

# Polymorphic Routing using Proactive and Probabilistic Approaches for MANETs

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## ABSTRACT

This paper describes a new approach for routing in Mobile Ad Hoc Networks that is based on the concept of polymorphic behavior. This approach combines the benefits of proactive routing and probabilistic routing in time in a periodic manner in order to get the best of each approach at the appropriate time. The polymorphic behavior aims at improving the routing information in order to minimize the usage of false routes and to improve connectivity. Simulation results shows that the scheme is achieving very high conformity with real (simulated) and accurate routing information.

## Keywords

Polymorphic Routing, Proactive Routing, Probabilistic Routing, MANETs, Mobility monitoring

## 1. INTRODUCTION

In a mobile ad hoc network, random mobility of nodes is an important factor affecting the topologies of the network. Indeed, with mobility (either high/low) nodes can get out of the transmission ranges of their peers and make them appear and disappear frequently. Other factors that add to this dynamic evolution of the network topology is battery depletion and adopted power saving mechanisms.

Besides, the routing function is distributed among all the nodes where each one can operate as source, destination or router. Each node has to build the paths it needs and may have to maintain a routing table depending on the routing scheme it is using.

Broadly, routing protocols can be classified into three categories, namely, proactive, reactive, and hybrid. Proactive routing protocols maintain constantly network topology information using periodic exchanges of such an information. This allows Mobile Node (MNs) to continuously

monitor topology changes and use that knowledge for efficient, low latency data transmissions. Common proactive routing protocols include the Wireless Routing Protocol (WRP) [18], Dynamic Destination-Sequenced Distance-Vector Routing (DSDV) [7], the Optimized Link State Routing (OLSR) [4], and others.

Reactive routing protocols [5, 21, 6, 19] on the other hand follow a *passive* approach to communication requirements whereas MNs react only on-demand to data transmission requests and perform path finding operations only when needed in order to save channel usage.

Besides, *hybrid* routing protocols are those which combine both types of behaviors into a single framework [22, 20, 13] that is theoretically supposed better than any single behavior considered alone.

Going a step further in the design of protocols that are suited for dynamic networks, a new paradigm known as polymorphic behavior based routing was introduced in [1, 2, 23, 24]. In general, polymorphic routing protocols exhibit hybrid, adaptive, multi-stimuli based routing. Such a protocol is empowered by various operational (i.e., behavioral) modes that are triggered by specifically defined surrounding factors and with specially defined (mostly performance based) targets.

In this paper, we propose another aspect of polymorphism in routing behavior that is following the time dimension and that uses a predefined knowledge about the efficiency scope of a given routing behavior. Specifically, we focus on the proactive routing that was considered to perform the best due to the periodic collection of topological information of the network by all MNs. However, in a recent work [9], the authors showed that proactive routing techniques are not all the time suitable for mobile multi hop ad hoc networks as routing tables rapidly lose accuracy.

This is due to the fact, in presence of high mobility or in case of long routing periods, the topological information collected at the beginning of these periods becomes quickly obsolete, leading subsequently to invalid paths.

In such mobile networks, we should strive to choose the most stable paths. That is, paths who have high persistence likelihood. The question naturally arises as to how should we select and decide on these links and routes. Finding the most stable path must anticipate or predict topological changes. Stability of a path is based upon the stability of all nodes it passes through and all links connecting them.

To adapt more efficiently to the dynamics of the network,

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the authors of [10] proposed a probabilistic routing that was shown to outperform conventional proactive routing in terms of providing correct and valid routes.

In this current work, we exploit this idea further and focus on the fact that, in the beginning of the routing period, the freshness of the network topological data gathered by the MNs, using proactive routing, constitutes an important asset that is still of great benefit for the routing task. Furthermore, knowing that the information freshness weakens with time, we propose a polymorphic timely routing, that combines proactive and probabilistic routing dynamically in order to achieve some desirable performance targets in presence of measured networks dynamics (such as the current average mobility speed of the MNs). The paper is organized as follows:

In section II, some overview of related works is given. Section III describes our proposed algorithm. In section IV a description of the simulation setup and the obtained results is presented. Concluding remarks, given in section V, wraps up the paper.

