that the whole route is chosen by the source, and it is put within each packet sent. Each node keeps in its cache the source routes learned. When it needs to send a packet, it first checks its cache, if it finds a route to the corresponding destination then it uses it, otherwise, it launches a Route discovery by broadcasting a Request (RREQ) packet through the network. When receiving the RREQ, a node seeks a route in its cache for the RREQ's destination, if it finds such a route, it sends a Route Reply (RREP) packet to the source, if no appropriate route exists then it adds its address to the request packet and continues the broadcasting. When a node detects a route failure, it sends a Route Error (RER) packet to the source that uses this link, then this one applies again the route discovery process.

3.4. Ad Hoc On Demand Distance Vector

Ad hoc On Demand Distance Vector (AODV) is a hop by hop routing [18]. When a node needs to send a data packet to a destination to which it has no route, it has to broadcast a RREQ to all its neighbors, then each neighbor do so until reaching the destination. This one sends a RREP packet that travels the *inverse* path until the source. Upon the reception of this reply, each intermediary updates its routing table. In this way, a route between the source and the destination is built. Unlike DSR, the source does not put the whole route within the packet, but the decision about the next hop is made separately after each hop.

3.5. Associativity Based Routing

Associativity Based Routing (ABR) is based on nodes' associativity, and a new metric known as “associativety degree” is used [13]. Each node sends periodically a special control message called

"Beacon". When a neighbor node receives this Beacon, it increases its associativity value with respect to the sender. The associativity value of a node becomes null when the node loses its link with the corresponding neighbor. When a node needs a route to a destination, it broadcasts a Broadcast Query (BQ). Upon its BQ reception, the appropriate receiver adds its address and its associativity degree to the BQ. The destination node chooses the best route depending on the associativity degrees, then it sends back a reply to the source. A source's next hop link failure causes a new BQ-RPLY process. When a link fails, due to destination or intermediate nodes mobility, a Local-Query packet (LQ [H]) is sent to launch a partial maintenance request, where H is the hops number till the destination. When the destination receives this packet, it chooses the best partial route, then sends it to the LQ [H] packet sender.

3.6. Location Aided Routing

Location Aided Routing (LAR) is similar to DSR, except that it is based on localization [12]. Its purpose is to limit route request packets broadcast. For this purpose it uses Global Positioning System (GPS) localization information. Before launching any request, the source node acquires the destination's position information from the GPS, and puts it in the request packet. The broadcast of this packet is limited to the nodes located within the smallest area covering the two nodes (the source and the destination), nodes beyond this area will drop this packet if they receive it.

4. Simulation Environment

In this paper, we evaluate six protocols, four reactive; ABR, DSR, AODV, and LAR, and two proactive; FSR and WRP, using GloMoSim [20]. We have extended GloMoSim by adding ABR as well as other parameters and metrics. We have simulated 50 nodes moving in a 1600m x 400m during 15 minutes, each one has a power-range of 250m.

Our simulation environment is characterized by the following parameters:

- *Mobility model*: Among GloMoSim's mobility models, we have chosen the random way-point, which is the closest to the real motion. In this model, a node selects randomly a destination from the physical area and it moves toward it. When the node reaches this destination, it stays there for a giving time (pause time), and it repeats this process. We have fixed the pause time during all the simulation to 1 seconds, and changed the nodes speed to change the mobility.
- *Propagation model*: We have chosen the Free Space model, which supposes that there is no obstacles between a sender and a receiver, and the signal dim is proportional to the distance between these two nodes. This is a simple model in which obstacles are eliminated during the simulation. We opted for this model since obstacle effects are out of the scope of our study.
- *MAC layer protocol*: We have chosen for this layer the IEEE 802.11 protocol, largely used in wireless networks.
- *Application layer*: During the simulation time, 16 nodes generate Constant Bit Rate (CBR) traffic, each one generates 1 packet per second, each of size 1 Ko. This kind of application uses UDP as the transport layer, it is largely used in wireless networks and video applications flexibility.

