Analyzing Control Traffic Overhead in Mobile Ad-hoc Network Protocols versus Mobility and Data Traffic Activity

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Abstract—**This paper proposes a general, parameterized model for analyzing protocol control overheads in mobile ad-hoc networks. A probabilistic model for the network topology and the data traffic is proposed in order to estimate overhead due to control packets of routing protocols.**

Our analytical model is validated by comparisons with simulations, both taken from litterature and made specifically for this paper. We identify the model parameters for protocols like AODV, DSR and OLSR, and confirm that our model corresponds with the simulation results

Our model permits accurate predictions of which protocol will yield the lowest overhead depending on the node mobility and traffic pattern.

I. INTRODUCTION

Mobile ad-hoc networking (MANET) has experienced a growing interest since the apparition of affordable radio interfaces, allowing wireless connectivity of mobile nodes. A key-point in connecting a group of mobile nodes is the design of a routing protocol that allows otherwise out-of-range nodes to communicate through having their traffic relayed by intermediate nodes. This is the subject of the IETF MANET working group [5], [13] where several protocols are being proposed.

The different routing protocols can be divided into two disjoint classes according to the way routes are created:

Reactive protocols
> find routes on demand when needed by a source. They usually rely on flooding when no topology information is available. I.e. the source floods a packet and the path followed by the packet to reach the destination is used.

Proactive protocols
> proactively discover the topology with every node emitting regular hello packets and an optimized mechanism is used to broadcast local topology information.

These two approaches have different characteristics with regard to control traffic overhead. Reactive protocols generate overhead only when a new route is needed, while proactive

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protocols continuously generate control traffic. Link failure, mainly due to mobility, will produce additional overhead with both approaches since routes must be repaired as quickly as possible. In a reactive protocol, routes either have to be repaired or rediscovered. In a proactive protocol, the broadcasted topology in the network has to be updated to reflect the change.

Comparing the overhead from these two very different approaches is thus a challenging task. The objective of this paper is to propose a model for analyzing control traffic overhead of MANET routing protocols in order to better identify which protocol is better suited for a particular situation. By control traffic overhead, we mean the bandwidth utilization due to control packets.

It is evident, that control traffic overhead mainly depends (apart from the routing protocol used) on the topology (and its changes) and the data traffic. Our main result is a reasonably simple model for the relationship between control traffic overhead and both topology and traffic. We use simulations of real protocols to infer the parameters of our model and to verify that the predictions of the model correspond with the simulation results. Finally, this allows us to compare these protocols for all mobility and traffic activity patterns - not only those situations covered by simulations.

	Reactive	Proactive
Fixed	$\lambda o_r N^2$	$h_p N + o_p t_p N^2$
Mobility	$o_r \mu a L N^2$	$o_p \mu A N_p N^2$

TABLE I

GENERIC CONTROL TRAFFIC OVERHEAD OF BOTH PROTOCOL FLAVORS IN NUMBER OF PACKETS.

Our approach is analogous to complexity analysis: we focus on the main contribution term to the bandwidth cost of control traffic overhead. Table I presents the estimation of control traffic overhead for the two main flavors of protocols. The main parameters are: N the number of nodes, μ the failure rate of a link (which models mobility), and a the number of active routes per node (which models activity of the traffic).

Reactive protocols include AODV [19] by C. Perkins et. al.,

Network parameters	
N	number of nodes
M	number of edges
$\Delta = 2M/N$	average degree of a node
$d = \Delta/N$	link density
μ	link breakage rate (mobility)
L	average length of a route

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TABLE II

PARAMETERS DESCRIBING THE NETWORK.

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Traffic parameters	
λ	route creation rate per node
a	number of active routes per node (activity)

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TABLE III

PARAMETERS DESCRIBING THE DATA TRAFFIC.

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TORA [18] by M. S. Corson and V. Park, DSR [12] by J.Broch, D.Johnson and D.Maltz, ODMRP [16] by S.-J. Lee, M. Gerla, and C.-C. Chiang, and RDMAR [1]. Most of these protocol optimize their flooding cost. These various optimizations are not analyzed in this paper.

Proactive protocols include OLSR [4] by Qayyum, Jacquet, Muhlethaler, Laouiti, Clausen and Viennot and TBRPF [2] by R. Ogier and B. Bellur. Finally, there are hybrid protocols such as ZRP [9] by Z.J. Haas and M.R. Pearlman, which try to take advantages of both the proactive and reactive approaches.

We are going to see, through applying our analytical model, that both proactive and reactive protocols are advantageous in different situations, depending on the on the profiles of the network and the traffic.