## 2. RELATED WORK

Finding stable routes is of main concern for dynamic ad hoc networks. Several works established already that choosing routes based on positions, battery level, etc. of nodes should make paths selection more efficient regarding to the life-time of routes. Thereafter, a new routing approach has then come out considering the route stability as a routing metric.

Stable routing or stability-based routing is an emergent approach which is unique to dynamic wireless networks. It aims at choosing routes which are stable in time and hence more reliable and coping better with the networks dynamics. The stability of a path relies on the stability of its composing links. The authors of [15] proposed to classify links based on the mobility behavior of their end point nodes. Links between stationary or very slowly moving nodes are considered as stationary links. Links which exist only for a short period of time are handled as transient links. Newly formed links are also considered to be transient as they are more likely to break down.

Routing should use then stationary links whenever it is possible. A ticket-based probing procedure was proposed to find stable routes. Classification of links was also adopted in [17] where authors used the strength of the received signal from each neighboring node to determine whether the associated link is weak or strong. Routing is then made through paths maximizing the received signal strength.

Associativity Based Routing (ABR) [16] used a metric called associativity which defines the stability of the link between two given nodes. ABR considers that the longer the two nodes has being neighbors, the longer they would stay connected. To express its associativity, each node broadcasts periodically a *Beacon* to indicate its presence. Upon the reception of a *Beacon*, a counter associated to the generating node is updated. The counter is reset to zero if the associated node is no longer accessible. The optimal route towards a destination is the one maximizing its associativity metric.

Furthermore, few probabilistic techniques were proposed although they seem to better cope with the unpredictable behavior of ad hoc topologies. In [14], a probabilistic technique is proposed to estimate the residual lifetime of routes.

Routing is then made through the ones with maximum residual lifetime. Lifetime of a route is computed as a function of the existence probability of each link which is derived from the distribution governed by the underlying mobility model. In contrast to the latter, in [10] the authors proposed a new routing approach which is based rather on the existence probability of routes. Mobility is represented through a generic behavioral analytical model.

For our case, the protocol we are proposing in this paper, belongs to the class of hybrid and adaptive protocols that were tagged as *polymorphic* protocols [1] [23] [24]. We argue here that the concept of polymorphic protocols is gaining acceptance in the networking research community, and is used to denote and describe adaptive multibehavioral protocols with one single word.

We can cite the work presented in [24], where the authors proposed Polymorphic optical networks that are able to simultaneously support several optical switching paradigms over a single physical network. By this, they provide service differentiation at the optical layer by letting the network layer decide about the most appropriate paradigm for each service. In [23], a similar concept used for routing in optical networks was proposed.

However, our proposed protocol, in this work, presents a novel definition of polymorphic behavior that still uses environmental information (that is mobility speed range in this case), but is dynamically activated in time. Indeed, our protocol uses specific settings and routing accuracy condition monitoring to decide about the polymorphic behavior to adopt in a timely manner. This will be described in the protocol description below with more details.

## 3. THE PROPOSED PROTOCOL

The algorithm we propose can be described as a routing protocol that is polymorphic in time. Its main principle is based on switching between a proactive routing and a probabilistic routing within the same routing period. Its essence is derived from the observation we had on the results on the pure proactive routing. In fact, the observations dictate that the usefulness of the proactive routing fades out with the passage of time in the same routing period. Common sense instructs then to decrease the routing period length.

However, doing that increases the traffic overhead related to the proactive collection of topological information. Another observation tells us that the efficiency of the proactive routing degrades slowly in time for low mobility speeds and degrades very quickly in time for high speeds.

Hence the polymorphic behavior (i.e., the dynamic switching between both modes; proactive and probabilistic) will be guided by the current measured average mobility speed.

Furthermore, mode switching is driven by specifically defined efficiency thresholds. That is, for each speed range different threshold values are set (i.e., predefined). It goes to the extent that for a given speed range (usually high) where the proactive routing is almost useless from the start (as it can be seen in Fig. 1(a)), the switch is eminent from the start of the routing period.