4.1. Mobility Definition

Mobility is an important parameter for MANETs routing protocols evaluation. In the previous studies, this parameter was represented by nodes speed, or by the pause time when using the random way-point model. These representations, however, are meaningless, and do not reflect the topology changes. Nodes may move either in a high speed or a low pause time, but toward the same direction without causing any topology change. On the other hand, nodes may have a low speed or a high pause time, but they move away from each other, resulting in important topology changes. This illustrates the weakness of this mobility representation. A more rigorous mobility definition that better expresses the network topological change was proposed by Larsson *et al*. [13]. This definition is based on relative nodes' movement, and represents the mobility by a parameter called mobility factor (mob) that depends on both, the nodes speed and the movement pattern (directions). It is given by the following formula:

$$mob = \sum_{i=1}^{n} \frac{M_i}{n}$$

$$M_x = \sum_{t=0}^{T-\Delta t} \frac{|A_x(t) - A_x(t+\Delta t)|}{T}$$

$$A_x(t) = \sum_{i=1}^{n} \frac{dist(n_x, n_i)}{n-1}$$

Where:

dist (n_x, n_y): The distance between nodes x and y.

n: The nodes number.

$A_x(t)$: The average distance between node x and all the other nodes, at time t.

M_x: The average relative mobility of node x regarding all other nodes, during the simulation time.

T: Simulation time

At: Time period used in computation.

In our implementation, this parameter (called mobility factor) is computed during the simulation. After each At, $A_x(t)$ is calculated, i. e., it is calculated for: t = 0, t

= Δt, t = 2Δt, … t = T. For our simulation, we have added to GloMoSim the mobility factor computation.

To verify that this definition reflects the topological change, we measured the mobility factor vs. the average link change that represents the topological change. A link change may be either a new link creation or a link failure. We define the average link change LINKCHANG by the following formula:

$$LINK\_CHANG = \sum_{t=\Delta t}^{T} link\_change(t) \times \frac{\Delta t}{T}$$

$$link\_change(t) = \sum_{i=0}^{n-1} \sum_{j=i+1}^{n} \left[state(t,i,j) \oplus state(t-\Delta t,i,j) \right]$$

$$state(t,i,j) = \begin{cases} 1 \text{ if } i \text{ is linked with } j \text{ at time } t \\ 0 \text{ otherwise} \end{cases}$$

We have added the computation of this parameter LINKCHANG to GloMoSim, then we made the appropriate measurements presented by Figure 1. This figure shows how mobility is proportional to the links changes.

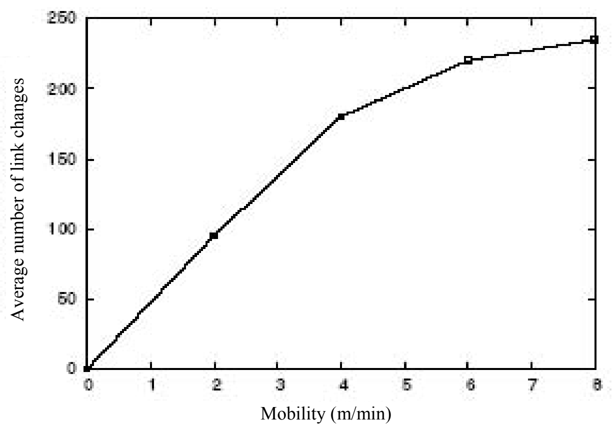


Figure 1. Average number of link changes vs. mobility factor.

4.2. Computed Metrics

The protocols comparison will be carried out by investigating the mobility impact on five metrics, that we consider relevant.

4.2.1. Data Reception Rate

It is the number of received packets divided by the number of sent packets, computed at the application layer level. It reflects the routing protocol reliability which is a very important issue. High values of this parameter reflect a good reliability, i.e low packet loss.

4.2.2. Consumed Energy

Because energy resources of devices used in MANETs are limited, energy consumption is an important issue related to routing protocols. A routing protocol is as better as it causes less energy consumption compared with others in the same conditions. GloMoSim's Energy computation is based on NCR Wavelan radio model. The consumed energy computation of a node i (PCi) formula is the following:

$$PC_i = \sum_{reception} TD(RRR - RSR) + \sum_{transmission} TD \times (RTR - RSR) + RSR \times (Roff - Ron)$$

Where:

TD: Packet size */bandwidth + ST, ST* = 192 micro second.

RTR: *3/second, RRR = 1.48/second, RSR* = 0.18/ *second*

Ron: The radio turning on time (simulation start).

Roff: The radio turning off time (simulation end).

