Study of the Path Average Lifetime in Ad Hoc Networks Using Stochastic Activity Networks

Teresa Albero-Albero[1], Víctor-M. Sempere-Payá[1], and Jorge Mataix-Oltra[2]

[1] Instituto Universitario Mixto Tecnológico de Informática,
Universidad Politécnica de Valencia,
Camino de Vera s/n, 46022 Valencia, España
{maala10,vsempere}@dcom.upv.es
[2] Universidad Politécnica de Cataluña (UPC)
Av. del Canal Olímpic, s/n, 08860 Castelldefels, España
jordi.mataix@upc.edu

Abstract. The supervision of industrial processes requires the exchange of information in real time between users and control systems. Users may be moving around a working area and need to consult information to supervise a particular process. Therefore, it is important to study the characteristics and stability of the paths to determine which services can be offered. In this paper, the effect of mobility on duration and stability of the links in an ad hoc network is analysed using stochastic activity networks. The ad hoc network is made up of six mobile nodes where the routing protocol is AODV. This study shows the path average lifetime which enables the evaluation of which type of services can be offered by the network.

Keywords: SAN (stochastic activity networks), modelling, MANET, routing protocols, route maintenance, path average lifetime.

1 Introduction

In industrial environments the need to exchange information between mobile users within a working area is becoming increasingly common. The services offered to a user include:

- Information on process alarms.
- Access to previously stored control images [1], [2] or images related to a previous event.
- General images of the plant and images of specific processes which need to be monitored or controlled in real time by cameras installed in the plant.

In this paper we have studied the link performance which will in turn enable us to understand which services can be supported by an ad hoc network with sufficient quality and under which conditions.

A path is created when two users are in communication. A path can include two or more links. The length of the path is the number of links. Therefore,

K. Al-Begain, D. Fiems, and G. Horváth (Eds.): ASMTA 2009, LNCS 5513, pp. 71–88, 2009.

link stability is crucial when generating a path between users. The protocol performance depends on the duration of a path between the source and the destination (path average lifetime).

In this paper we analyze the effect of the number of hops, the transmission range and the speed of the mobility on the path average lifetime. Node mobility is the major factor affecting the performance of the routing protocols. Since a link break from a node movement invalidates all the routes containing this link, alternate routes have to be discovered once the link is detected as broken. Because of this, we have studied how node mobility affects these paths, causing breaks in the links. The path average lifetime enables us to identify which services can be offered on the ad hoc network designed, always taking into account that the new route discovery will create a flood of routing requests and extended delay for packet delivery.

This paper presents a study, in which formal models were used to analyse the effect of mobility in an ad hoc network with six mobile nodes on the duration and stability of the paths in order to determine how the services were affected. The scenario to which these results may be applied does not require a large number of nodes. Six nodes are sufficient to cover the working area, and there are not usually more users needing to exchange information in these circumstances.

Although these results were obtained from a simulation, our aim is to create a scenario as close to reality as possible. Our study is based on the routing protocol AODV (Ad Hoc On-Demand Distance Vector Routing) [3], which is one of the routing protocols under active development inside the IETF MANET working group [4]. AODV is together with OLSR (Optimized Link State Routing) [5] the most mature routing protocol from the implementation standpoint. It is for this reason that they are the two most studied protocols. In [6], [7] are described real experiments where the performance of these two routing protocols is compared, using a number of nodes ranging from 5 up to 12 nodes (laptops and PDAs). Other experimental evaluations have been carried out with a similar number of nodes, in [8] 5 laptop computers were used to study AODV routing protocols and OLSR protocols. Previous studies [9] have shown the existence of an Ad Hoc horizon (2-3 hops and 10-20 nodes) after which the benefit of multi-hop ad hoc networking disappears. As Conti states in [10], it is unrealistic to centre the research on networks with hundreds of mobile nodes involved in CBR (constant bit rate) data transfers.

AODV is a reactive protocol that minimizes the number of route broadcasts by creating routes on-demand. Route discovery is initiated on-demand, the route request (RREQ) is forwarded by the source node to the neighbours, and so on, until either the destination or an intermediate node with a fresh route to the destination, is located. The response to the route found is sent via a RREP packet (route replay). This route can be single hop, which is a direct communication or multi-hop when neighbouring nodes are necessary to reach the destination.

In section 2 previous results are presented and in 3 the scenario and the various parts of the model are explained. The measurements and results are presented in section 4, while the conclusions and future work are shown in section 5.

2 Previous Results

In previous works by the authors, stochastic activity networks have been used to create formal models that enable the study of mobility and reachability between nodes [11]. In these models the tool used was UltraSAN [12] and now the tool used is Mbius 2.1 [13], [14] both of which supports the specification of SAN [15] models.

With our previous models the probability of the source reaching the destination in an Ad Hoc network was studied in function of radio transmission range [11], determining direct and indirect communications and failed attempts at communication in which the destination was unreachable. In multi-hop[1] communications, with a radio range of more than 150m successful communications began to decrease; direct communications with distances greater than 150m will probably[2] be successful. In other words, 150m was identified as the range for which the number of multi-hop communications reached maximum[3] value. The radio range that offers this maximum value of multi-hop communications was previously difficult to identify and with the SAN tool it has been obtained in a simple manner.

Later, a more detailed study was carried out on multi-hop communications [16], [17] dividing these according to the number of hops in each path established. We observed that communications with two or three hops were the most numerous, confirming the findings of Tschudin et al. in their studies [9]. Furthermore most MANET routing protocols focus on minimizing the hop count of the chosen path [18]. The number of hops corresponds with the number of times a packet must be transmitted and received to reach its destination. Each additional transmission has some consequences; a longer path consumes additional bandwidth and additional hops add more delay due to the additional buffering, contention, and transmission time required. For this reason, in the models preference is given to shorter routes, thereby minimizing the number of links that may break causing a path failure. From the percentages of multi-hop communications and according to the number of nodes participating in the path, we were able to make an estimation of the potential energy savings obtained by using this type of communication.

