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Additional Information

Group-based Protocol and Mobility Model for VANETs to Offer Internet Access

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Abstract

Some public transport vehicles embed devices that allow passengers to connect to Internet while traveling. These vehicles are true mobile Internet access zones inside public paths. These zones could be used by other vehicles moving close to them in order to have Internet access. At the same time, other vehicles in the influence area could be used as relay nodes which would increase this access area. In this paper, we present a group-based protocol and mobility model for vehicular ad hoc networks (VANETs) where each public transport vehicle forms a group of vehicles. They can access and allow access to Internet through the public transport vehicle. Each vehicle is moving inside the group and can leave and join any group at will, while all groups are moving. First, we will show the algorithm and protocol to achieve our purpose. Then, we will study the probability of having Internet access in order to demonstrate that it is a feasible proposal. Finally, we simulate a study case based on real values in order to obtain the performance of our proposal in terms of several network parameters such as the number of hops per route, the network traffic, the page response time, network delay, network load and so on.

Keywords: Group mobility, group-based architecture; mobility model, VANETs

1. Introduction

Ad hoc networks can operate without an infrastructure deployment and can be available in a geographic space, during a period of time, and it depends on itself to be operative. No other administrative agents need to be present for its proper operation [1]. When nodes in ad hoc networks are mobile, then we are addressing a mobile ad hoc network, or MANET. This is a special case in ad hoc networks family. MANET increases the level of difficulty in operation. When nodes move, their links can fade and thus connections can be lost. Routing protocols in MANET networks must be aware of these situations [2]. On the other hand, MANET boosts new applications that would not be possible without this technology, for example, oceanic sensor networks, battlefield ad hoc networks, sport monitoring, etc.

Within MANET we can find another sub-family of networks, the so called VANET or Vehicular Ad hoc NETWORK. In this case, mobile nodes are vehicles. VANETs have their own singularities that make them different to their related MANET. Differences are more evident in mobility models, where nodes velocities use to be greater than conventional MANET nodes, and nodes paths tend to be predefined in some cases, for example in vehicles moving along a highway [3]. Some recent works are proposing delay and reliability aware inter-vehicle routing protocols [4]. A good survey on routing protocols and beaconing approaches in vehicular ad hoc networks can be seen in [5].

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In the recent years, some effort from the research community in creating standards for use in vehicular environments has emerged. As result of this work in progress we can find [6, 7]. Moreover, an European Consortium has been created [8], whose mission, among others, follows the next objectives:

- The development and release of an open European standard for cooperative Intelligent Transport Systems (ITS) and associated validation process with focus on Inter-Vehicle Communication Systems.
- To provide its specifications and contributions to the standardization organizations including in particular ETSI Technical Committee ITS in order to achieve common European standards for ITS.
- To push the harmonization of Car-2-Car Communication Standards worldwide.
- To promote the allocation of a royalty free European wide exclusive frequency band for Car-2-Car Applications.
- To develop realistic deployment strategies and business models to speed-up the market penetration.
- To demonstrate the Car-2-Car System as proof of technical and commercial feasibility.

As time goes by, it is more common to find public transport companies offering more comfort and new services to the customers. One of these new services is the wireless access to Internet inside the public vehicle during the route [9]. In this case, the vehicle incorporates a mobile access using a GPRS or 3G operator, and by means of a router with Wi-Fi technology, facilitates Internet access to the travelers. Moreover, an external antenna could be added in the public vehicle to provide coverage to larger distances. Then with an appropriate networks protocol this range could be expandable using the presence of other vehicles acting as relay nodes in the network.

One last issue to solve before granting Internet access to ad hoc network users is the procedure, or the set of procedures, applied between nodes involved in communication. This set of procedures includes, but it is not limited to, ad hoc routing protocols, topology configuration, security, performance improvement, etc. [10]. When ad hoc networking is mixed with some kind of node mobility, the challenge is greater, and this new requirement must be addressed from ad hoc routing protocols to the use of specific network layer protocols like Mobile IP. A work discussing the ways to grant Internet access for ad hoc network users is shown in [11]. Moreover, there are some ad hoc network proposals that use the Internet to integrate world communities [12].

The rest of the paper is structured as follows. Section 2 introduces some related work. Our group model proposal and the designed protocol are described in Section 3. Section 4 presents the analytical model about the probability of success. A real case analysis that compares our system for several group densities is shown in Section 5. Section 6 provides the simulations obtained in order to study the performance of our proposal. Finally, Section 7 shows the conclusion and future work.

2. Related Work

In the related literature, there are some work about group-based networking and topologies aimed at ad hoc networks. We are especially interested in these ones because our system can be viewed as a group-based network.

It is well-known the issues of long-hop routing in mobile ad hoc networks [13]. Group-based networks appear as a solution for large networks. The first time group-based topologies were defined and discussed was in [14]. This paper provides group-based topologies benefits and discusses real environments where they could be used. Moreover, the authors classify group-based topologies and compare them.

In [15], the authors define group-based ad hoc topologies and show how some wireless ad hoc sensor networks (WAHSN) routing protocols perform when the nodes are arranged in groups. Connections between groups are established as a function of the proximity of the nodes and the neighbor's available capacity (based on the node's energy). The authors describe the proposed architecture as well as the messages that are needed for the proper operation. There is a simulation of how much time is needed to propagate information between groups. Finally, they present a comparison with other architectures.

A novel routing protocol for wireless ad hoc networks, called Landmark Ad Hoc Routing (LANMAR), is presented in [16]. LANMAR combines the features of Fisheye State Routing (FSR) and Landmark routing. The key novelty is the use of landmarks for each set of nodes which move as a group in order to reduce routing update overhead like in FSR. Nodes exchange link state only with their neighbors. Routes within Fisheye scope are accurate, while routes to remote groups of nodes are “summarized” by the corresponding landmarks. A packet directed to a remote destination initially aims at the Landmark; as it gets closer to destination it eventually switches to the accurate route provided by Fisheye. Later, the same authors presented an enhanced version of LANMAR in [17]. The enhanced version features landmark election to cope with the dynamic and mobile environment. When network size grows, remote groups of nodes are “summarized” by the corresponding landmarks. As a result, each node will maintain accurate routing information about immediate neighborhood; at the same time it will keep track of the routing directions to the landmark nodes and thus, to remote groups.

In our case, the group-based ad hoc network is applied to VANETs, so we are going to introduce the research background of VANETs, the most well-known VANET mobility models and some study cases related to the one proposed in this paper.

H. Hartenstein and K.P. Laberteaux authored a good overview of VANETs in [18]. VANET applications and their requirements are described. They provide motivations, followed by challenges of VANETs and a snapshot of proposed solutions, both technical and socio-economic. Authors also tackle other VANET topics such as topology, channel features and models, protocols, architectures and standards, and finally, security and privacy.

The mobility model is a basic research tool in order to develop simulations. In [19], the authors propose a framework that can be used as a guideline for the generation of vehicular mobility models. Then, they show the different approaches chosen by the community for the development of vehicular mobility models and their interactions with network simulators. After that, they present an overview and taxonomy of a large range of mobility models available for vehicular ad hoc networks. Their objective is to provide to the readers a guideline to easily understand and objectively compare the different models, and eventually identify the one required for their needs.