A. Paper outline

The organization of the remaimder of this paper is as follows: a generic model is given in section II, taking in account density of the network, mobility, traffic creation and traffic density. Sections III and IV are devoted to the estimation of control traffic overhead by analyzing both the number of control packets and their bandwidth cost for bare-bone versions versions of both reactive and proactive protocols. Section V compares our analysis to simulations of reactive protocols, taken from litterature, as well as to simulations of OLSR conducted for the purpose of this paper. Section VI compares OLSR to DSR with respect to mobility and traffic activity.

II. MODEL FOR NETWORK, TRAFFIC AND PROTOCOLS

To allow analysis of different protocols, we propose a simple model. While the model is simple, we will see that existing simulations of routing protocols confirm the model. For simplicity we assume that no congestion occurs in the network (this assumption greatly simplifies the analysis of protocol behaviors since it implies that few control packets are lost).

A. Network model parameters

The parameters used to model the network are summarized by table II. N denotes the number of nodes in the network, M the number of edges. We consider that two nodes are linked by an edge if they are able to communicate directly, i.e. each one is then neighbor of the other. Δ is the average degree of a node, the degree being the number of neighbors of a node.

The network density is an important parameter for the analysis. We will use the link density $d = 2M/N^2 = \Delta/N$ to represent this.

To model mobility, we introduce μ, the average number of link breakage per link during a second. I.e. a link lasts on average $1/\mu$ seconds. We assume that the link breakage is constant and that link creation balances link breakage. I.e. that M is supposed constant. This implies that $M\mu$ links, in total, are created per second. Notice that it is logical to suppose that the total number of link creation or link breakage is proportional to the number of links.

Another parameter, depending mainly on the shape of the network, is the average length L (number of hops) of a route.

We further make the assumption, that the abovementioned parameters remain constant, as well as that the network always remains connected.

B. Traffic model parameters

Concerning control traffic overhead, we mainly need to model data traffic creation and diversity. The parameters used to model the data traffic are summarized by table III. λ denotes the average number of route creation destination) by a node during a second. The average number of simultaneous active routes per node is denoted by a. An *active route* is a pair (source, destination) where the source continuously sends packets to the destination.

This is a rather simplistic traffic model, however we find that it is sufficient to compare the reactive and proactive approaches to routing.

C. Proactive protocol parameters

A set of parameters depend on the protocols. In this and the following subsection we provide an abstract description of the characteristics of proactive and reactive protocols, respectively. The descriptions are sufficienty detailed to allow reasoning about the protocols, however at the same time sufficiently abstract to allow that - by choosing the correct parameters - any protocol can fit in the model.

Future work will be required to validate the model for each protocol and identifying the values of the parameters for each protocol. Notice that some parameters may depend on the topology of the network or the traffic pattern. However, the analysis of the bare-bone reactive version give satisfying results when compared to simulations found in the literature (see section V).

Proactive protocols are relatively easy to model due the regularity of control packet emission.

Proactive protocols parameters	
h_p	hello rate
H_p	average size of hello packets
t_p	topology broadcast rate
T_p	average size of topology broadcast packets
o_p	broadcast optimization factor
AN_p	active next hops ratio

Reactive protocols parameters	
h_r	hello rate (0 when possible)
H_r	average size of hello packets
RQ_r	average size of route request packets
o_r	route request optimization factor

Control packets mainly include packets for proactively discovering the local topology (usually called hello messages) and topology broadcast packets for allowing global knowledge of the topology. The parameters used to model the proactive protocols are summarized in table IV. h_p and t_p are the number of hellos and broadcast information packets, respectively, emitted by a node during a second. These parameters are expressed in terms of rates. H_p denotes the average size of hello packets (typically $H_p = O(\Delta)$) and T_p denotes the average size of the topology packets broadcasted by a node. We will see in section IV-B that a proactive protocol may need to send additional topology broadcast packets in order to react to topological changes. We introduce a parameter *active next hop* AN_p to accomodate this. The active next hop is the average number of active links per node (when an active link breaks, a topology broadcast has to be carried out).

Proactive protocols can benefit from their knowledge of the topology in order to to optimize broadcasting [14],[8],[2]. Ideally, N/Δ emissions are sufficient to broadcast an information to every node, compared to N emissions for a complete flooding.

The parameter B_p is the average number of emissions to achieve a topology broadcast, and we denote by o_p the *broadcast optimization factor*, *i.e.* $o_p = B_p/N$ ($1/\Delta \leq o_p \leq 1$). Estimating T_p and o_p are the main difficulty when describing a given proactive protocot.