---

1 The terms direct or single-hop communications and indirect or multi-hop communications are used interchangeably.

2 In the models designed, preference was given to communications with the lower number of nodes (just as an AODV behaves), and therefore direct communications have preference over multi- hop, and it is because of this that with a certain value of radio range an inflection point occurs after which there is a decrease in multi-hop communication giving way to a greater percentage of direct communications between source and destination.

3 The most significant characteristic of ad hoc networks is the use of neighbouring nodes to reach the destination, and this is denominated multi-hop communication. It is always possible to choose a range of radio ranges which enables us to obtain a balance between energy savings through use of multi-hop communication against single hop and a satisfactory number of communications obtained.

In light of these results, we consider it interesting to study more deeply the performance ad hoc networks. SAN enables us to modify and widen these models, in a simple way and without having to redesign them. New submodels that represent the working of the AODV protocol at the moment when the requested route is obtained and when a lost route is recovered can be added.

3 Models

In this section, firstly we describe the scenario in which the ad hoc network was incorporated, along with the parameters used in its design. Secondly there is a description of each of the subnetworks that form the formal model of the ad hoc network in question, in which the AODV was the routing protocol used. The objective of these formal models is the evaluation of the effect of mobility on the duration and stability of the routes in an ad hoc network.

3.1 Scenario

An area of 350x350m^2 is large enough to cover most industrial installations. The shape of the area is determined by the use of hexagonal cells. This type of cell facilitates the representation of movement of nodes and their coverage radio range. Six nodes were distributed (A, B, C, D, E, F) in the area, see Fig. 1. In order to be sure that the initial position of the nodes did not affect the results, different tests were carried out. This initial position was varied, without variations in the results.

Regarding the number of nodes used in models, the scenario to which these results may be applied does not require a large number of nodes, because this number is sufficient to cover the working area. For this reason, in our case we considered 6 to be the maximum number of mobile nodes. Moreover it is known that a high density can cause traffic problems and reduce the efficiency of the channel usage [10]. Furthermore, experiments in real scenarios are made up of a few nodes, see [19], in which a multi-hop wireless ad hoc network was constructed in a testbed of 8 nodes, 2 of them fixed, over an area of 700x300m^2 and [7] where experiments in string topology were set up in an open field about 300 meters long. In [6], [7] real experiments were carried out, using a number of nodes ranging from 5 up to 12 nodes.

As the area used is divided into hexagonal cells of the same size, see [20], the probability of one node to visiting its neighbouring cells has an assumed value, p = 1/6. The mobility model used in the results presented in this paper is a random walk model.

We assume the time that a mobile node stays in a cell and the number of communication attempts. These have an exponential time with mean value $1/\lambda$m and $1/\lambda$c respectively [20]. The values of search rate and movement rate have been chosen to adjust with real values of movement of the nodes [21], [22]. To this end, considering that every cell is equivalent to 50m, we can calculate the mean velocity of the users and this enables choose the most appropriate movement rate.

In the experiments, session times of 20s, 1 and 3 minutes were used. The authors have chose typical session times used in the supervision of industrial processes. In a real scenario, during this time the user could see control or multimedia information. Depending on the service requested, it is logical that the user will have to wait for differing periods of time. For example, if the user requests detailed information on a process from a sensor, 20s can be considered long enough to obtain and evaluate this information. However, when the user wants to see control images from the installation or of a process, more time will be needed to see and evaluate the images.

Another parameter used in these models is the radio transmission range, (R) with values between 100m and 200m. In the experiments this was a nominal range, with no variation. Two nodes can establish a connection when the distance between them is equal to or less than R. In our case for example, as each hexagonal cell measures 50m across, one node with a radio range of 100m can connect with all those nodes situated within the 2 rings around the cell in which the node is located. In Fig. 1 the lined cells represent the radio coverage of 100m from the node located in cell (1, 1).

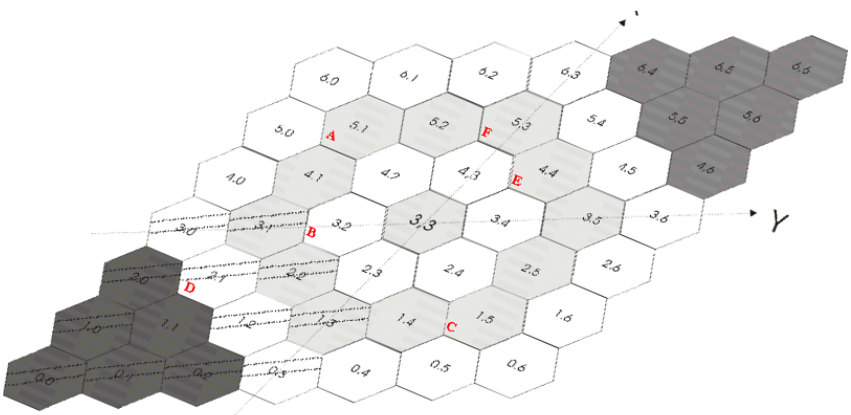

Fig. 1. Working area, 350x350m^2, numbering of cells and start position of mobile nodes

It is known that the characterization of the wireless channel is one of the critical points in MANET simulation modelling. Although ideally we would like the scenario to be as realistic as possible, certain assumptions were necessary. For example, no link layer effects, such as HELLO packet losses were considered, although it has been shown that this has a real effect on the link establishment in MANETs [23]. It can also be assumed that interference from neighbouring nodes will be nil. The hidden[4] node problem has not been considered. The exposed[5]

[4] Those nodes that cannot establish a connection directly between each other could still be transmitting messages simultaneously to a common neighbour on the same frequency.