In [20], S. Durrani et al. propose a new equivalent speed parameter and develop an analytical model to explain the effect of vehicle mobility on the connectivity of highway segments in a VANET. They proved that the equivalent speed is different from the average vehicle speed and it decreases as the standard deviation of the vehicle speed increases. Using the equivalent speed, a novel analytical expression for the average number of vehicles on a highway segment is derived, which accurately predict the network 1-connectivity. The results show that increasing the average vehicle speed increases the equivalent speed, which leads to a decrease in the average number of vehicles on a highway segment and consequently degrades the connectivity. On the other hand increasing the standard deviation of the vehicle speed decreases the equivalent speed, which leads to an increase in the average number of vehicles on a highway segment and consequently improves connectivity. The results also show that vehicles in a VANET can adaptively choose their transmission range to ensure network connectivity in highway segments while minimizing power consumption.

A main point of interest when working with VANET is the use of a routing protocol based of node position. In [21] a position-based routing algorithm for VANET called on demand geographic routing (ODGR) is proposed. It suits well for highway scenarios. ODGR uses two mechanisms to make sure that the information about positions of the destination nodes and neighbors are valid and accurate when choosing next hop. They also guarantee the reliability of the routing algorithm. On one hand it uses two independent messages to update the position information of the destination. On the other hand, it uses the idea of on-demand to build the neighbor table. In their paper, the authors provide an AODV and ODGR performance comparison using the network simulator NS-2 with a specialized node mobility model simulator called VanetMobiSim to produce realistic vehicular movement trace. The final results prove that when a node moves with acceleration of 4.9m/s^2 and at max speed of 50m/s ODGR outperforms AODV.

Because our proposal is focused on the mobility of vehicles in a highway, we sought for works in this environment.

In [22], F. Kaiser et al presented a quantitative model to evaluate existing routing protocols of VANETs on a highway where cars run in the same direction. This model is used to compare two main classes of routing protocols: topological protocols and geographic protocols. The studied criterion is the scalability property, i.e. performance preservation in spite of the increase of the network size. They concluded that a geographic protocol using has a better scalability than any other existing routing protocol on vehicular network on highways.

V.K. Muhammed Ajeer et al studied the connectivity of a VANET formed between vehicles that move on a highway in [23]. They also present an analytical model to determine the network connectivity of the VANET assuming that the speed of the vehicles follows a normal distribution. They brought out the exact dependence of vehicle speed statistics on VANET connectivity. They also present the dependence of vehicle speed statistics on both, the node isolation probability as well as the critical transmission range required to maintain the desired connectivity probability. The results show that when the vehicle transmission range increases, the network connectivity also gets increased, and the network connectivity gets degraded when the average vehicle speed increases. Further, as the average speed increases, the critical transmission range required to meet a given connectivity probability criterion increases. On the other hand, when the standard deviation of the vehicle speed increases, the network connectivity gets improved. It is also shown that, for a given connectivity probability requirement, the critical transmission range decreases as the standard deviation of the speed increases.

A model for the connectivity patterns of chains of vehicles that are traveling in a highway is presented in [24]. This information is crucial to provide insight in the design of VANET protocols and applications, which are dependent on the connectivity characteristics. The accuracy of the model is shown through its application to specific study cases. The obtained results show that, in highway scenarios, the connectivity availability between relay nodes can last for a significant amount of time (in the order of tens of seconds).

As far as we know there is not published any group-based protocol for VANETs.

3. Group-based Protocol and Mobility Model Proposal for VANETs

This section describes the mobility model and the group-based protocol. First, we will describe the environment of application and the starting parameters for each node.

The whole network can be viewed as an ad hoc network where there are groups of nodes moving. Every group is formed by the public transport vehicle, the vehicles under their coverage area and the vehicles until k -hops to the public transport vehicle (the number of hops will be discussed later). All vehicles in the network are moving out of a group or inside the group and can leave and join any group at will, while all groups are moving. Furthermore, groups could have intersection zones during some time.

Taking this mobility model from a general point of view, every group could have any direction and different speeds. Moreover, vehicles could have any direction and different speeds with respect to each group. Now, we will apply this mobility model to our environment of application: a dual highway. In this case, there will be several groups moving in the same way (as much groups as public transport vehicles) and several groups moving in the opposite direction. Any vehicle with higher or lower speed than the public transport vehicle may join or leave a mobile group. So there will be an inter group mobility model and an intra group mobility model. Figure 1 shows the proposed environment of application.

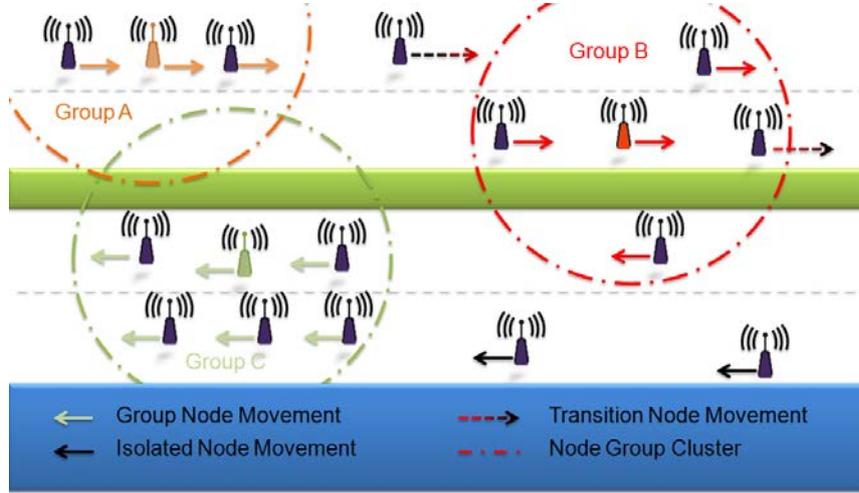


Figure 1. Intra and Inter group model proposal

In order to design our protocol, we will assume that each vehicle can use the GPS to obtain its position, speed and displacement vector of the vehicle. This information will be used to route the information intelligently. Every group of nodes is identified by a controller node (which in our case will be the public transport vehicle) using the *grupID* identifier and the group size will be limited by the number of hops to the group controller node. The maximum coverage area of a group is determined by the maximum coverage distance of each node and the maximum number of hops. So, the maximum group coverage area is given by equation 1.

$$d_{max_group} = 2 \cdot n_{max} \cdot r_{max_coverage} \quad (1)$$

Where n_{max} is the maximum number of hops between nodes inside a group, and $r_{max_coverage}$ is the maximum coverage area of a node.

Figure 2, shows an example of the coverage area of a group with 9 nodes where each node has a radio coverage area of r .

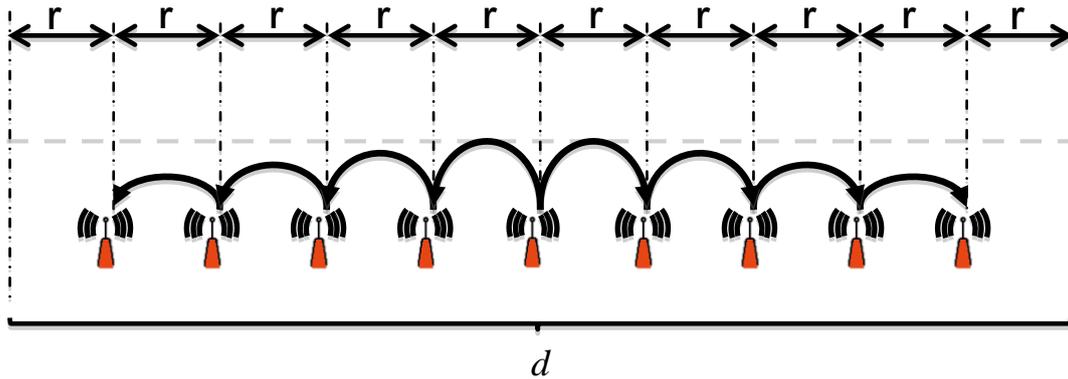


Figure 2. Coverage area of a group with 9 nodes.