D. Reactive protocol parameters

The parameters used to model the proactive protocols are summarized in table V. Reactive protocols may include hellos for detecting link breakage. If hellos are used, h_r denotes their rate and H_r their size. Otherwise, information provided by the link layer is used to detect link breakage, in which case $h_r = 0$ and $H_r = 0$. The main contribution to control traffic overhead is due to the emission of route request and route reply messages. Route request packets are flooded by a source creating a route. Route reply packets are unicasted by the destination (or intermediate nodes, knowing a route to the destination) to the source, taking the path followed by the route request packet. To keep the model simple, we will not distinguish (regarding the cost of a route request) route reply packets from route request packets. This is acceptable since they usually have a comparable size and their emission is triggered by route request packets. RQ_r will denote the average size of route request (and route reply) packets.

Some reactive protocols propose reduction of the flooding overhead by trying to limit the spread of floodings. This, e.g., by limiting the maximum number of retransmission (TTL) of the route request packet. This is often denoted *expanding ring* [7]. The danger of employing an expanding ring technique is that to reach a far destination, several floodings with increasing TTL may have to be performed. If B_r is the average number of emissions for a route request (including route reply messages), we will denote by $o_r = B_r/N$ the *route request optimization factor*. With the expanded ring technique, beginning with a TTL 2, we get $B_r \geq 1 + \Delta$ and thus $d \leq o_r \leq k$ (if k is the maximum number of floodings for a route request). With pure flooding and a route reply from the destination, we get $o_r = 1 + L/N$ (L is the number of route reply messages in that case). When route caching is used, some route requests may be avoided, this should also be captured by o_r. The main difficulty in estimating the parameters of a given reactive protocol resides in o_r.

Alternatively, some protocols propose that also the route reply is flooded. This can also be captured with this parameter (with pure flooding, $o_r = 2$).

Given these parameters, we are now able to analyze protocol overheads of both routing approaches.

III. CONTROL TRAFFIC OVERHEAD IN FIXED NETWORK

In this section, we will consider the control traffic overhead in a fixed network (*i.e.* supposing that there is no mobility). The additional cost of mobility is considered in the next section.

A. Route creation overhead

To create a route in a reactive protocol, the source makes a route request and a route reply is sent to the source by a node knowing a route to the destination (eventually, the destination itself). In our model, λN route requests are produced every second, producing $\lambda o_r N^2$ packets. This corresponds to a bandwidth overhead of $\lambda o_r RQ_r N^2$. Notice that using the same route from time to time may be considered as route creations since entries of a routing table have a timeout. If the period between two emissions on the same route is greater than this timeout, the second emission will produce a route request.

Indeed, since route requests are transmitted by flooding, any node in the network may receive a route to a source initiating a route request (not only the requested destination). That means that when a node needs a route for the first time to some destination, it may already know a route if the destination has recently initiated a route request. The route request then produces no control packet. This should be captured in the o_r parameter.

Notice that o_r thus depends on the network and traffic parameters.

Proactive protocols have the advantage of having all routes ready for use and do not make any overhead at route creation. On the other hand, their fixed control traffic overhead includes the cost of route creation.

B. Fixed control traffic overhead

With a proactive protocol, each node emits h_p hello messages per second and initiate t_p topology broadcast per second. This produces an overhead of $h_p N + t_p o_p N^2$ packets per second, corresponding to a bandwidth of $h_p H_p N + t_p o_p T_p N^2$.

If a reactive protocol uses hellos to detect link breakage, its hello overhead will be $h_r N$ packets per second, using a bandwidth of $h_r H_r N$. Notice that the size H_r of reactive hello packets usually have constant size compared to a size proportional to Δ for proactive protocols where hello messages usually include the list of neighbors addresses.

IV. CONTROL TRAFFIC OVERHEAD DUE TO MOBILITY

The most challenging task for our model is to quantify the emissions of control packets in reaction to mobility. Mobility is visible for the routing protocol through link creation and link breakage. MANET protocols do usually not generate additional control packets in reaction to link creation. However, it is very important to react quickly to link breakage when the link is actively being used for transfering data. A link breakage is detected either when some hellos are no longer received or when a link failure is reported by the link layer.

A. Reactive protocols

Upon link breakage detection, reactive protocols will basically issue a new route request to repair routes using that link. The route request is either initiated by the source of the route (in that case a notification of route error is sent to the source) or by the node detecting the link breakage (in that case, the term *local route repair* is often used). The policy used influences the o_r parameter.

With aN routes, there are aNL active links. When an active link breaks, a route request has to be carried out for each destination reached through that link. This yields a total overhead of $\mu \times aNL \times N$ packets corresponding to a bandwidth utilization of $o_r \mu a L R Q_r N^2$.