[5] A node near an active sender is ineligible to send or receive.

node has also not been considered. We assume that links are symmetrical and this is far from reality. Finally, it is important to note that there is no traffic on the network, and so there are always resources available. We know that one drawback with models is that when simplifications and assumptions are introduced; they sometimes mask important characteristics of the real protocols performance. For this reason, so that the performance of the models used is as realistic as possible, we are working on the introduction of transmission errors in the model along with heavy loads on the ad hoc networks being studied.

3.2 Characteristics of the Models

Most MANET studies are base on simulation tools. The most popular simulators used in Ad Hoc networks are OPNET, ns-2 and Glomosim, but these are not the only valid tools for studying this type of network. In this paper, we use the power of stochastic activity networks (SANs) to observe the performance of ad hoc networks based on submodels already designed in previous studies.

Stochastic activity networks are a stochastic extension of Petri nets to define temporary characteristics with statistical parameters. Colored Petri nets [24] and Fuzzy Petri nets [25] have been used to study mobility in ad hoc networks. UltraSAN is used by different authors [20] to model mobility in mobile terminals. Mbius, the successor of UltraSAN, is used for the creation of the formal models whose results are presented in this paper.

The models designed are formed by five submodels:

- The "search" submodel shows the attempt of communication between two nodes.
- The "position" submodels represent the position of every node in the area and its movement through it. There is one position submodel for every node in the network.
- The "recover route" submodel studies whether a path remains active after a movement. In this submodel if a path is lost, a new one is sought.
- The "time" submodel.
- And the "time to recover" both of which submodels are necessary to find the average lifetime of a path.

The five submodels are interconnected, sharing some of their elements. In Fig. 2, there is a brief outline plan of the global functioning, in which this interconnection can be seen.

The "search" submodel, marked as (1) in Fig. 2, is used when there is a communication attempt between source and destination, and the source node sends a RREQ packet. The model is designed in such a way that the source and destination nodes were always the same to simplify the programming. Knowing the position of every node[6] in the model, we find out if the communication with

[6] To find a route from a source node to a destination, the source node in the Petri net model should have its neighbours identifications to send broadcast messages. Note that it is not necessary for nodes in a real MANET to know their neighbours, [24].

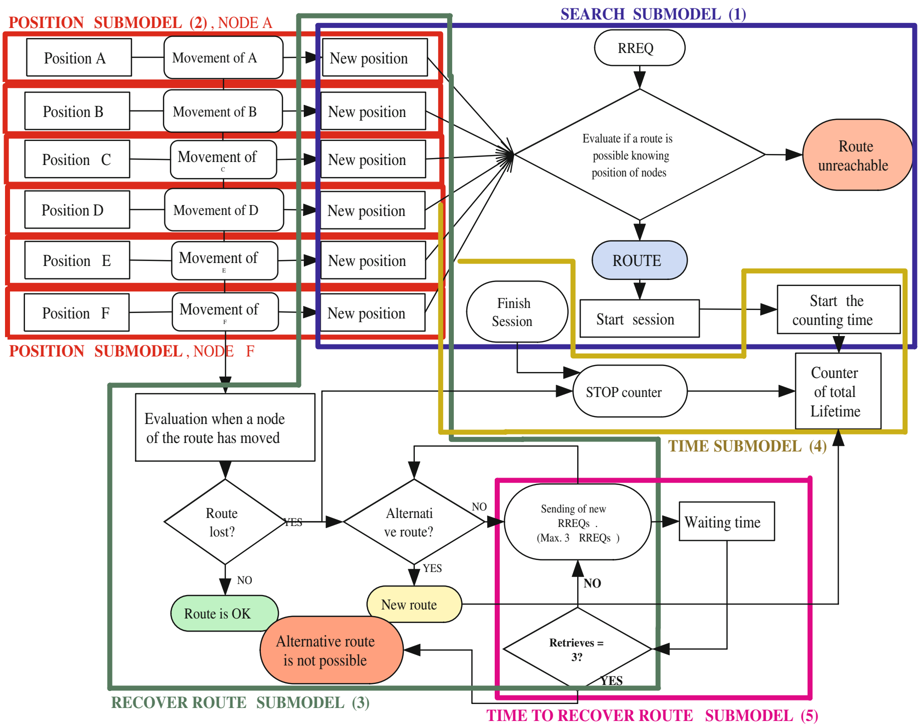

Fig. 2. Diagram of how the model works. Interrelation between submodels.

the destination is direct, indirect (we obtain the number of hops) or if it is not possible to communicate, using the supposition that there are no errors and no traffic. In this calculation, the exact[7] path is obtained. With no prior knowledge, one path is equally likely to be as good as another, so in the model, the first path found is chosen, always with the least number of nodes. At this moment, the session is initiated because the user has requested a communication with the destination and the request has been satisfied. The start of service means the start of the count of the time that the route is active; the counter is situated in the "time" submodel (4). This count will stop when the user terminates the session or when the connection is broken, see "recover route" submodel (3).

In the "search" submodel, see Fig. 3, if after the first RREQ there has not been response, the process established by the AODV is initiated whereby there are waiting times before the next RREQ packets are sent. Therefore, before a destination is given up as unreachable, the route is requested up to three times. If after the sending of the first RREQ, a positive response is not received, the

[7] Discovering the exact path and storing it is very difficult in terms of programming, but is necessary in order to be able to establish whether, after the movement of a node forming part of a path, the path has been affected.