### 3.1 ALGORITHM DESCRIPTION

#### *Assumptions:*

We suppose that at the start of each routing period, each node gets the net cartography.

This cartography is constituted by a set of couples repre-

senting current coordinates of nodes:

$C_r = \{(x_0, y_0), (x_1, y_1), \dots, (x_n, y_n)\}$ , for a network of  $n$  nodes. This information is supposed imbedded in the proactive routing protocol used. In the simulation, we are using an augmented DSDV protocol. The routing messages (i.e., the Hello messages) are augmented by location information on the node's current position, that are supposedly taken from a GPS device.

Based on the position information a mobile node (MN) gets from the routing messages, each node will compute an average speed. What we mean here by average speed is a relative speed computed by each node locally using its own coordinates and the overall information gathered about the other nodes.

Before we proceed further, let's recall an observation made on probabilistic routing made in [10] which is the fact that probabilistic routing amounts to much longer routes than the real optimal routes given by the actual network. This is due to the enforced preference given by probabilistic routing to short stable links. Conventional proactive routing provides very few valid routes (see Fig. 1) exactly those that are very stable in the actual networks at the beginning of the routing period.

To deal with this issue, we propose to upper bound the length of the paths generated by the probabilistic routing. We make use of two metrics to compute each probabilistic route: the minimum cost which guarantees the greatest probability and an upper limit on the number of hops. A probabilistic route must then have the greatest probability of existence among all possible routes, yet its length should not exceed (in terms of number of hops) a maximum threshold. We use an integer value  $L$  that denotes the maximum additional allowed number of hops relative to the mean length of the proactive routes. In our algorithm the value of  $L$  is used to define grades of probabilistic routing that enriches the polymorphic behavior of the protocol.

Next we define the *Couple of Route Validity Tolerance (CRVT)* per speed range as the two threshold values below which a switch in behavior is triggered. The couple is defined as:  $\{(Th_{Pr}, Th_{PL1})\}$ , where  $Th_{Pr}$  represents the *Threshold of Route Validity Percentage (TRVP)* achieved at a given instant using the proactive routing, and the  $Th_{PL1}$  is the *TRVP* using a probabilistic routing with  $L = 1$ . This couple is used with the second routing policy we propose below.

As a first policy (*policy I*) we assume that the settings of the *TRVPs* with regards to a given speed range is determined empirically by results derived from the curves depicted in the figures 1 and 2, and stored in a data structure within each node. As an example, from Fig. 1, (considering proactive routing), for a speed of  $v = 0.5m/sec$ , to maintain a performance efficiency greater than 90%, we should set the switching instant  $SI_{Pr}$  to 12secs from the beginning of the routing period.

Then, during operation, each node has to calculate the network relative average velocity (NRAV) at the beginning of each routing period. Each node gathers the positions coordinates of all other nodes from the routing control messages (hello messages), in order to determine the current routing period coordinates. This information along with the previous routing period coordinates and the elapsed time (i.e., the length  $T$  of the routing period) allow a node to compute all the nodes' effective relative speeds and their average. This average represents the *NRAV*. Thereafter, for

any specific NRAV value, the node deduces the switching instants  $SI_{Pr}$  that would trigger a switch in behavior from the proactive routing mode (*PM*) to a probabilistic routing mode with  $L = 1$ , and the  $SI_{PL1}$  needed to trigger the switch from probabilistic routing with  $L = 1$  to probabilistic routing with  $L = 2$ . In this way the switching moments in any routing period are decided a priori from the behaviors learned from Fig. 1 and Fig. 2 (according to the designer's target performance goals for specific NRAVs). This policy is depicted in the pseudo-code given by the algorithm *inferred\_behavior\_based\_routing*.

The second policy (*policy II*) we adopt, is based on the principle of having the routing process be constrained by some target performance levels. In the simulations, these target performance levels represent the minimum tolerable percentages of valid routes that should be maintained regardless of nodes or network' speed. For example, we can require that we should maintain a performance target of 90% of valid routes to be produced by the routing process. Thus, it is the responsibility of the routing protocol to maintain the target performance level by switching between the different routing behaviors available, namely, the proactive routing behavior or the probabilistic routing with  $L = 1$  or 2. At each observation period (e.g.,  $t = 1$  sec), the node computes its current efficiency of generating valid routes and decides whether a mode switch is required. This policy is depicted in the pseudo-code given by the algorithm *performance\_targets\_based\_routing*.