This estimation may be pessimistic when several routes have identical destinations. However, we claim that this estimation is good up to a factor $1/2$ when the traffic is symmetric, *i.e.* whenever there exists an active route from s to d, there is also an active route from d to s following the same path. This is a realistic assumption, considering that transport protocols such as TCP require bidirectional data transmissions in order to operate. Thus, even in the case where a node is an intermediate node for more routes to the same destination, a link breakage on the next hop to the destination will affect all routes transversing this link. While all routes from the intermediate node towards the destinations can be repaired at once, the routes from the destination towards the multiple sourcs require individual route

Reactive protocols		
	Packets	Bandwidth
Fixed Mobility	$\lambda o_r N^2 + h_r N$ $o_r \mu a L N^2$	$h_r H_r N + \lambda o_r R Q_r N^2$ $o_r \mu a L R Q_r N^2$

Proactive protocols		
	Packets	Bandwidth
Fixed Mobility	$h_p N + o_p t_p N^2$ $o_p \mu A N_p N^2$	$h_p H_p N + o_p t_p T_p N^2$ $o_p \mu A N_p T_p N^2$

TABLE VI

CONTROL TRAFFIC OVERHEAD IN AD-HOC NETWORK PROTOCOLS.

repair or route request. This $1/2$ factor also holds when a route and its symmetric route do not necessarily follow the same path (the analysis is a little more subtle and is not detailed here.)

B. Proactive protocols

It could be assumed that a proactive protocol would produce few additional control packets when a link breaks since the node detecting the breakage will probably know another route to the destination. However in some situations, this alternative route may go through nodes that are not yet informed of the link breakage. This is a possible cause of routing loops. The easiest way to avoid such loops is to inform those nodes by first sending an additional topology broadcast packet. A very optimized protocol could unicast this topology packet to the destination. However, it would still be very difficult technically to ensure that loop freedom. Moreover, longer routes might result until the next broadcast of a topology packet. A better optimization would consist in sending a topology broadcast packet with a reduced TTL (according to the distance from the destination in number of hops). For the purpose of this analysis, we will suppose that a node detecting a link breakage on a route will emit an additional topology broadcast packet.

Again, a given node is, on average, on aL routes. As with reactive protocols, several routes may use the same outgoing link. However, the probability that the next hops for these routes are the same is certainly greater than the probability that the destinations for these routes are the same. We thus introduce the *active next hop* parameter AN_p which is the average number of active next hops of a node. For a given protocol, this parameters depends on the nature of the network and the traffic. The total overhead will thus be $o_p \mu A N_p N^2$ packets corresponding to a bandwidth of $o_p \mu A N_p T_p N^2$.

Table VI summarizes the analysis of both protocol flavors control traffic overhead. They both include an $O(N^2)$ overhead. To validate our estimates, we will in the following section V compare our analysis to simulations from litterature for AODV and DSR, as well as to simulations for OLSR.

V. THE ANALYTICAL MODEL AND SIMULATION RESULTS

To our knowledge, the only published work related to our analysis and model are simulations of the various protocols [11], [7], [3], [6], [15].

The routing load defined in [6] and [15] does not allow an easy way of deducting the number of control packets. For that reason, we do not try to compare our analysis to these results.

This section will therefore compare and evaluate our proposed model with the simulations from [11], [7], [3] as well as to ns2 simulations of OLSR.

A. Johansson et al. simulations

[11] is close to the point of view in this paper since a mobility metric is defined and simulations results are presented according to that metric. Like most simulations in literature, the "random waypoint" mobility model [3] is used. The metric for mobility is defined in terms of relative speed between nodes. [11] shows that the average number of link changes is approximately proportional to this mobility metric. It is thus consistent with our definition of mobility which is also proportional to the average number of link changes.

The simulations of AODV, DSR and DSDV in [11] show, that for AODV and DSR there is a close to linear relationship between control packet emissions and mobility. This confirms what is predicted by our $ao_r \min(ud_r \mu L, r_r)N^2$ factor when the r_r rate of route requests is not reached. DSDV produces a constant number of control packets. This is due to the fact that DSDV does not broadcasts additional topology packets in reaction to mobility. This fact can be expressed in our model by $t_p^M = 0$.

Unfortunately, only results for a fixed number of nodes (50) and fixed number of sources of traffic (15) are shown. Other scenarios are presented but again with fixed parameters preventing us from further comparing our model to the simulation results obtained in [11].

B. Broch et al. simulations

The most complete set of simulations of DSDV, TORA, DSR and AODV can be found in [3], which also is the paper originating the "random waypoint" mobility model. The traffic is produced by a fixed number of constant bit rate sources. Our parameter a is thus simply the number the number of sources (10, 20 or 30) over the number of nodes (50).