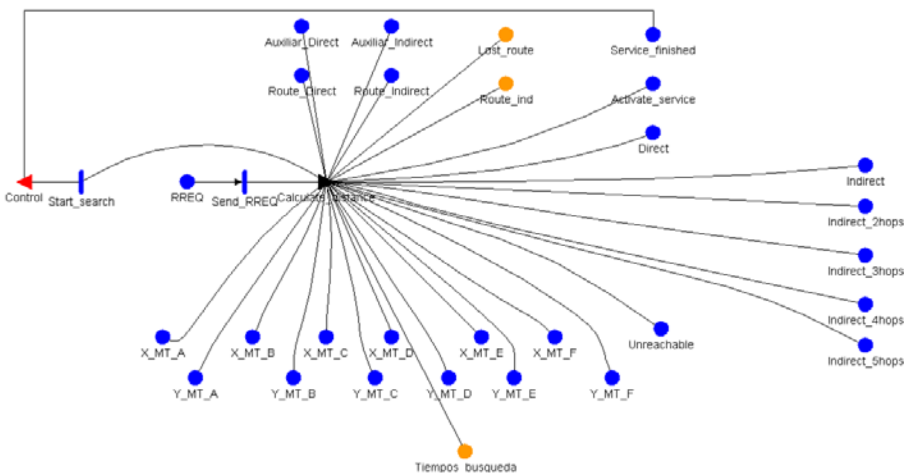

Fig. 3. Search submodel designed with Mbius

following RREQ packet is not sent until 0.4s has elapsed. Once this time has elapsed, if no response has been received, a new RREQ packet will be sent. In the same way, if there is still no response after this second sending, a new packet will be sent, this time after 0.8s. Finally, last request will be sent after 1.6s further waiting time. If no route is possible, the destination is given up as unreachable and the user cannot begin the session.

There is a "position" submodel, marked as (2) in Fig. 2, for every node in the network. This submodel evaluates the position of the node and its movement, obtaining the new position[8], which in turn depends on the angle of movement. If the node changes cell, the distance to the other nodes of the network is obtained. Also, if the node that has moved belongs to the active route, it is necessary to check if the movement has caused a break in the route or if the route remains active. In Fig. 4, the position submodel of node A designed with Mbius is presented.

The evaluation of the route after a node moves is done in the "recover route" submodel, marked as (3) in Fig. 2. Knowing the distance between nodes and the current route, it is checked whether the movement of a node belonging to the route has caused a break. There are two possibilities:

– A break has not occurred. The route remains the same as before although the node is not in the same position. This means that the node that has moved is still within range of its neighbours in the route.
– A break has occurred. The distance between the node that has moved and its neighbours is now greater than the radio transmission range; therefore new calculations are made to find an auxiliary route if possible. The auxiliary

[8] Note that at the start of the simulation (Fig. 1) every node is alone in this cell but after its movements two or more nodes can share cell.

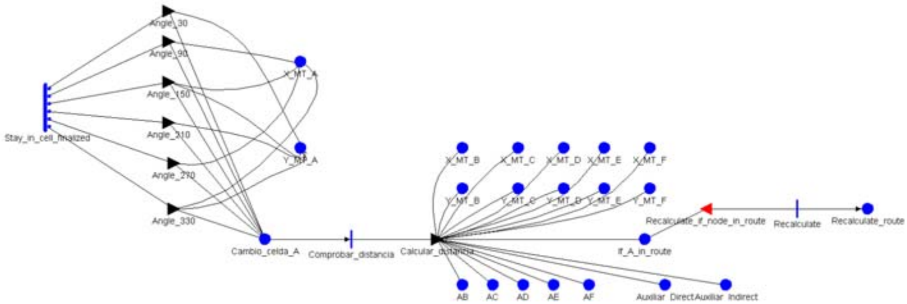

Fig. 4. Position submodel of node A designed with Mbius

route chosen will always be the shortest in the case that there is more than one possibility. In order to find an auxiliary route the route request (RREQ) is sent up to three times, repeating the same mechanisms as in the "search" submodel. This is done in the "time to recover route" submodel. The model takes into account the time needed to find the route and the number of nodes which form it.

In Fig. 5, the "recover route" submodel designed with Mbius is presented. We have highlighted the different blocks that make it up; therefore it can be more easily understood. It is important to state that "recover route" submodel programming is very complex (mainly the programming of some output gates), and for this reason we have included the flow chart to show how it works with the others submodels, Fig. 2. This complexity is due to the decision to create a "position" submodel in order to know the exact position of each node in the network. Without knowing the exact position in the network, it is not possible to know the exact route when a communication is requested between origin and destination, and consequently it is impossible to know when a movement will mean a loss of path. Authors such as Murata et al. [24], have previously studied, through simulations, how mobility affects the performance of the AODV, but without knowing the exact topology of the network in question, they conclude that it is not easy to build a CPN (colored Petri net) of a MANET because a node can move in and out of its transmission range and thus the MANETs topology dynamically changes. Therefore, they propose a topology approximation to address this problem of mobility. According to the authors, it is possible to model a MANET without information on its exact graph structure, but this makes it impossible for them to study a break in the path and its recovery. Other authors [25] have also analysed the AODV with a variant, but in their algorithm they dont need to compute the ad hoc network topology and they only need the information of neighbouring nodes for each node. However, they use the mechanism of Fuzzy Petri net to find a route with the highest reliability but they have not studied what happens after a route is obtained.