In our study, we measure the average consumed energy in the network *(average_power)*, given by:

$$average\_power = \sum_{i=1}^{n} \frac{PC_i}{n}$$

4.2.3. Overhead

It is the number of packets generated by the routing protocol during the simulation, formally speaking it is:

$$overhead = \sum_{i=1}^{n} overhead_i$$

Where *overheadi* is the control packets number generated by node i. The generation of an important overhead will decrease the protocol performance. Although control packets are essential to ensure protocol functioning, their number should be as less as possible.

4.2.4. AverageData Packet Transfer Delay

It is the average time separating the data packets sending from source nodes and their arriving at destination ones, at the application layer level. If we note this metric by *delay,* then:

$$delay = \sum_{i \in pr} \frac{delay_i}{nbr - pr}$$

pr: Is the set of packets received by all the destination nodes

nbrpr: Is the received packets number (|| *pr* ||)

delayi: Is the transfer delay of packet i, such that:

delayi: Packet i arrival time - packet i sending time

This metric is very important to study the quality of service, especially for real time applications.

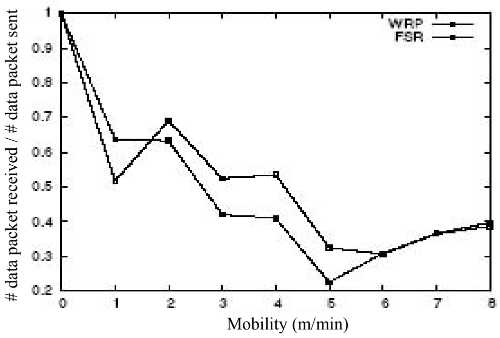
5.Simulation Results

5.1. Data Reception Rate

In Figure 2-b, we see that the Data reception rate

(Drr) of AODV and LAR is not much affected by the mobility, and it is relatively stable for all mobility values. It is more than 84% for AODV and 94% for LAR for the highest mobility. On the other hand, ABR's and DSR's Drr decrease when the mobility increases. We point out that ABR has a slightly better Drr than DSR for high mobility, but both ABR and DSR have important data loss for high mobility. The reasons for this are: First, for ABR, the associativity approach supposes that a path with higher associativity value will be more stable, ABR is fully based on this supposition which is not inevitably held when the mobility increases. Second, for DSR, link failure is detected just when sending a data packet via a failed link. This packet will be lost if the link detector node has no route to the packet's destination. On the other hand, AODV reacts more quickly to link failures, and each node sends an error packet to all its active neighbors as soon as it detects a link failure. For LAR, the localized broadcast strategy allows it to choose stable routes.

In Figure 2-a, we remark that both WRP and FSR lose a great amount of data packets since a low mobility (1 m/min), and the lost keeps increasing when the mobility increases, and may exceed 60%. In vicinity of mobility 0, both proactive and reactive protocols give good Drr, but from mobility 1 m/min, which is relatively low, Drr of proactive protocols decrease disastrously. This is justified by the fact that packets are sent before routing tables converge to a stable state, which leads nodes to take failed routes supposed to be valid.



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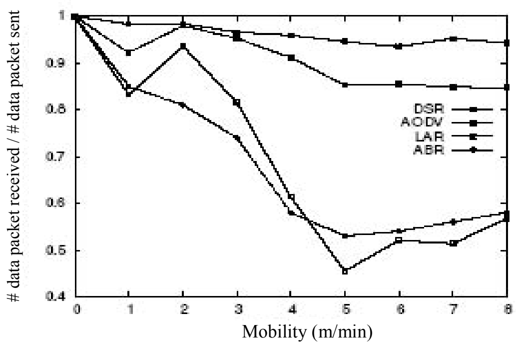
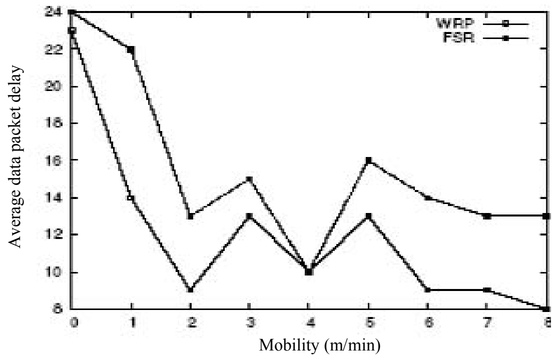


(b)

Figure 2. Data reception rate vs. mobility.