The results for DSDV show, as expected, an approximately constant number of control packets. The results for TORA are quite unstable due to network congestion. As our model does not take congestion into account, we do thus not consider the TORA results.

Figure 1 extracts results presented in [3] for the highest mobility simulations (maximum speed of $20m/s$) obtained for AODV and DSR. The figure presented is modified to achieve that the x-axis represents the average number of connectivity changes instead of the pause time used originally in [3]. This yields something proportional to our definition of mobility.

Except from the cases of very high mobility (about > 9000 connectivity changes), the results from [3] confirm our model. The relatively low overhead cost for the highest mobility points could come from an implementation bounding the maximum rate of floodings per node. In [3], this is not discussed further.

Figure 2 shows the same results presented versus $\mu \times a$. For each simulation point (S, C, n) where n is the number of control packets observed, C the number of connectivity changes
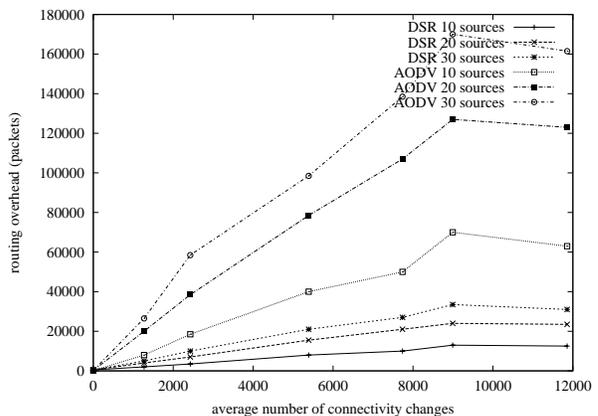

Fig. 1. Simulation results extracted from [3] with abscissae proportional to mobility (the number of connectivity changes can be expressed as $900 \times \mu \times DN$ when the simulation lasts $900s$).

and S the number of sources, we have computed the point $(\mu \times a, n)$. The best approximating line the points is also plotted.

This confirms the linearity of control traffic overhead with activity a as predicted by our $o_r \mu a L N^2$ factor. The difference between AODV and DSR results may explained by different o_r factors: [3] points out that DSR makes extensive use of caching for limiting the number of route requests and uses possibly a "non-propagating" route request for limiting the cost of a route request. We can infer from the curves that $o_r^{AODV} \approx 2$ and $o_r^{DSR} \approx 0.4$ (we use $L \approx 3$).

Additionally, [7] points out that more caching results in lower packet delivery rate, but delivery rate is not predicted by our model.

C. Das et al. simulations

The simulations in [7] use the same simulation model as [3]. However in [7], a version of AODV employing an "expanding ring" technique to reduce the cost of route request floodings is used. Two sets of simulations are presented: one set with the same parameters as in [3] (the 50 nodes set), the other with 100 nodes and a larger field.

Comparing our analysis with the results found in [7], the simulations with 50 nodes again agree with our model for low data traffic rated but not for high data traffic rates.

For the simulations in [7] with 100 nodes, our model and the simulation results are in complete agreement.

Figure 3 shows the simulation results for [7] with 100 nodes presented as number of control packets per second versus $\mu \times a$. (This curves are approximately deduced from the curves showing routing loads and packet delivery fractions in [7].) Thus in this case, we can infer from the figure $o_r^{DSR} \approx 2$ and $o_r^{AODV} \approx 4$.
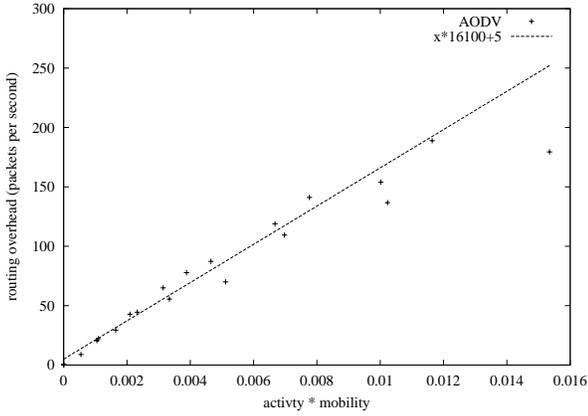
D. OLSR simulations