The "time" and "time to recover route" submodels, are marked such as (4) and (5) respectively in Fig. 2. These submodels together with the elements of the

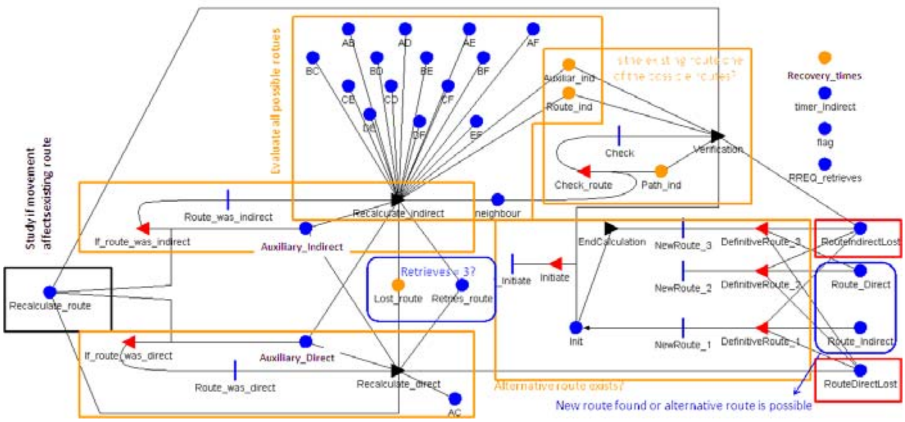

Fig. 5. Recover route submodel designed with Mbius

other submodels with which they interact are necessary to obtain the average time that a route remains active (average path lifetime). The "time to recover route" submodel (5) interacts with "recover route" (3), and the same as when a route is lost due to a movement of a node ("position" submodel), a recovery process is initiated. This process is similar to the one carried out when an initial route is required between source and destination, as there are also three attempts to find an alternate route. In Fig. 6 "time to recover route" submodel is presented.

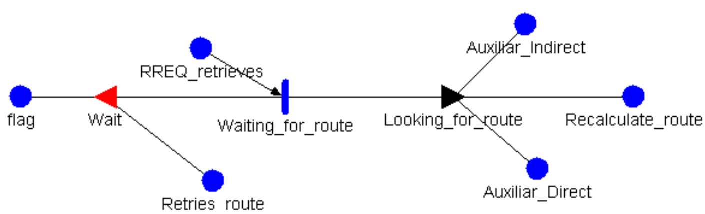

Fig. 6. Time to recover route submodel designed with Mbius

The submodel "time" (4) in Fig. 2, measures the time during which the route is active, whether this is in direct or indirect form. If a path is found in the "search" submodel (1), the session is initiated and in the "time" submodel the counting time is initiated too. In reality, there will finally be the sum of all the times when communication has been possible (total lifetime) in the counter, and knowing the number of routes that have been obtained (direct or indirect) we can obtain the average time that the routes have been active (average link lifetime).

Because of this, in this submodel it is necessary to know:

- When the direct or indirect route has been possible; this initiates the session and the total lifetime counter.
- When the route has been lost (recover route submodel), this stops the counter.
- And when the user finishes the session, at this moment the counter is stopped. The "time" submodel designed is shown in Fig. 7.

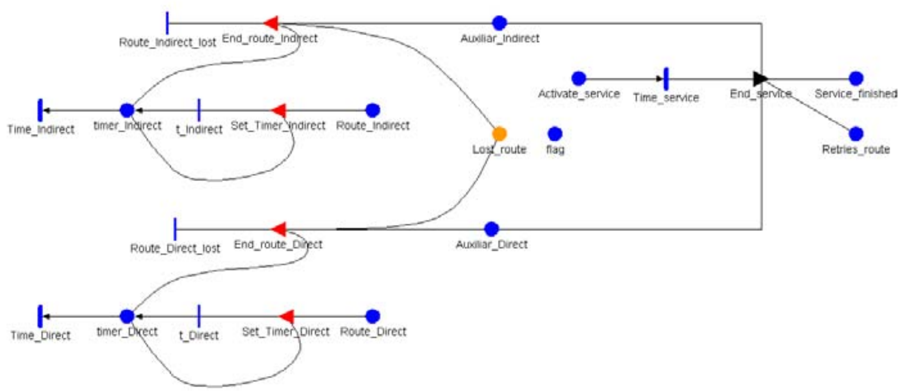

Fig. 7. Time submodel designed with Mbius

4 Measurements and Results

In this section the results using the models designed with 6 nodes according to the design described in section 3 are shown.

- Firstly, the lost and recovered paths are evaluated. Lost and recovered paths are also divided into direct and indirect.
- Secondly, average path lifetime is evaluated. This is the average time that a path remains active.

The programming of some elements of the model is very complex. For this reason, they were resolved through simulation rather than analytically.

Reward formalisms are functions that measure information about the system being modelled. Currently, Mbius provides one reward formalism, performance variables. The reward variables used to measure the results are impulse rewards that can be used to count the number of times an action is executed during an interval of time. We have used 6000 time units (seconds), as simulation time. Rate reward variables are used to evaluate the number of tokens that have accumulated in certain places. Each reward variable was evaluated for a confidence level of 0.80 and a confidence interval of 0.1, that is, the average value of the result will not be satisfied until the confidence interval is within 10% of the mean estimate 80% of the time. Each experiment was repeated 5 times to check the validity of the results.

The mobility rate (λm) has been chosen as 10/6, that is, 10 movements every 6 minutes. With this rate and knowing that the size of a cell in the area is 50m, the speed of movement of the nodes is: (10 movements x 50m / 6 minutes) = 1.38m/s. This is the speed used in all the experiments except for the representation of link average lifetime where other speeds have been used, [1.38, 5, 6, 7, 8, 9, 10, 15, 20] m/s. The values of λm used in the experiments to correspond with these speeds were: 0.1, 0.12, 0.14, 0.16, 0.18, 0.2, 0.3, and 0.4. This enables us to observe the evolution of the path average lifetime with the speed of the nodes and compare the results with those shown in [18]. Maximum speeds are chosen in order to test the routing protocol because maximum speeds result in frequent routing changes and test the abilities of the protocol to react. In fact, with the above-mentioned speeds we are not really considering a realistic scenario, but rather an extreme scenario in order to evaluate the protocol under these conditions.