We can observe in this premise that exist several cases for the nodes inside the mobile network. The main ones are: (1) the node is inside a group and (2) the node is out of a group. Starting from these cases, there are several sub-cases. They are numbered in the next list.

1. When the node is inside a group, there could be the following sub-cases:
 - The node continue being inside the group with the same speed of the group.
 - The node has higher or lower speed than the group so it will leave the group.
 - The node finds another group with better movement vector and/or speed than the current one.
2. When the node is out of the group, there could be the following sub-cases:
 - The node reaches the group (because it has higher or lower speed) and joins the group (because it is close to the group).
 - The node does not reach a group.

In order to add our protocol procedure and algorithm, we have modified the logical link control sub-layer. This sub-layer will take the appropriate decisions provided by the access algorithm and the group management algorithm. Our system relies on existing data checking mechanisms at MAC layer and IP layer in order to provide error correction and/or detection.

In the following sub-sections we are going to describe the algorithms when a node is looking for a group and finds it and when a node is inside a group and send requests to Internet, forward requests from other nodes and receives new joining nodes. All figures have been developed using UML diagrams [25].

3.1. Procedure when a node finds a group and joins it

When a node is in the network, it will try to find a group in order to join it and access to Internet. At the beginning it will broadcasts intra-group requests periodically in order to find a group. When it receives an intra-group ACK (because there is a node in its coverage area that belongs to a group), it process the received frame. The intra-group ACK has the position, the direction vector and the speed of the sender of the frame. Before joining the group, the node compares the received information from that group with its position, direction vector and speed. If the node receives several intra-group ACKs at the same time, it will join the group with the most appropriate direction, position and speed bearing in mind to choose the best option to be more time connected the group, and thus to Internet. The algorithm in figure 3 shows the described procedure.

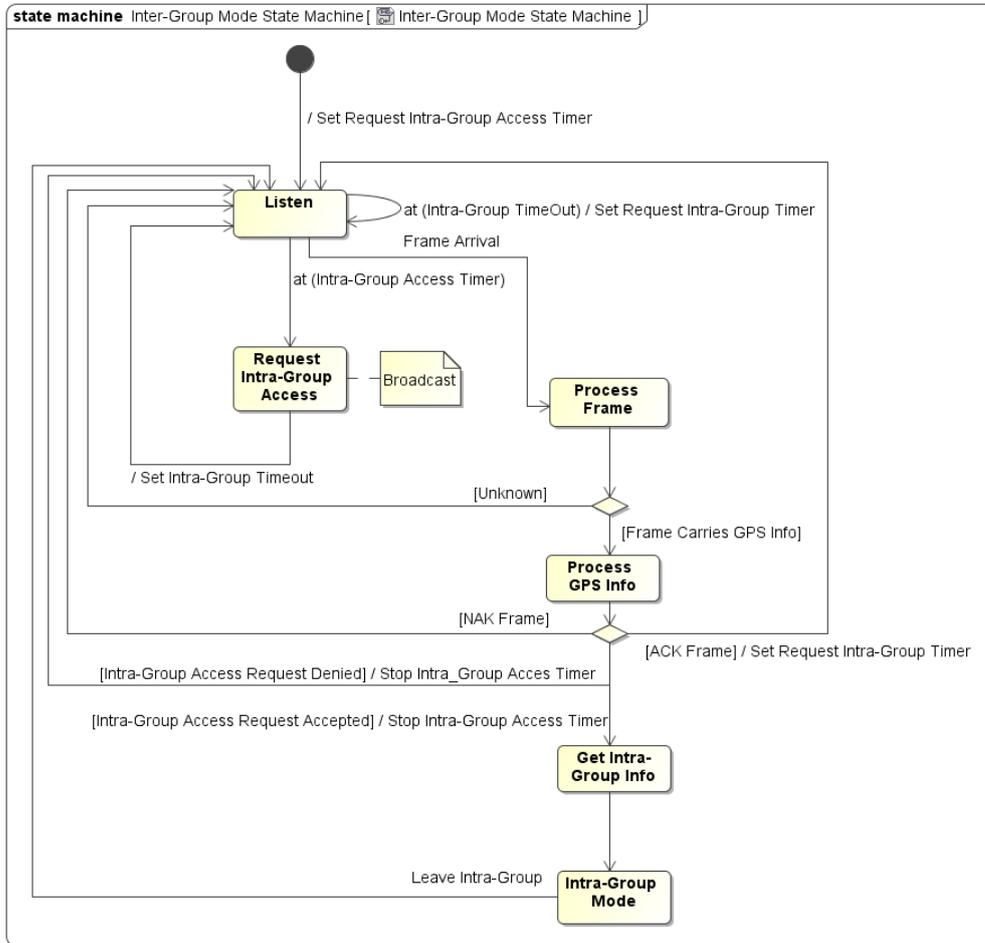


Figure 3. Algorithm for a node when it seeks for groups and joins a group.

3.2. Procedure of a node when it is inside a group

Any node in a group is listening in order to receive frames from other nodes. Moreover it has to be able to transmit its own traffic to its neighbors in order to reach Internet and receive frames from it. Any frame sent from the group controller node will have the controller's position, direction vector and speed. Every node in the group will select the most appropriate neighbor to forward the information based on these parameters, in order to have the most reliable path. Reliable paths are estimated following the algorithm shown in Algorithm 1. Each node selects the best neighbor to forward the information based firstly on the direction of the group controller node. If it is in the same direction, the closest neighbor in the same direction to the group controller node (which have less than 20 km/s of difference, because it assures 30 seconds of Internet access at least) will be selected. If it is not in the same direction, the node will select the closest neighbor to the controller node but only if it has less speed than the other neighbors, which assures Internet access during more time. The algorithm tries to maintain those links that will be available during a large period of time, thus closer vehicle speeds are preferred. Each node has a routing table to route the information to the group controller node where appears the selected neighbor and the number of hops to the group controller node.

Algorithm 1 Neighbor selection

Input: Controller node position (P_{cn}), controller node direction (D_{cn}), controller node speed (S_{cn}), neighbor position (P_n), neighbor direction (D_n), neighbor speed (S_n), source node direction (D_s), source node speed (S_s)

Output: Neighbor selection to forward the information

```

1: Nbors ← Sort all 1-hop neighbors with their  $P_n$ ,  $D_n$  and  $S_n$ 
2: Sel_Nbor:=Nbors(1)
3: for i:=2 to Nborsmax do
4:   if  $D_{cn}==D_s$  then
5:     if  $D_{cn}==D_{Nbors(i)}$  then
6:       if  $P_{cn}-P_{Nbors(i)} < P_{cn}-P_{Sel\_Nbor}$  then
7:         if  $S_s-S_{Nbors(i)} < 20$  then Sel_Nbor:=Nbors(i)
8:         end if
9:       end if
10:      end if
11:     else if  $D_{cn} \neq D_s$  then
12:       if  $P_{cn}-P_{Nbors(i)} < P_{cn}-P_{Sel\_Nbor}$  then
13:         if  $S_{Nbors(i)} < S_{Sel\_Nbor}$  then Sel_Nbor:=Nbors(i)
14:         end if
15:       end if
16:     end if
17:   end if
18: end for

```

Once, the neighbor selection algorithm to forward the information is defined, we are going to explain the procedure of a node when it belongs to a group. A node is always estimating which is the best neighbor based on algorithm 1. When a node in a group has to connect to Internet or receives some information from other nodes to forward to Internet, it will send/forward the information to the selected neighbor.