Formally, the proposed algorithms enforcing the above policies are defined below. Prior to that we define the three behavioral modes adopted as follows :

*PM*: Proactive Mode  
*BM<sub>1</sub>*: Probabilistic Mode with L=1  
*BM<sub>2</sub>*: Probabilistic Mode with L=2

**Policy I:** *inferred\_behavior\_based\_routing*

Routing algorithm at Node  $i$

**BEGIN**

At the start of the first the routing period node  $i$  gets the set  $C_r$  of nodes' coordinates and initializes its network velocity relative average (NRAV) to zero.

**Loop forever**

let  $t = current\_time$  relative to the start of the current routing period  $T$ .

get the *CRVT* couple (i.e., the  $Th_{Pr}$  and the  $Th_{PL1}$ ) for the current value of the NRAV

Lookup the switching instants  $SI_{Pr}$  and  $SI_{PL1}$  corresponding to the *CRVT* couple

if (node in *PM* and  $current\_time \geq SI_{Pr}$  )

then switch to *BM<sub>1</sub>*

else if ( node in *BM<sub>1</sub>* and  $current\_time \geq SI_{PL1}$  )

then switch to *BM<sub>2</sub>*

$t += s$  //  $s$  being a sampling period (e.g.,  $s=1sec$ )

if ( $t \% T == 0$ ) then switch to *PM*

get the new set  $C_r$  of nodes' coordinates

compute the new network relative velocity (NRAV)

**End Loop**

**END**

## Policy II: *performance\_targets\_based\_routing*

Routing Algorithm at Node  $i$

### BEGIN

Define the target Performance Lower Bound (PLB) to be  $x\%$  of valid routes.

At the start of the first the routing period node  $i$  gets the set  $C_r$  of nodes' coordinates and initializes its network velocity relative average (NRAV) to zero.

### Loop forever

Compute the current efficiency of delivering valid routes (CEDVR) using the current (NRAV)

if (CEDVR < PLB) then

    if (node in  $PM$ ) switch to  $BM_1$

    else if (node in  $BM_1$ ) switch to  $BM_2$

$t+ = s$

if ( $t\%T == 0$ ) Then

    switch to  $PM$ ,

    get the new set  $C_r$  of nodes' coordinates and

    compute the new network relative velocity (NRAV)

End Loop

END

## 4. SIMULATIONS AND RESULTS

### 4.1 SIMULATION SETUP

To experiment our polymorphic routing proposition, we designed a simulator in Java Language and JGraphT library [8] implementing a dynamic ad hoc network where nodes move according to the Random Walk Mobility Model [3]. The time axis is seen divided into consecutive routing periods each of length  $T$  seconds. At the beginning of each routing period, a new random connected graph is generated serving as the current real topology of the network. Consequently, at the beginning of each routing period each and every node computes its conventional proactive routing table which will serve during the entire routing period.

This initial topology provides also the distances between all the nodes so that we can compute the probabilistic routes from any source to any destination at any given time. The routing period is divided into  $T$  equally spaced observations points. At each observation time point we have three different views of the network: the actual real view provided by the underlying mobility model used in our simulator, the conventional proactive routing table computed at the start of the routing period and the probabilistic routes computed by the probabilistic model [10].

A route from a source node to a destination node is termed valid if it exists in the real network. To ascertain the efficiency and accuracy of our proposed polymorphic routing, we shall compare the number of valid routes from a designated node (*node 1*) to all destinations given by both the proactive routing and the probabilistic routing. The optimality of provided routes is also of great concern but we will not discuss optimality here in this paper as it is beyond its scope.