The call rate (λc) chosen is 1 communication attempt every 180s (λc=0.005), that is, the user requests information from the installation with a mean value of 180s for 6000s, which is the simulation time used. This means that for one experiment, more than one route request is produced. It is necessary to clarify one point about this parameter; the route requests according to this parameter should be approximately 33, but the value is less than this as there will not be a new request while a session is in operation. Previous studies on the performance of AODV with Petri nets [24], [25] do only the search for one path every simulation. In the model presented, when the session time is finished another path can be requested by the source node. The session times used were 20s, 1 and 3 minutes, as explained in the section describing the scenario. The number of nodes used was 6 and the radio transmission range varied between 100m and 200m.

4.1 Lost and Recovered Paths

In Fig. 8 we show the performance of the AODV in the search, loss and recovery of a path to the destination. In A, we show the total percentage of paths found with respect to paths requested. It is clear that this percentage increases as radio range increases. With 100m, the percentage of possible paths is 37.65%, however, with 150m, 71.11% of the paths requested are possible, and if we increase the radio transmission range to 200m the percentage rises to 91.54%.

We also show the percentage of direct and indirect routes lost due to the movement of one of its nodes, see B and C in Fig. 8. Lost routes are lower when radio range is great as is to be expected. We can observe that multi hop paths suffered more losses. This is because more nodes participate in this type of communication; therefore the probability that one of the nodes moves is higher, leading to a higher probability of a break than in the case of a path formed by only two nodes, source and destination.

Finally, we show the percentage of direct and indirect routes recovered compared to the number of routes lost, D and E respectively. It was to be expected that as radio range was increased, recovered routes increased correspondingly as D and E show. Given that the AODV gives preference to single-hop paths over multi-hop paths, the majority of recovered routes should be direct communications; but the results indicate that the majority of recovered routes were found through multi-hop communication. The reason is that in spite of the low probability of losing a path when radio range is high, if a direct route is lost, it is recoverd almost 100% of the time via a multi-hop path.

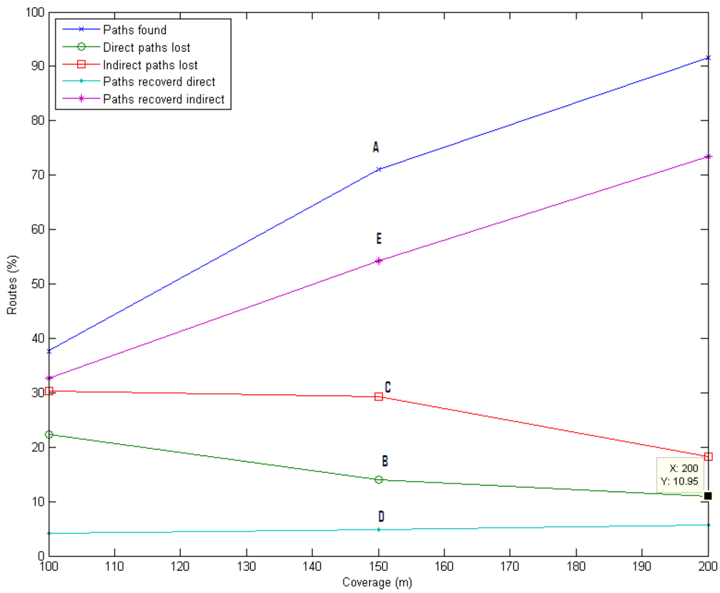

Fig. 8. Percentage of paths found with respect to path requests made$^{(A)}$, direct$^{(B)}$ or indirect$^{(C)}$ paths lost with respect to the number of established routes and recovered through single-hop$^{(D)}$ or multi-hop$^{(E)}$ communication when these had been lost

In Table. 1 labelled as "path lost" we show the sum of the percentages of direct and indirect routes lost with respect to those that were active. The results are shown for 3 radio ranges. Under the label "recovered paths", we show two percentages. The first (*) is the sum of the percentages of direct and indirect paths recovered compared with those lost. The second (**) shows the paths recovered compared to those found after a request which were in effect, active paths. The second percentage of "recovered paths" was obtained through the other two percentages in the table. Showing the same value in two ways anables us to look at the results from two different perspectives. The paths recovered with respect to those lost (*) enable us to see how the protocol reacts to a break of link and loss of path. The paths recovered compared to those active (**), enable us to understand in what measure the paths that are being used for transmission of information could have problems through a momentary loss of the path.

We can say that with a range of 100m, 52.68% of active paths are lost (the sum of direct and indirect losses, curves B and C in Fig. 8). Of the total of paths lost, 36.83% were recovered, which is equivalent to 19.4% of the paths that were found. We can also state that on 19.4% of all occasions, information was sent with some packets lost due to momentary losses of path, but it was possible to continue sending the information because the route was recovered within the time established by the AODV. Along the same lines, we can state that 47.32% (100% - 52.68%) of total communications were completed practically without problems. This is the percentage of paths not lost compared to active paths.

For a radio range of 150m in 43.24% of active paths some links were lost, causing a loss of path. 59.22% of the time, the lost links were recovered, which is equivalent to a recovery of 25.6% of active paths lost.

For a radio range of 200m, only 29.21% of active routes were lost, and of these paths 79.09% were recovered. That is to say, in 23.10% of active paths, there are problems on some occasion during the transmission, and in 6.11% (29.21%-23.10%) of active paths these problems could not be solved without loss of information.