When a new node wants to join the group, and the node inside the group receives the request, it will accept it if and only if the group controller node is at 9 hops or less to the node inside the group. Otherwise it will deny this request. This acceptance/rejection is notified by sending ACK/NACK messages respectively. This will assure the group coverage area under some the appropriate values of reliability and delay. Moreover, while being joined a group, if the node finds a node from another group which offers more appropriate direction, position and speed than the actual group (based on the same statements shown in Algorithm 1), its affinity to this group will be higher so it will change the group. Figure 4 shows the described procedure.

Any node belonging to a group can use the services offered by the network controller node to the group, in our case Internet access.

A node may leave the group because of one of the following reasons:

- The node requests its leaving.
- The node fails down.
- Loose of link to the neighbor nodes that provide connectivity to the group.
- The network controller node leaves the network.
- The node finds a most appropriate group and wants to belong to the other group.

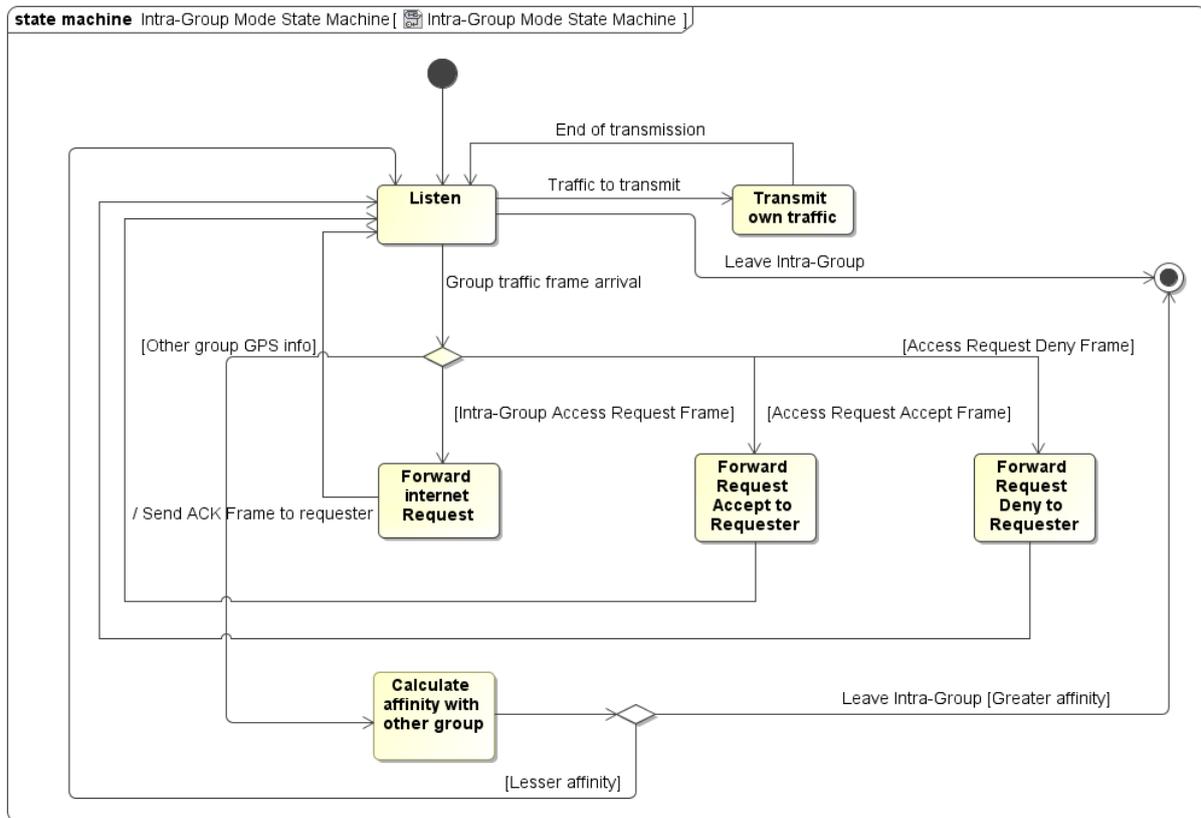


Figure 4. Algorithm procedure of a node that belongs to a group

Any node belonging to the network will firstly run the algorithm described in figure 3 and, after finding a group and joining it, it will run the algorithm described in figure 4.

Figure 5 shows the message flow diagram. First, it shows that a new node in the network broadcasts a message to join a group (Intra-Group Request TimeOut message), but there is no node listening under its coverage area, so there is a timeout. Later, it sends again a request to join a group (Request intra-group access message), but although there is a node listening under its coverage area, it does not belong to a group so it replies with a NAK message. Next, it sends an intra-group access request in order to join a group (Request intra-group Access message) and there is a node listening that belongs to a group and accepts its request. Then, that node sends a register message to the group controller node (Register a new node in the group message) in order to let it know that there is a new node in the group, and replies to the new node with an acceptance (Request accept message). Finally, when the new node wants to request for a web page to Internet, it sends a request message (Web page request message), which will be forwarded by the node to the controller node (Forward web page request message) in order to reach Internet. But, first, it will acknowledge this message (ACK message). When the information from Internet is available, the node controller will forward the reply (Web page reply message) to the appropriate node, which will forward to the requesting node (Forward web page reply message).