In OLSR, all optimizations are made through the concept of multipoint relays (MPRs) [14], [10]. Each node selects a set of MPRs in its neighborhood and only those MPRs retransmit flooding packets transmitted by the node. Topology updates
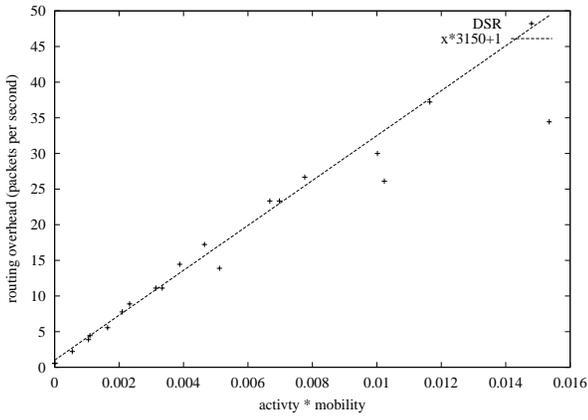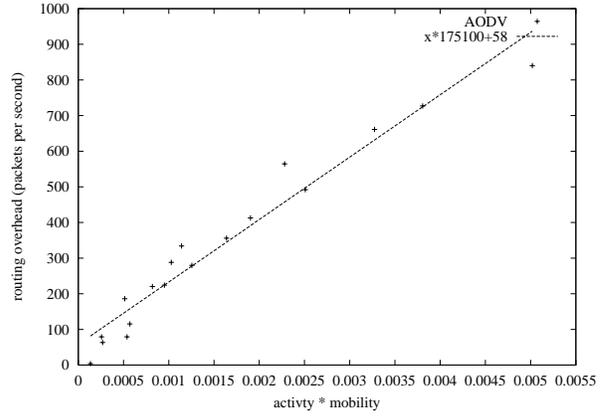
(a) DSR
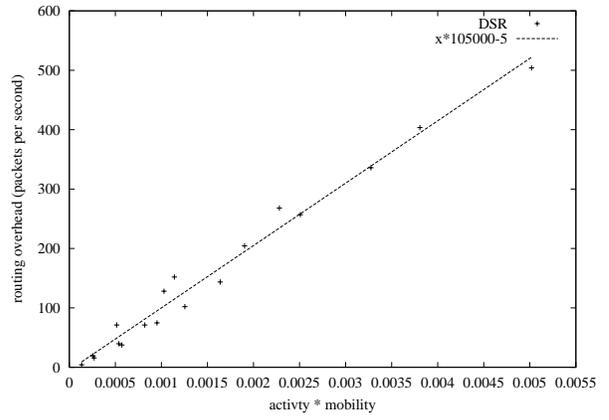
(a) DSR

(b) AODV

(b) AODV

Fig. 2. Simulation results taken from Figure 5 in [3] showing number of control packets per second versus $\mu \times a$.

Fig. 3. Simulation results extracted from Figure 4 and 5 in [6] showing number of control packets per second versus $\mu \times a$.

are made of MPR selector lists (each node sends the list of the nodes that have selected it as MPR). The active next hops must be multipoint relay selectors and their average number is thus equal to the average number of multipoint relays.

We have conducted ns2 simulations of OLSR in the same framework as Johansson et al. simulations [3]. We first notice that control traffic generation does not depend on the data traffic characteristics. This is not surprising since reaction to mobility is made only with regards to MPR changes.

Figure 4 shows the simulation results. Since the data traffic rate is of no impact on the results, the x-axis represents only mobility. We again observe the linearity of control traffic overhead with respect to mobility. We can infer from the figure $o_p^{OLSR} AN_p^{OLSR} \approx 749/50^2 = 0.3$ and $o_p^{OLSR} \approx 66/0.2/50^2 = 0.13$ ($t_p^{OLSR} = 0.2$).

To cross check these results, we have made simple simulations to infer the average number of MPRs of a node (which is equal to AN_p^{OLSR}) and the average number of emissions per MPR flooding (which is equal to $o_p * N$). In the 1500x300 field with $N = 50$, we found $AN_p^{OLSR} \approx 2$ and $o_p^{OLSR} \approx$

$8.2/50 = 0.16$. For the 2200x600 field with $N = 100$, we found $AN_p^{OLSR} \approx 3.2$ and $o_p^{OLSR} \approx 28/100$. (The average degree is around 10.5 for both scenarios. We also found $L \approx 3$ for the 1500x300 field with 50 nodes and $L \approx 4$ for the 2200x600 field with 100 nodes.)

There is a slight difference for the two estimations of o_p^{OLSR} (0.13 and 0.16) in the 1500x300 field with 50 nodes. This can be explained by the fact that only nodes having non-empty lists of MPR selector send topology updates. When there is no mobility (first estimation) some nodes do not send any topology update, yielding a better broadcast optimization factor. With mobility, nodes whose list becomes empty must still send an empty topology update to invalidate old information, yielding a slightly worse optimization factor. We will in the following use the second estimation in the sequel as it gives a sharp upper bound for the 1500x300 scenario ($820\mu + 82$ control packets per second instead of $749\mu + 66$) and allows to give estimations for the 2200x600 scenario.