We consider a multi-hop mobile ad hoc network composed of  $N=100$  mobile nodes located in an area of 200 by 200 meters. We use a transmission range of 50 meters. Nodes move according to the Random walk model within the defined area. Table 1, below, summarizes the different parameters used in our simulations. We vary the maximum node speed

Table 1: Simulation parameters

Parameter	T	N	R	Simulation area	C
Value	20 s	100	50 m	200x200 m	1

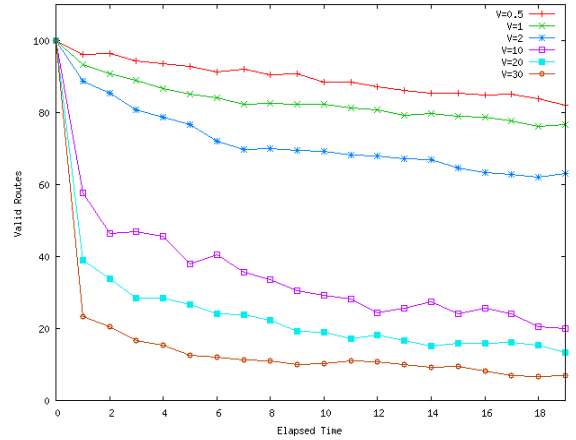


Figure 1: Percentage of valid proactive routing routes vs. time

( $V_{max}$ ) from 1m/s to 30m/s. For each speed and each observation point, we run 20 routing periods (equivalently 20 simulations). Averages are taken on these 20 simulations.

In the following we present the simulation results and discuss their pertinence.

### 4.2 RESULTS AND ANALYSIS

The plot of Fig. 1) depicts the high sensitivity of the proactive routing to mobility speed. It can be noticed how the proactive routing output performs well for relatively slow mobility, but for higher speeds (10 m/s and above) the proactive routing suffers badly in accuracy. On the other hand, probabilistic routing with  $L = 1$  and  $L = 2$  respectively achieves much higher accuracy even for high mobility speeds (Fig. 2). For  $L = 2$  (the top bunch), the validity of routes produced is higher than the case when  $L = 1$ .

In Fig. 3, we plot the performance of the polymorphic routing versus time. This plot and the subsequent one illustrate the use of *policy I*. We can notice that the curves' patterns illustrate the way the polymorphic routing guides the routing mode switching with the passage of time to maintain the desired performance according the target thresholds.

For the case of  $v = 0.5$ , the proactive degradation is not much in Fig. 1, that we have set the triggering threshold at 90% of routing efficiency. Below that, the protocol has to switch to the probabilistic routing with  $L = 1$  till the end. This has occurred at the instant 9 seconds. This can be confirmed from the results of Fig. 4 that tracks the switching patterns between routing modes in time for the curves of Fig. 3.

Next for the case of  $v = 1$ , the degradation is a bit more severe in Fig. 1. The threshold for the proactive was set at 85% efficiency, below which the protocol switches to the probabilistic routing with  $L = 1$ . The Threshold for the switching from  $L = 1$  to  $L = 2$  for the probabilistic was set at 90% efficiency. As a result the first switch was triggered