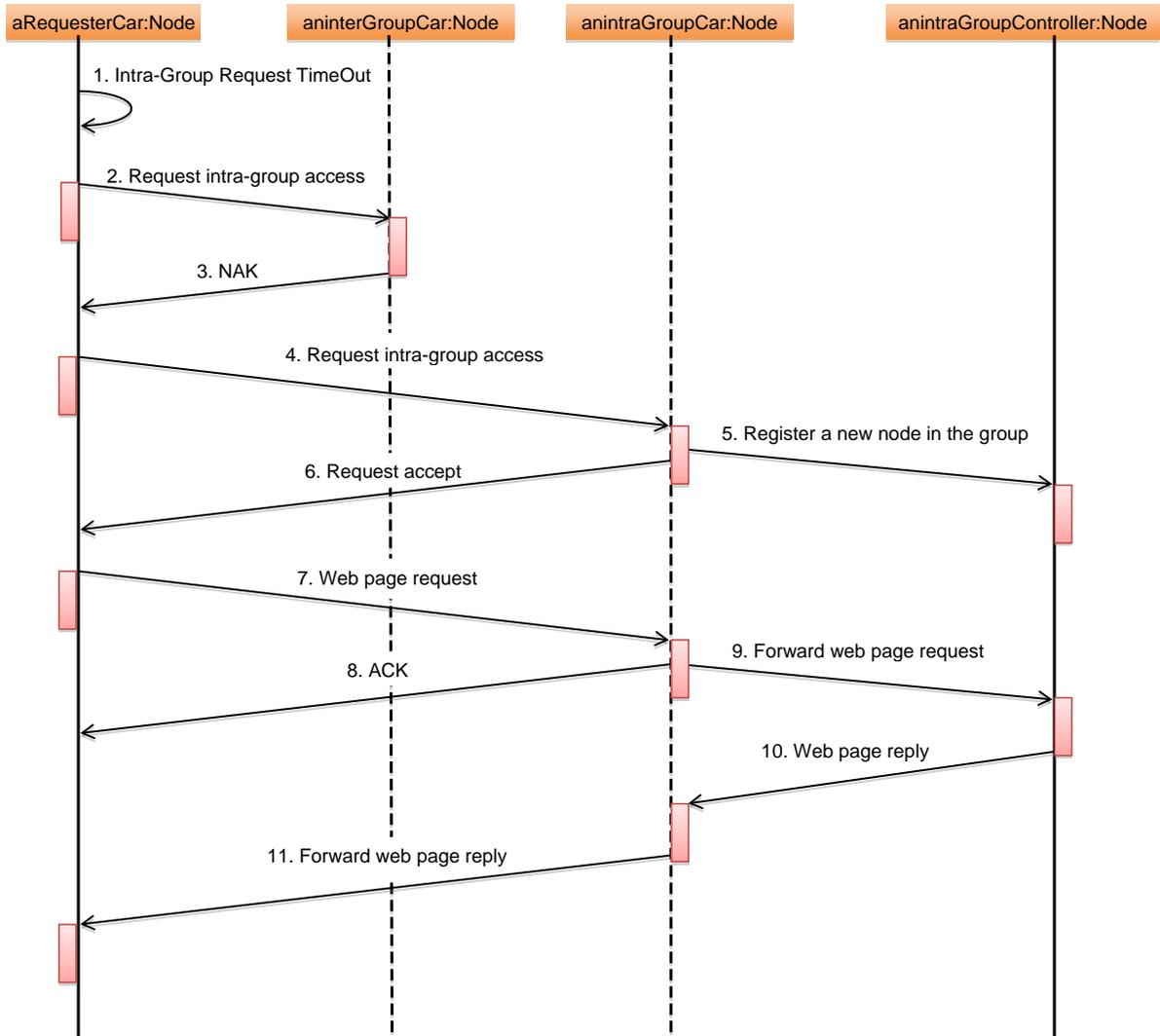


Figure 5. Message flow diagram example.

4. Analytical Model

In this section we study the probability of getting Internet access when a vehicle runs through a highway where there are several public transport vehicles travelling in both ways. So, we will take into account that there will be moving groups in both ways at different hours starting from different places offering Internet access. We will also study the impact of the speed of displacement of the vehicles, as well as, the impact of the density of vehicles in the road.

In order to develop our analytical model, we will suppose a scenario where the network is formed by groups of nodes and by nodes that do not belong to any group. Our model uses the following starting hypothesis:

1. The node to be analyzed is somewhere between two groups. There are two ways and vehicles are travelling in both directions.

2. The speed of the node is higher than the speed of the closest group. The nodes inside the group could be uniform or not.
3. We will suppose the speed of the nodes constant (in order to have an easier model).
4. The distance between groups running in the same way is constant during all the analysis.

First, we will study the probability model for getting Internet access when a new node enters the highway in a place between two groups. Next, we will study the probability model to join several groups during a trip.

4.1. Probability to join a group

In order to estimate the probability of a node to join a group, first we have to take into account the coverage area of a group. Using the third hypothesis of the previous list, the coverage area of a group is given by equation 1. The distance between the most remote vehicles is given by d_{group} . At $t=0$, and bearing in mind the 1st, 2nd and 4th hypothesis, the scenario to be studied is given by figure 6.

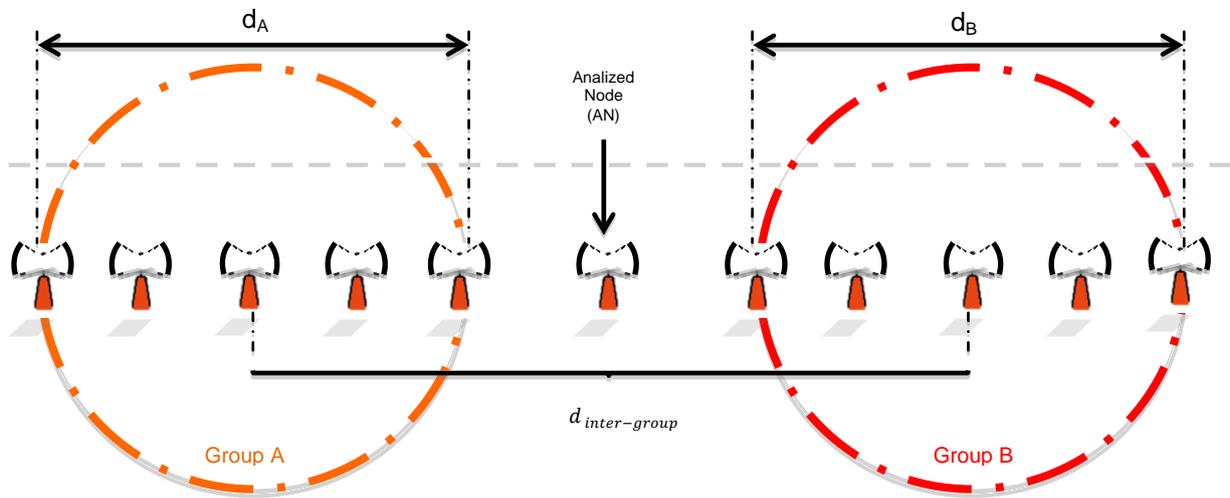


Figure 6. Scenario to study the probability to join a group.

The node to be analyzed is placed between both groups, although we don't know exactly where. The probability to join a group will depend on the distance between groups. Studying the possible cases of being placed inside a group versus all possible cases, we can estimate the probability of being inside a group. Let d_A and d_B be the diameter of group A and group B respectively, then, the probability to be inside a group is given by equation 2.

$$P_{intra-group} = \frac{d_A + d_B}{2 \cdot d_{inter-group}} \quad (2)$$

One of the variables that determine the probability of a node to reach a group is the d , and this variable depends on the density of nodes and their displacement inside the group. The other variable is the distance between groups $d_{inter-group}$ which depends on the group density in the way of the node when it is running in the highway. The probability to find a group of nodes at time t can be estimated using Bayes' Theorem as it is shown in equation 3.

$$P(N_{group}, t) = P(N_{group}|t)P(t) \quad (3)$$

Where $P(N_{group}, t)$ is the whole probability to find a controller node in the network for a given time, $P(N_{group}|t)$ is the conditional probability to be inside a group of nodes in a given time (that is $P_{intra-group}$), and $P(t)$ is the probability to be in that time interval.

If we bear in mind that in a regular transportation system, public transportation vehicles appear periodically in the highway, we can determine the probability to find groups in the network based on the number of public transportation vehicles on the road, that is, the density of group of nodes. So, the closer they are the more probable to find a group is. Equation 4 gives the probability for a node to find a group during its trip.

$$d_{inter-group} = P_{intra-group} \cdot d_{trip} \quad (4)$$

Where d_{trip} is the distance of the trip of the node in the highway. This will be used later to perform the probabilistic analysis of our mobility model in a study case.

4.2. Probability to find several groups during a trip.

In this case we are going to estimate the probability of finding groups during a trip depending on the time parameter. We will take into account several variables such as position, direction and speed of the group and of the analyzed node. In order to estimate the probability, we have considered the following cases that should be added because of the two directions of the highway:

1. The node starts in different position and time respect to the groups that are running in the same direction of the highway.
2. The node starts in different position and time respect to the group but in the opposite direction in the same highway.