Given the estimated parameters of the protocols, it is now possible to conduct comparisons for a wider range of scenarios.
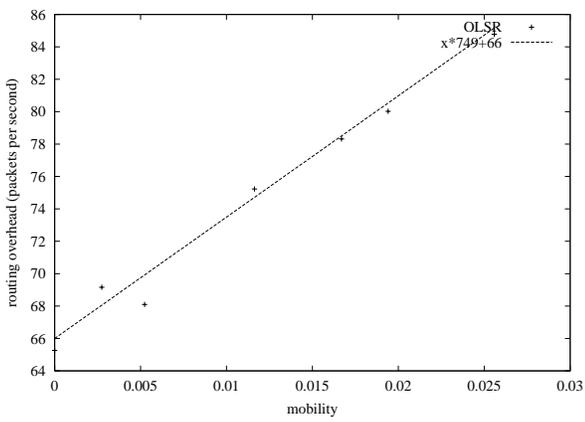
Fig. 4. Simulation results for OLSR showing number of control packets per second versus μ (50 nodes moving in the 1500x300 field).

VI. Control traffic overhead comparison

We observe that among the reactive protocols, AODV generates more control traffic than DSR. Thus, for the purpose of this paper, we choose to compare the proactive protocol OLSR with DSR.

A. Tolerance to mobility

When the length of a route is L, some link on the route breaks at the rate of $L\mu$. To be able to route packets between two constructions of the route, reactive protocols require that this rate does not exceed h. The maximal allowable mobility is thus $\mu_F = h/L$ for reactive protocols.

Since a proactive protocol can repair a broken route locally, the maximal allowable mobility μ_H is simply bound by the duration of routes of length 2, giving $\mu_H = h/2$.

Notice that report of link breakage by the link layer could allow reactive protocols to increase their reactivity and, thus, flooding rate. To our knowledge, link-layer notifications are not uniformly supported by existing technologies, and is not yet standardized.

To compare the protocols, we will thus consider $0 \leq \mu \leq h/L$. Notice that it $\mu = h/L$ still represents a very high mobility since for $h = 1$ (usual value proposed in protocols) and $L = 10$, this gives $\mu = 1/10$, meaning that the average duration of a link is then 10 seconds. In the mobility model of [3], this corresponds to an average node speed of 25 meters/sec.

B. Parameter values for comparisons

To compare both protocols, we need to determine some parameters. First of all, the protocol parameters are known: $h_p^{OLSR} = 0.5$ and $t_p^{OLSR} = 0.25$ and $h_r^{DSR} = 0$. Other protocol parameters are deduced from the simulations presented in section V.

We will compare the two protocols in terms of μ and a.

The final parameter is λ, which models traffic creation. Considering typical traffic such as web browsing, it is natural to suppose that a given source of traffic changes its destination from time to time - say every 60 seconds. Thus for this comarison, we use $\lambda = a/60$ (notice that the overhead thus introduced for DSR is neglectable as soon as $\mu \geq 0.05$).

To compare bandwidth utilization, we have to estimate the overhead of packet emission. We will suppose the use IEEE 802.11 MAC layer [17]. The average duration of the backoff is 310 microseconds, the DIFS interval is 50 microseconds and the synchronization overhead is at least 96 microseconds. Supposing 1 Mb/sec data rate, this corresponds to an overhead of 456 bits (or equivalently 57 bytes) per packet emission. Moreover each packet must contain a MAC header of 34 bytes and an IP header of 20 bytes.

A DSR route request will include 8 additional bytes plus at list two adresses. An OLSR topology update will include 20 additional bytes plus AN_p adresses. An OLSR hello message will include 36 additional bytes plus Δ adresses. Considering IPv4 adressing, we will thus suppose: $RQ_r^{DSR} = 127$, $T_p^{OLSR} = 131 + 4\,AN_p$ and $H_p = 147 + 4\Delta$.