Table 1. Percentage of paths lost and recovered for different radio transmission ranges

	Radio transmission range (m)		
	100	150	200
Path lost	52.68%	43.24%	29.21%
Recoverd paths (*) with respct to path lost (**) with respect to active paths	 36.83%(*) 19.4%(**)	 59.22%(*) 25.6%(**)	 79.09%(*) 23.10%(**)

4.2 Average Path Lifetime

The average path lifetime is the total time (the sum of the parts if there are breaks) at the end of the experiment during which there is a usable path between source and destination, divided by the number of different paths found. An example of this can be seen in Fig. 9 where we can see firstly the ideal path lifetime. This is the time for which the source and the destination can maintain communication, single-hop or multi-hop, until the source and the destination are definitively out of range.

Secondly, we can see the time that we want to measure. The path begins to be available when after a route request (RREQ), there is a route reply (RREP), and it is at this moment that the usable path lifetime begins. In both cases when the source and destination are out of range the time count stops and continues if there is a new path after the new search. The average path lifetime is obtained through the sum of the usable path lifetimes[9] divided by the number

[9] It is important to note that we modelled more than one path request during the simulation, and it is because of this that Fig. 9, showing the times, is repeated as many times as there are requests, and so we can define the average path lifetime as the sum of these times divided by the number of routes.

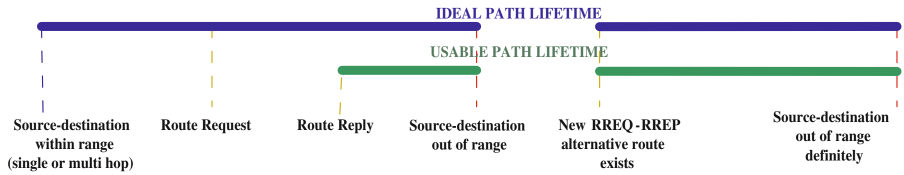

Fig. 9. Diagram of times showing the Path Lifetime

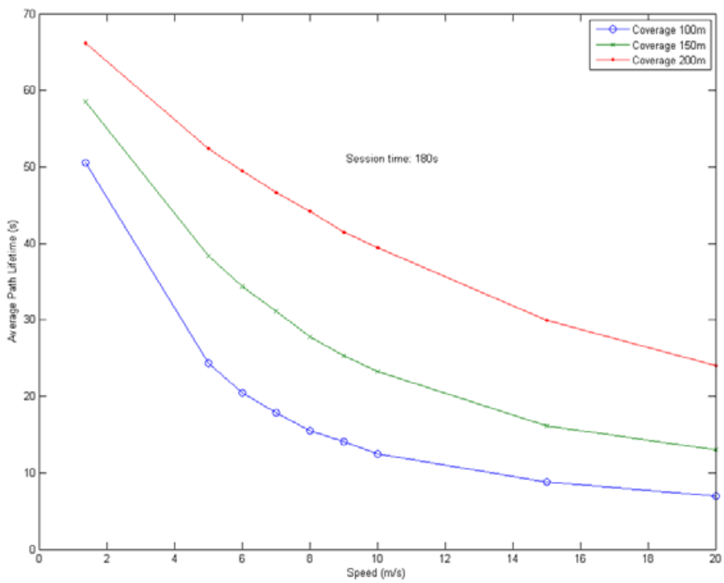

Fig. 10. Average path lifetime for a session time of 180s

of paths found throughout the simulation time. Average path times have been obtained for different session times. The performance is the same independent of the session time, but average path times values are not independent of this time. The difference in results is because the session time affects the period in which the paths active time is accumulating, and therefore affects the average path lifetime.

In Fig. 10, we can see the average path lifetime for a session time of 180s. It shows how the average time evolves as the speed of the nodes is increased from 1.38m/s to 20m/s, in function of the range. The average path lifetime decreases as the speed of the node increases. In turn, we can also see that as the radio transmission range is greater, the average time is also greater. The results obtained are comparable with those obtained by Ishibashi et al. (see Fig. 15 in [18]), in which they present the effects of mobility in an ad hoc network. Although the lifetime is only dependent on the mobility and transmission range, the density of the nodes in the network affects the quantity of links formed.

In [18] the authors use 50 nodes and the mobility model used is the random waypoint. Because of this, we cannot make a direct comparison between both sets of results, but it is possible to state that the basic performance is the same. The speed of the nodes affect the link lifetime.

5 Conclusions and Future Work

In this paper, formal models have been used to analyze the average path lifetime. These models represent an ad hoc network in which AODV is the routing protocol. The values obtained enable us to better understand the temporal performance of the paths created with this algorithm. It enables us to evaluate which services can be offered in an environment with the characteristics of the ad hoc network described here; where mobile users can request information in real time (images or alarms). Although in the experiments 3 radio ranges were used to give an overview of how this parameter affects maintenance of the path, we consider a radio transmission range of 150m to be the best choice as we have demonstrated in previous works [16], [17]. With this value of radio transmission range and taking into account the assumptions mentioned previously; the average path lifetime is 58.49s when the session time is 180s.

If we think of a scenario where the technicians are consulting images in order to control the normal operation of an industrial system, a session of 58s would be sufficient to observe the installation or how a process is working at a particular time. However, it is important to take into account that 43.24% of paths (Table. 1) are lost due to movement of the nodes, but that 59.22% (Table. 1) of these lost paths are recovered. Therefore, this type of network is best suited to offering images or alarm services, or to check the operation of a process within the plant at a particular moment. However, it is important to highlight that it would be difficult to offer services such as video streaming or voice. Providing multimedia applications in ad hoc networks is becoming a critical issue nowadays, but these applications are delay-sensitive and have high bandwidth requirements. Studies such as those made in [23] state that to provide efficient QoS routing over wireless ad hoc networks, problems such as scalability, power control, energy drain balancing and an efficient design of QoS MAC protocols need to be further investigated.