The first case is similar to the one previously studied but with temporal continuity. The probability to reach a group by a node depends on the node's speed and the density of groups in the highway during its trip. The worst case is the one where the node has the same speed than the groups and the node is outside of any group. In this case the node will not reach any group. Now, the probability to be inside a group will depend on the number of groups that is able to reach. From the temporal point of view, we can estimate the probability of being inside a group during a period of time during the time needed to do trip. Supposing that the speed of the nodes and the groups are constant, the time inside a group depends on the size of the group, its speed and the speed of the node and is given by equation 5.

$$t_{intra_group} = \frac{d_{group}}{v_{node} - v_{group}} \quad (5)$$

Where v_{node} is the speed of the node, v_{group} is the speed of the group, and d_{group} is the diameter of the group. The trip time of a node, at a constant speed, is given by equation 6.

$$t_{trip} = \frac{d_{trip}}{v_{node}} \quad (6)$$

Where t_{trip} is the trip time of the node, and d_{trip} is the distance of the trip.

In order to estimate the probability to be inside a group in a given time during the trip depends on all possible cases respect to all cases. For only one group, the possible cases are the time to be inside the group respect to all the trip time. Thus, the probability to be inside a group during the trip is given by equation 7.

$$P_{intra-group} = \frac{t_{intra-group}}{t_{trip}} \quad (7)$$

But this probability will be increased when the density of groups in a trip is higher.

Now, we estimate the distance needed for a node to reach a group. In the most pessimistic case (the car is just at the front of a group and has to reach next group), the distance needed to reach a group is given by equation 8 (we have supposed that both groups have the same d_{group} for simplicity).

$$d_{reach-group} = \frac{v_{node}(d_{inter-group} - d_{group})}{v_{node} - v_{group}} \quad (8)$$

Using the probability model used for equation 3 and 4, and we can estimate the number of groups (N_{group}) that a node will be able to reach during its trip. It is given by equation 9

$$N_{group} = \frac{d_{trip}}{d_{reach-group}} \quad (9)$$

Now we can estimate the probability to find a group in the highway during a trip using equation 4 and equation 8. It is given by equation 10.

$$P_{find-group} = P_{inter-group} \cdot N_{group} \quad (10)$$

Now, we should take into account the groups coming from the opposite direction. In this case the time to reach a group is given by equation 11.

$$t_{opposite-group} = \frac{d_{group}}{v_{node} + v_{group}} \quad (11)$$

The probability to be inside a group of the opposite direction will be all possible cases respect to all cases during the trip. It is given by equation 12.

$$P_{opposite-inter-group} = \frac{t_{opposite-group}}{t_{trip}} \quad (12)$$

By performing again the same operations used for the same direction, we can estimate the distance to reach a group from the opposite direction. It is given by equation 13.

$$d_{reach-opposite-group} = \frac{v_{node}(d_{inter-group} - d_{group})}{v_{node} + v_{group}} \quad (13)$$

In the same way, the number of groups will be given by equation 14.

$$N_{group} = \frac{d_{trip}}{d_{reach-opposite-group}} \quad (14)$$

Thus, the probability to find a group in the highway during a trip is given by equation 15.

$$P_{find-opposite-group} = P_{opposite-inter-group} \cdot N_{group} \quad (15)$$

The whole probability is obtained by adding all these probabilities, the probability to find a group (in the same way and in the opposite way) and the probability to be inside the group. It is shown in equation 16.

$$P_{whole} = P_{intra-group} + P_{find-group} + P_{find-opposite-group} \quad (16)$$

5. Real Case Analysis

In order to perform our study, we will use real values taken from a public transportation enterprise in the Valencian Community (Spain) in the proposed analytical model. Nodes are cars and the controller nodes, that form groups, are buses. An example of with one bus and 6 cars (3 in front of the bus and 3 behind the bus) is shown in figure 7. We will suppose that the average coverage radius of each vehicle is 200 meters. This value has been obtained supposing that the wireless devices have a transmitting power of 17 dBm, use omnidirectional antennas of 5 dBi, and have wire losses of -2 dB. This values let us know that we will obtain -86 dB at 200 meters in the 2.4GHz frequency band.

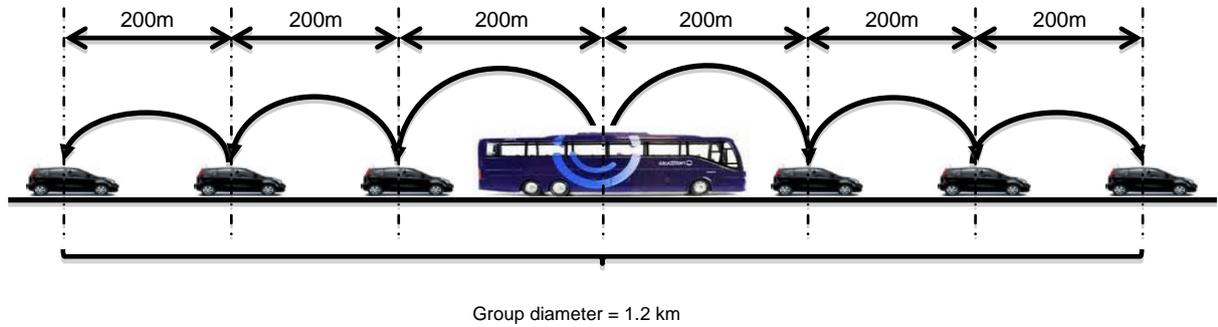


Figure 7. Group of vehicles

The cars and the bus are travelling a constant speed of 90 km/h. Let us add a new car in the highway driving with a constant speed of 120 km/h. The highway has both directions, that there will be groups running in both directions. The highway used for our case is the highway between Alicante and Valencia Cities.

The size of the groups will be limited by 10 hops (although we can increase this number in order to have bigger group sizes). The maximum distance of a group (where the coverage radius of a vehicle is 200 meters) is 4 km. In order to perform our analysis, we will place the new car in two locations, the first one will be between two groups (see figure 8), and the second one will be inside a group (which is the best case). Because the speed of the new car is higher than the speed of the groups, the time to reach each one of the groups depends on the distance between groups. This distance depends on the density of buses in that route. We suppose that the distance

between buses is constant. In order to perform our analysis we use the data of the ALSA bus company [26]. But, we can easily add information from other companies going to different cities or to the same destination in order to increase the percentage probability of having Internet access.