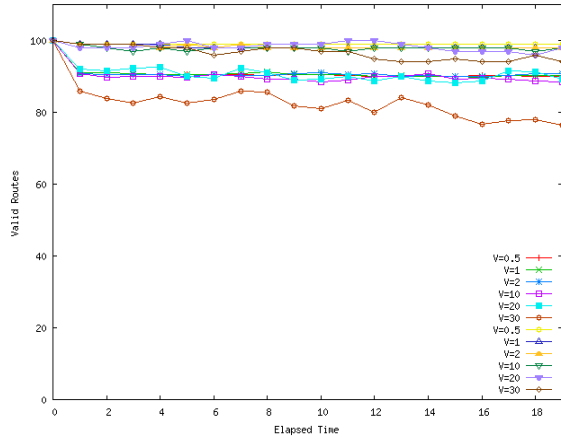


Figure 2: Percentage of valid probabilistic routing routes vs. time

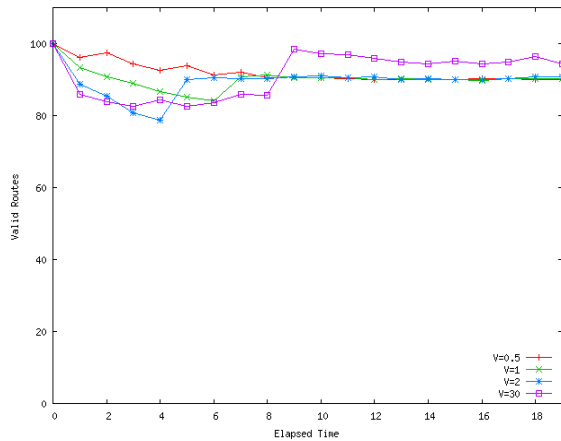


Figure 3: Routes' validity of polymorphic routing vs. time (policy I)

at the 8th second, but the second switch never happened as the efficiency of the probabilistic routing with  $L = 1$  didn't fall below 90%.

Next for the case of  $v = 2$ , the proactive routing degradation is sharper in Fig. 1. The first switch (to probabilistic routing with  $L = 1$ ) happened at the instant 4 corresponding to a threshold trigger of efficiency below 80%. It can be clearly noticed that the performance rebounds from the 80% efficiency to 90% and more. The second threshold of minimum allowed efficiency was set at 90% and this has triggered no further switch in the routing scheme, that is the system retained the probabilistic routing with  $L = 1$  till the end of the period.

Last for high speeds of 10 and 20m/s (not shown in Fig. 3, for clarity purpose), it was noticed from Fig. 1 that the proactive routing accuracy falls below 50% from the very start of the period (i.e., the instant 1). As such the switch to the probabilistic routing is made from the very first instant since we have used the same threshold settings used for the case of  $v = 2$ .

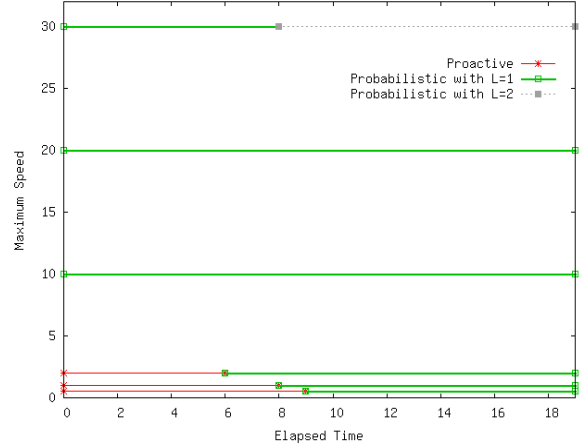


Figure 4: Protocol usage patterns over time(policy I)

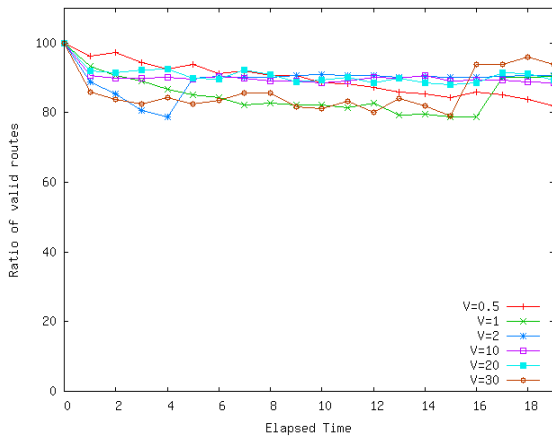
As such the performance in accuracy achieved was above the threshold sets for the whole period and there was no further speed. However, for the case of  $v = 30m/s$ , and as the degradation of the proactive routing is very severe from the beginning of the period, the routing adopted was the probabilistic one with  $L = 1$ . The first threshold was set at 85% of routing efficiency. The switch to the probabilistic routing with  $L = 2$  occurred at the instant 9 and remained as such till the end of the period. Beyond all the switches done in this experiment it was crystal clear how the routing accuracy improved each time and aligned with the efficiency level desired.

Next Fig. 5 and Fig. 6 are used to illustrate the results of *policy II*. As mentioned earlier, after setting a certain desirable efficiency level, the protocol is left to choose the right routing mode to adopt or to switch to, in order to maintain the target performance. The results are shown for a target performance of 80% efficiency in delivering valid routes.