As we have stated in this paper, various suppositions were made in the development of the model, and therefore we should point out that the average path lifetime values would probably be a little lower. To address this, we are currently working on the introduction of traffic and transmission errors into the model in order to simulate the performance as close to reality as possible. Moreover, it is widely recognised that the performance of an ad hoc network varies according to the mobility model used [26], and because of this, we are also working on the use of the random waypoint mobility model, RW. With all of these improvements in the model, it will be possible to obtain values which are very close to those of real situations. This would enable study the repercussions of node mobility in the quality of service perceived by a user in supervision and control application within an industrial environment.

Acknowledgments. This work was supported by the MCyT (Spanish Ministry of Science and Technology) under the projects TSI2007-66637-C02-01/02, whose are partially funded by FEDER.

References

1. Molinero, F.G.: Real-Time Requirements of Media Control Applications. In: 19th Euromicro Conference on Real-Time Systems, Pisa, Italy (2007)
2. Silvestre, J., Sempere, V.: An architecture for flexible scheduling in Profibus Networks. Computer Standards & Interfaces 29, 546–560 (2007)
3. Perkins, C., Royer, E.: Ad-Hoc On-Demand Distance Vector Routing (AODV), RFC 3561 (July 2003)
4. Official IETF working group MANET webpage, `http://www.ietf.org/html.charters/manet-charter.html`
5. OLSR webpage, `http://www.olsr.org`
6. Eleonora, B., Marco, C., Franca, D., Luciana, P.: Lessons from an Ad Hoc Network test-bed: Middleware and routing issues. Ad Hoc & Sensor Wireless Networks 1, 125–157 (2005)
7. Eleonora, B.: Experimental Evaluation of Ad Hoc Routing Protocols. In: 3rd International Conference On Pervasive Computing and Communications Workshops (2005)
8. Gupta, A., Wormsbecker, I., Williamson, C.: Experimental evaluation of TCP performance in multi-hop wireless Ad hoc networks. In: IEEE Computer Society's 12th Annual International Symposium on Modelling, Analysis, and simulation of Computer and Telecommunications Systems (2004)
9. Tschudin, C., Gunningberg, P., Lundgren, H., Nordstrom, E.: Lessons from Experimental MANET Research. In: Conti, M., Gregori, E. (eds.) Ad Hoc Networks Journal, special issue on Ad Hoc Networking for Pervasive Systems
10. Conti, M., Giordano, S.: Multihop Ad Hoc Networking: The theory. IEEE Communications Magazine 45(4), 78–86 (2007)
11. Albero, T., Sempere, V., Mataix, J.: A study of mobility and reachability in Ad Hoc networks using stochastic activity networks. In: 2nd Euro NGI Conference: Next Generation Internet Desing and Engineering (2006)
12. Sanders, W.H.: UltraSAN users manual, University of Illinois (1995)
13. Clark, G., Courtney, T., Daly, D., et al.: The Mbius Modelling tool. In: 9th International Workshop on Petri Nets and Performance Models, pp. 241–250 (2001)
14. PERFORM Group (Performability Engineering Research Group) of Illinois at Urbana-Champaign, `http://www.mobius.uiuc.edu/`
15. Meyer, J.F., Movaghar, A., Sanders, W.H.: Stochastic Activity Networks: Structure, Behaviour and Application, In: International Conference On Timed Petri Nets, Turin, Italy, pp. 106–115 (1995)
16. Albero, T., Sempere, V., Mataix, J.: A study of multi-hop communications in Ad Hoc Networks using Stochastic Activity Networks. In: Workshop on Wireless and Mobility (2006)
17. Albero, T., Sempere, V., Mataix, J.: Estudio de alcanzabilidad en Redes Ad Hoc mediante redes de Actividad Estocstica. VI Jornadas de Ingeniera Telemtica (JITEL 2007), Mlaga (2007)
18. Ishibashi, B., Boutaba, R.: Topology and mobility considerations in mobile ad hoc networks. Ad Hoc Networks Journal, Elsevier 3(6), 62–776 (2004)

19. Maltz, D.A., Broch, J., Johnson, D.B.: Experiences designing and building a multi-hop wiereless Ad Hoc Network Testbed, Technical Report CMU-CS-99-116, School of Computer Science, Carnegie Mellon University, Pittsburgh, Pennsylvania (1999)
20. Giner, V.C., Escall, P.G., Oltra, J.M.: Modelling mobility tracking procedures in PCS systems using Stochastic Activity Networks. International Journal on Wireless Information Networks 9(4) (2002)
21. Lundgren, H., Lundberg, D., Nielsen, J., Nordstrom, E., Tschudin, C.: A large-scale testbed for reproducible ad hoc protocol evaluations. In: IEEE Wireless Communications and Networking Conference Record (2002)
22. Yongguang, Z., Wei, L.: An integrated environment for testing mobile ad-hoc networks (2002)
23. Xu, S., Saadawi, T.: Does the IEEE 802.11 MAC protocol work well in multihop wireless ad hoc networks? IEEE Communications Magazine 39(6), 130–137 (2001)
24. Xiong, C., Murata, T., Tsai, J.: Networks using Colored Petri Nets. In: Kristensen, L.M., Billington, J. (eds.) Workshop on formal methods applied to defense systems, Adelaide, Australia. Conferences in Research and Practice in Information Technology, vol. 12 (2002)
25. Ma, H., Hu, Z., Wang, G.: A reliable routing algorithm in Mobile Ad Hoc Networks using Fuzzy Petri Net. In: Globecom Workshops. IEEE Communication Society (2004)
26. Camp, T., Boleng, J., Davies, V.: A survey of mobility models for ad hoc network research. Wireless communications & Mobile Computing, special issue on Mobile Ad Hoc networking: research, trends and applications 2(5), 483–502 (2002)