5.2. Average Data Packet Transfer Delay

We remark that ABR, AODV and DSR have low transfer delays and they are not so influenced by the mobility rise as shown in Figure 3-b. On the other hand, the more the mobility rises, the more LAR's average delay increases, and may go down to 160 ms for the highest mobility value. When the mobility increases, GPS information is more and more wrong. Therefore, partial propagation route discovery of LAR may fail. Consequently, route discovery will be achieved after a global broadcast, which causes a high transfer delay. In Figure 3-a, we remark that the delay is steady, and not significantly affected by the mobility. Delays of proactive protocols are smaller and more stable than those of reactive ones. Because the formers construct and maintain routing tables permanently, which eliminates the route discovery time. But we point out that, except for very low mobility, this results are misleading, since proactive protocols lose too many packets (section 5), and these packets are not included in the average delay computation.



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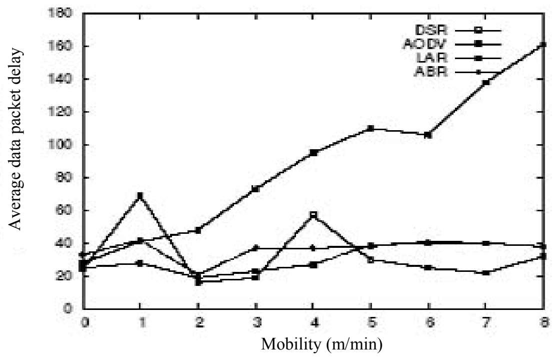


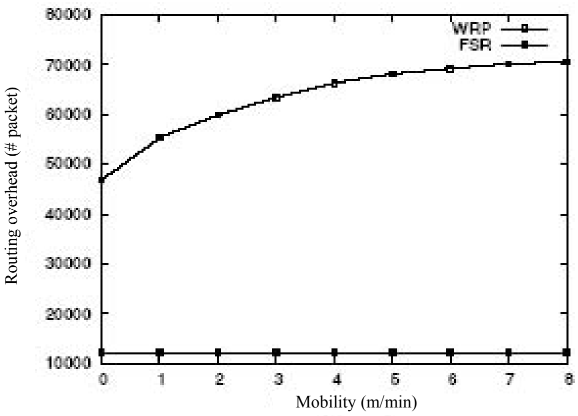
(b)

Figure 3. Average data packet transfer delay vs. mobility.

5.3. Overhead

We can see in Figure 4-b that the overhead generated by ABR, LAR and AODV increase when the mobility increases. Because mobility rise implies route failure rise, which causes the generation of more errors and route discovery packets. Between mobility values 0 and 4 m/min, AODV generates slightly more overhead than LAR, and beyond 4 m/min, we remark the opposite. As for DSR, we remark that the generated overhead is not stable, and it does not vary on a monotonous way, this is due to the use of caches that may contain multi-routes to a same destination. When at least a route to a destination is found in a cache, there is no search for another, and route obtaining from the cache is independent of the mobility. LAR also uses caches, but its effect is limited, because the localized route discovery obtains less routes than the standard discovery used by DSR. Consequently, there is less routes in the cache for LAR than DSR, and a route failure in LAR often causes a new route discovery. Note that the other protocols are not multi-route, i. e., their route discoveries provide solely one route, thus a link failure results in a new discovery launch, which explains their monotony vs. mobility.

ABR generates the highest overhead, we note down that the greatest amount of this overhead is due to periodic messages (Beacons). Although these packets' size is small, their number is high. In fact, 45000 packets are generated during 15 minutes by 50 nodes.