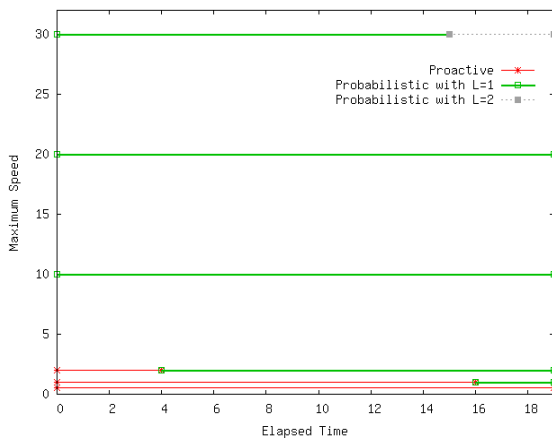
Fig. 5 depicts the efficiency in producing valid routes versus time in case of a polymorphic routing guided by *policy II*. For any curve we need to look at the switching patterns between routing modes that is depicted in Fig. 6.

For  $v = 0.5$ , it is clear that only proactive routing was used. There was no switching, as the efficiency of the proactive satisfied the target performance. As for  $v = 1$ , the switch from proactive to probabilistic routing with  $L = 1$  occurred only after the instant 16, when the efficiency has degraded below 80%. For  $v = 2$ , the start was with the proactive routing and the switch occurred at the instant 4 of the routing period. For  $v = 10$  and  $v = 20$ , only the probabilistic routing with  $L = 1$  was used throughout the period. there was no need for switching. Last, for the case of  $v = 30$ , we can see that the probabilistic routing with  $L = 1$  was used from the beginning up to the instant 15. After that a switch to the probabilistic routing with  $L = 2$  occurred, triggering a rebound in performance, that went up above 95% efficiency.

The results of figures 5 and 6 confirm the results of figures 3 and 4. The overall results testify to the ability of the polymorphic routing, using either *policy I* or *policy II*, in



**Figure 5: Routes' validity of polymorphic routing vs. time (policy II)**



**Figure 6: Protocol usage patterns vs. time (Policy II)**

ensuring specifically defined performance target in terms of efficiency. The other deduction we make, is despite the variable degradation of the proactive routing in the presence of variable mobility speed, still the polymorphic routing is able to exploit its potentials whenever possible and to complement its deficiency by switching to the backup probabilistic routing when needed.

The next issue we wish to discuss is the why we are designing a special simulator, and not using NS2 or any other net simulator and why we are not using any traffic data. The answer is that our objective was to evaluate the performance of the proactive and probabilistic routing modes independently of any traffic overhead.

Another issue is why aren't we comparing our proposal to other known routing protocol such as DSDV or OLSR. Again the answer is similar to the one given above, as our intention is to evaluate mainly the proactive routing (that is used commonly in many proposed hybrid routing protocols such as [22, 20, 13, 1, 2]) and to provide an alternative

routing protocol with a dynamically changing behavior that attempts to remedy to some of its deficiencies, while exploiting its strength whenever possible.

## 5. CONCLUSION

In this article, we proposed a new polymorphic routing protocol that is combining two routing techniques, namely the proactive and probabilistic routings, dynamically and in a complementary fashion. The proposed protocol selects the most suitable routing behavior depending on the current average mobility level and using specifically defined and targeted routing accuracy levels. The new protocol attempts to use the potential usefulness of the proactive routing whenever possible (specially for low speed mobility). In the presence of high speed mobility the proposed protocol complements the deficiency of the proactive routing by switching to a backup probabilistic routing mode. Simulations results showed clearly how our protocol could use efficiently the suitability ranges of each routing behavior it encompasses to improve and restore the performance of the routing task in terms of accuracy and conformity of the generated routes to the real valid routes.

We believe that this routing technique would show superiority to pure proactive, and to pure probabilistic routing techniques not only in terms of routing accuracy, but also in terms of goodput, delay and power conservation when simulated traffic data is considered. Future work will be directed at proving the above claim.

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