C. Comparison equation

Our aim in this section is to identify the set of scenario parameters where the reactive protocol performs either significantly better or significantly worse than its proactive counterpart. Restricting our analysis on control traffic overhead and taking the results of our previous analysis, this consists into identifying the areas where:

$$127 \left(\mu L + \tfrac{1}{60}\right) o_r^{DSR}\, a \lessgtr ((73.5/N + 2d) + o_p^{OLSR}(.2 + \mu\, AN_p^{OLSR})(131 + 4\,AN_p^{OLSR}))$$

D. Planar free space model

As in the simulations presented before, the nodes are in this model randomly placed on the plane. Two nodes may communicate if their distance is less than the radio range. This model is also known as the random unit graph model.
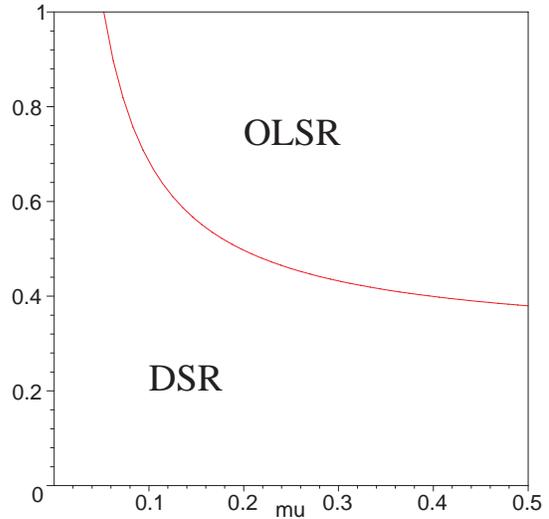

Fig. 5. Comparison of OLSR and DSR control overheads in the free space model. The abscissae is μ and the ordinate is a. $N = 50$, 1500x300 field.

Using our analytical model, we can now compare DSR and OLSR for any mobility and data traffic patterns. Figure 5 and figure 6 presents the regions favorable to each protocol in the plane μxa.
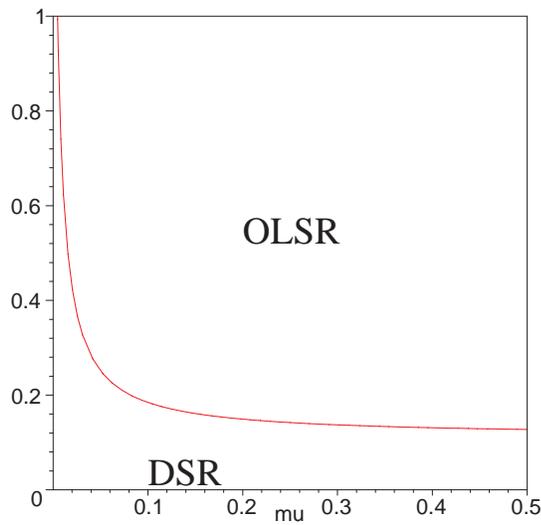
Fig. 6. Comparison of OLSR and DSR control overheads in the free space model. The abscissae is μ and the ordinate is a. $N = 100$, 2260x600 field.

We find that high data traffic favours OLSR, and we also notice that the area where OLSR is of preference is larger in the big network. On the other hand, for low traffic rates, DSR yields the better results.

We notice, that the usually admitted paradigm stating that reactive protocols behave better with regard to control traffic overhead when mobility increases proves to be wrong. While it is correct for low traffic rates, when the traffic rates in the network grow beyond a certain limit, the proactive protocols are of preference. We call this limit the activity limit a_l.

E. Rough high mobility asymptotic

We can roughly estimate the activity limit between proactive and reactive protocols for high mobility. Comparing a proactive protocol with a reactive protocol, we can first suppose that the sizes of control packets are similar for both (this assumption is reasonable when the overhead of sending a packet is quite high as with IP over IEEE 802.11). For high mobility the comparison equation thus becomes: $\mu L o_r a \lessgtr \mu A N_p o_p$. For the same broadcast optimization we obtain an asymptotic activity limit $a_l = A N_p / L$. Notice that a reactive protocol can achieve exactly the same broadcast optimization factor as a proactive protocol (e.g. DSR can employ hello messages and perform flooding using the MPR optimization of OLSR). We note that reactive protocols are better suited as long as $a N L \leq A N_p N$. Notice that aN is the number of routes and $A N_p N$ is the number of active links. This means that reactive protocols are better suited (with high mobility) as long as routes remain distinct.

VII. CONCLUSION

We have proposed an analytical model that allows us to describe and reason about MANET routing protocols. The model is parameterized such that it can accomodate any proactive or reactive routing protocol. We have found, when applying the model to scenarios where simulation studies exist, that the model accurately reflects the simulations.

We notice that the difficult task is to identify the correct values for the protocol parameters. However once these are extimated, it is possible to compare different protocols in a very wide range of mobility versus traffic patterns.

To extend our analysis, one should also consider overhead due to non-optimal routes.

Our model allows us to detect a fundamental limit between proactive and reactive approaches for high mobility tolerance. This limit shows, that proactive protocols are better suited as soon as a significant number of links can be reused for several routes.

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