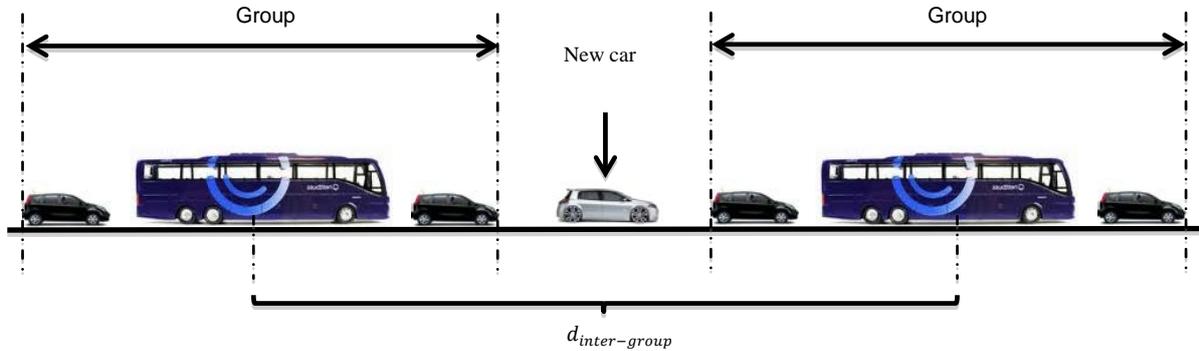


Figure 8. Scenario used to perform the study

One of the ways used to model our proposal is by providing a period of time and estimate the probability of joining a group somewhere in our trip. It depends on the whole probability of finding and reaching a group during that period of time. This probability is higher in the hours when the public transport service company offers more buses per hour. Concretely, in ALSA bus company case has three main range of time. During that range of time, the horary of the bus services is quite similar. We can also take into account that during this range of time, there may be other public buses from other companies in the same route or in a part of the route. This time we have not added but it may increase the probability. We have considered the following ranges of time:

- From 6 am to 2 pm: There are buses every 15 minutes in the road. Some of them do the whole route and some do parts, but they are complementary. Thus, there will be buses every 29.34 km.
- From 2 pm to 10 pm: There are buses every 50 minutes. Thus there will be buses every 97.82 km.
- From 10 pm to 6 am: There are buses every 2 hours. Thus there will be buses every 234 km (more than the distance of the road).

We can observe that the results depend on the considered range of time. That is, the results depend on the group density. Taking into account the estimated data for those ranges of time, and the equations shown in the analytical model, we obtain the values shown in table I.

	$d_{inter-group}$ (Km)	$d_{reach-group}$ (Km)	N_{group}	$P_{inter-group}$	$P_{intra-group}$	$P_{opposite-intra-group}$
6 am - 2 pm	29.34	117.36	1.27	0.13	0.127	0.025
2 pm -10 pm	97.82	391.28	0.38	0.04	0.038	0.01
10 pm – 6 am	234	936	0.16	0.01	0.016	0.003

Table 1. Values obtained for each range of time.

The whole probability to be inside a group for each range of time using the data from the ALSA Bus Company is shown in figure 9. We have not added any other bus company, nor the buses running in the regular road (which is parallel to the highway in big part of the route), although these additions will increase the probability considerably. We can observe that the most probable hours to join a group in order to have Internet access is between 6 am and 2 pm. The probability in the other two ranges is quite low if we just bear in mind ALSA bus company data. The other way to increase the probability is to let our network to have groups with more than 10 hops from the boundary nodes to the controller node.

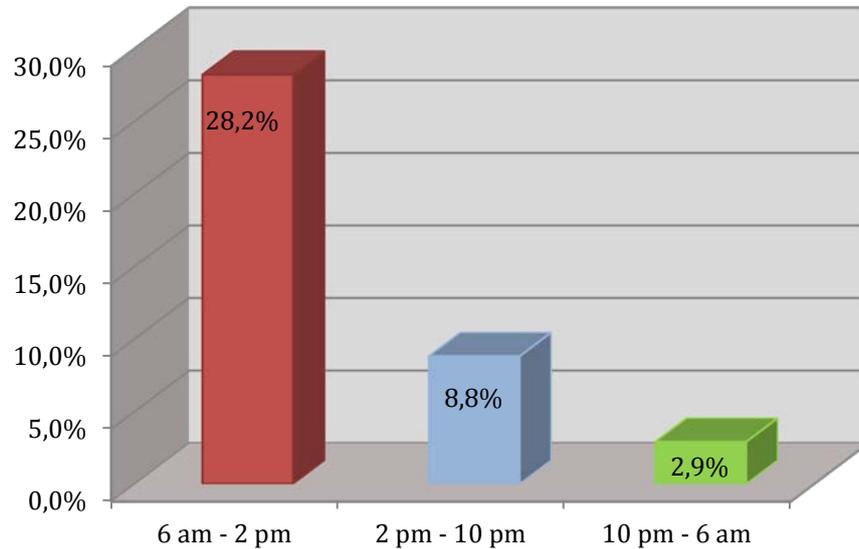


Figure 9. Whole probability in each range of time.

6. Simulations

In order to test the performance of our proposal we have made several simulations using OPNET Modeler Wireless simulator [27]. In order to perform a realistic situation, we have simulated the highway between Alicante and Valencia (two well know cities of Spain). The highway has 150 Km. We have considered 2 types of vehicles in our simulations. The first ones are the buses, which act as network controllers and provide Internet access to the rest of vehicles. Their speed is 90 Km/h. The second ones are the cars, which access to Internet using the ad hoc network formed by the cars, using as a Gateway node the network controllers. Their speed is 120 Km/h. We have performed a simulation during 2 hours in order to assure that the slowest vehicle covers the whole route.

The size of the groups is limited by 10 hops. We assume 200 meters as the maximum coverage distance for each vehicle, although we know that larges distance may be possible. Bearing in mind these data, the group is 4 km large. In order to test the performance of our proposal, we simulate that all cars in every group will send http requests to the network controller in their group.

We have tested our proposal in the three scenarios described in section 5: Scenario 1 (from 6 am to 2 pm), scenario 2 (from 2 pm to 10 pm) and scenario 3 (from 10 pm to 6 am). Bearing in mind those data, scenario 1 (S1) has 5 buses forming 5 groups, scenario 2 (S2) has 2 buses forming 2 groups and, in scenario 3 (S3), we suppose that the bus drives though the highway during our simulation. We have introduced 1200 cars in the 3 scenarios along the 2 hours. All scenarios have been simulated using 2 mobility models. In the first one (constant mobility), all cars have constant speed and travel in a predefined route. In the second one (Random Mobility), all cars have a random speed which fluctuates between 100 Km/h and 120 Km/h. In this second model, the buses continue having a constant speed of 90 Km/h.

The following subsections show the results obtained.

6.1. Number of Hops per Route

Figure 10 represents the average number of hops in the route table of all nodes in the network for each one of their routes to every destination. We can see that the worst case is the constant mobility in S3, because in no case there are 10 hops. This is due to the low density of buses and due to the constant speed of the cars. However, random mobility in S3 is quite more favorable because of the random mobility, which gives more chances to achieve close to 10 hops during almost all the trip. The rest of cases have an ad hoc network with almost 10 hops during the entire trip.