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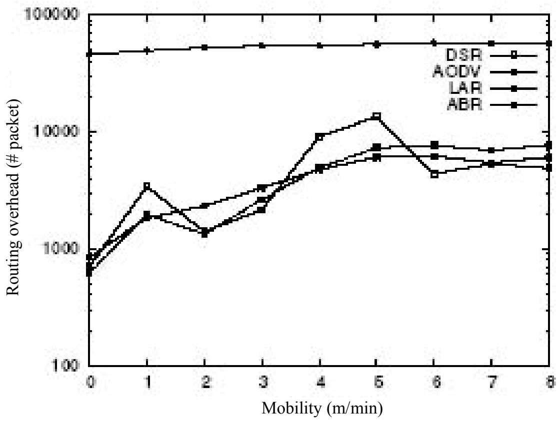
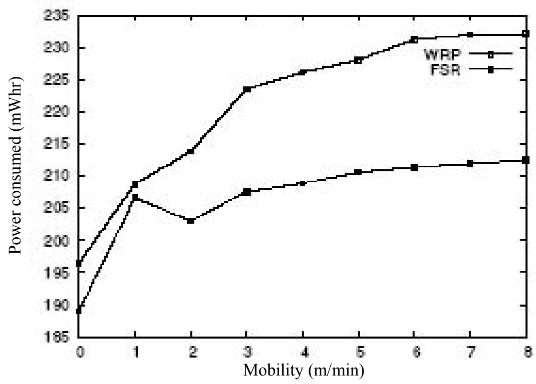


(b)
Figure 4. Overhead vs. mobility.

In Figure 4-b, we remark that FSR generates a constant overhead for all mobility values, this is because it generates packets on a periodic way. This overhead is less than the one generated by WRP, because this latter, in addition to periodic packets, it generates error messages when links fail. This also explains WRP's overhead rise with the mobility. Reactive protocols, except ABR, generates less overhead than proactive protocols. Because these latter generate periodic messages, whereas the reactive ones do not generate overhead unless there is a need for a route, or when a route is failed. We note that ABR generates more overhead than FSR, this is because the period time used to send Beacons in ABR is very short. We care to note that this periodic packets' size is very smaller than FSR control packets (routing tables).

5.4. Consumed Energy

We remark that consumed energy plots as shown in Figure 5, have the same shapes as the appropriate ones of the previous figure (Figure 4). The reactive protocols consume less energy than the proactive ones, because these latter, generally, generate more overhead. Moreover, the sizes of the proactive control packets are longer than those of reactive ones, this explains the fact that ABR generates more control packets than FSR (section 5.3) but it consumes less energy than it.



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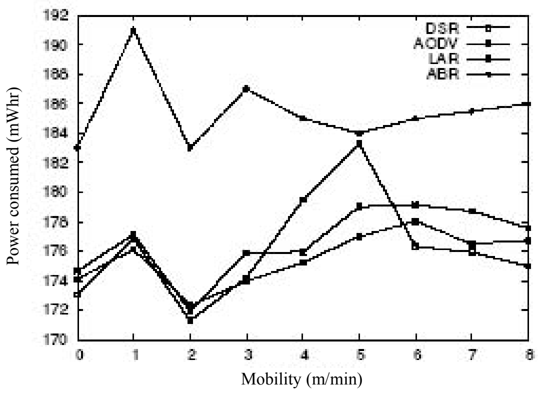

(b)
Figure 5. Consumed energy vs. mobility.

6. Conclusion

In this paper, we have conducted a GloMoSim based simulation study, to investigate the mobility effects on the performance of six MANETs' routing protocols; four reactive (ABR, AODV, DSR, LAR), and two proactive (FSR, WRP). This study is performed by measuring different quantitative metrics at different mobility levels. We have used a rigorous definition of mobility, that reflects accurately the topological change.

We realize from this study that the mobility, which characterizes MANETs, has negative effects on routing protocol. It causes more energy consumption, more latency, more packet lost, and more congestion (due to the increasing overhead). The results obtained also show that the reactive protocols are more adaptive to MANETs than the proactive protocols.

Performances of the proactive protocols go down when the topological change occurs in the network. They generate a great number of routing overhead, resulting in an important power consumption, which is unacceptable for mobile unities supplied by batteries. They also cause an important packets loss. However, the proactive protocols have low latency, since they need no route discovery phase. But this has no significant importance when the mobility appearers, because in this case proactive protocols cause an important data packets loss, these packet are not considered when computing delays. Finally, we point out that unlike the previous studies, ours show dramatic degradation of the proactive protocols performances with high mobility. This because mobility values used in the previous studies were measured in terms of the absolute speed or pause time, hence, values considered as high may not cause so many link changes (section 4.2) which gives false impressions on the performances vs. the mobility. However, the mobility definition we used is based on the relative mobility and reflects much better the topological change.

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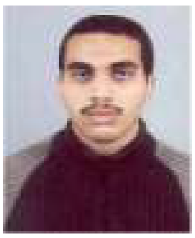

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