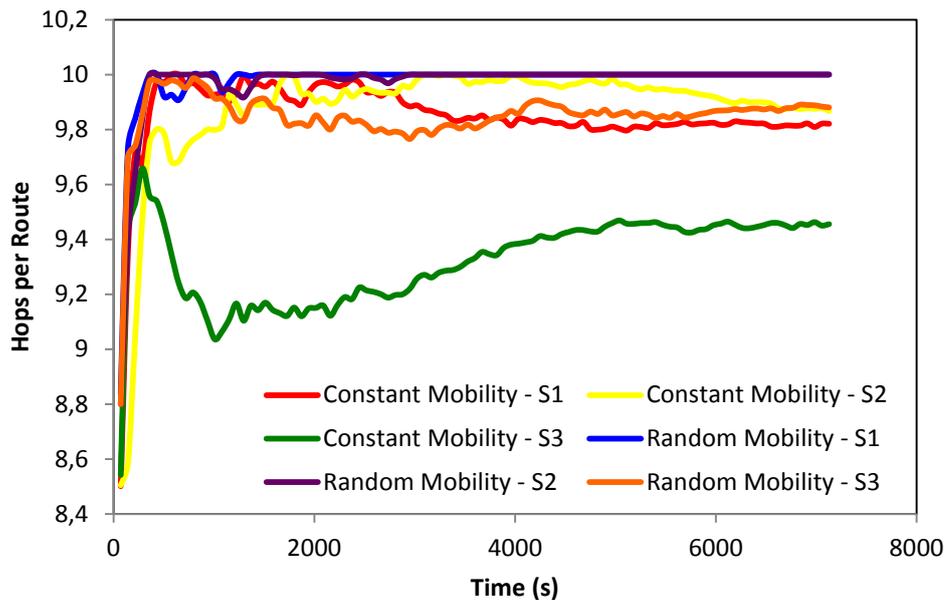


Figure 10. Number of Hops per Route

6.2. Traffic Received (bits/sec)

Figure 11 shows the amount of traffic received in bits/sec in because of the HTTP traffic forwarded in the entire network. We can observe different group peaks at about 5000 bits/sec that coincides with the number of groups in each scenario. E.g. in random mobility in S1, we can see 5 groups of peaks clearly. However, random mobility in S3 only shows 1 peak, which coincides with the number of groups. In the rest of cases happens the same. In constant mobility in S1 there is the biggest peak, which seems to be because of the accumulation of vehicles at that time, which generates great volume of traffic.

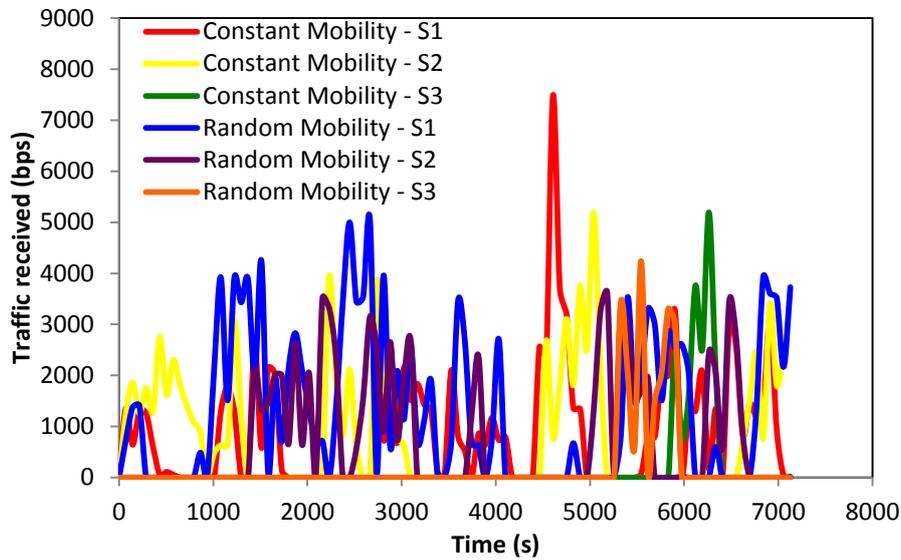


Figure 11. Routing Traffic Received

6.3. Total packets dropped

When no route is found to the destination, the node drops the packets queued to the destination. Figure 12 shows the total number of application packets discarded by all the nodes in the network. In this case there is not a big difference between constant mobility scenarios and random mobility scenarios. The lowest average value has been obtained in random mobility S3 (4294 packets dropped) and the highest average value has been obtained in random mobility S1 (4442 packets dropped). This difference is not too high, so the density of buses do not affect to the number of packets dropped.

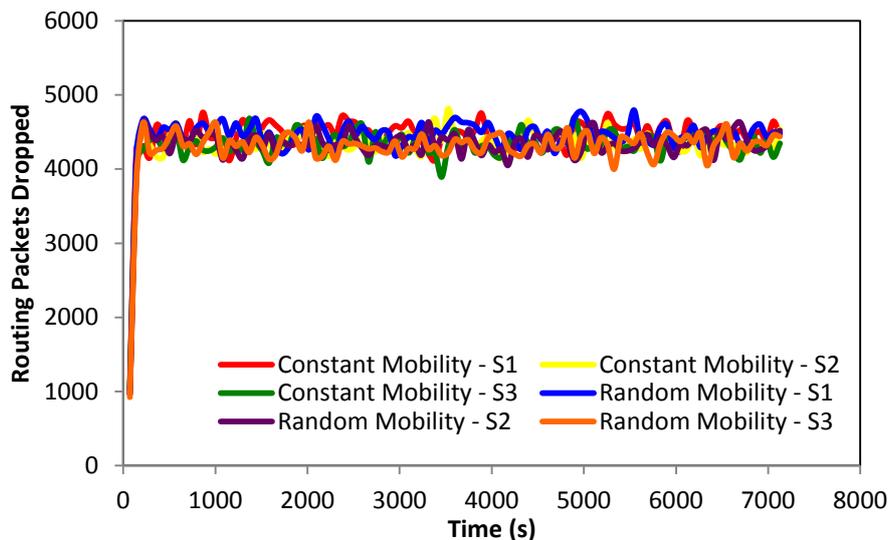


Figure 12. Total Packets Dropped

6.4. Total Route Requests Sent

Figure 13 shows the total number of route request packets sent by all nodes in the network during their route. We can see that the number of Route Requests Sent depends on the density of buses. The more number of groups there are, the more Route Requests Sent. The highest average value was obtained by the random mobility S1 (2882 requests sent) and the lowest average value was obtained by constant mobility S3 (2298 requests sent).

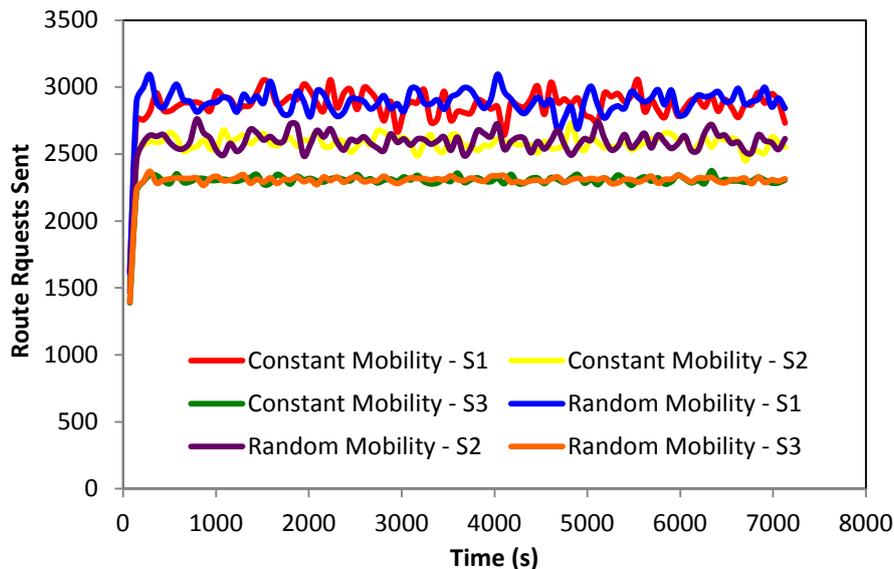


Figure 13. Total Route Requests Sent

6.5. Page Response Time (sec)

Figure 14 shows time required to retrieve the entire page with all the contained inline objects. This value directly depends on the number of interactions in the network, and thus on the number of groups because the more groups there are, the more interactions will be. The highest value has been obtained in constant mobility S1 (0.042 seconds) and the worst has been obtained in constant mobility S3 and random mobility S3 (0.05 seconds in both cases). We obtain a constant page response time for both random and constant mobility in S2.

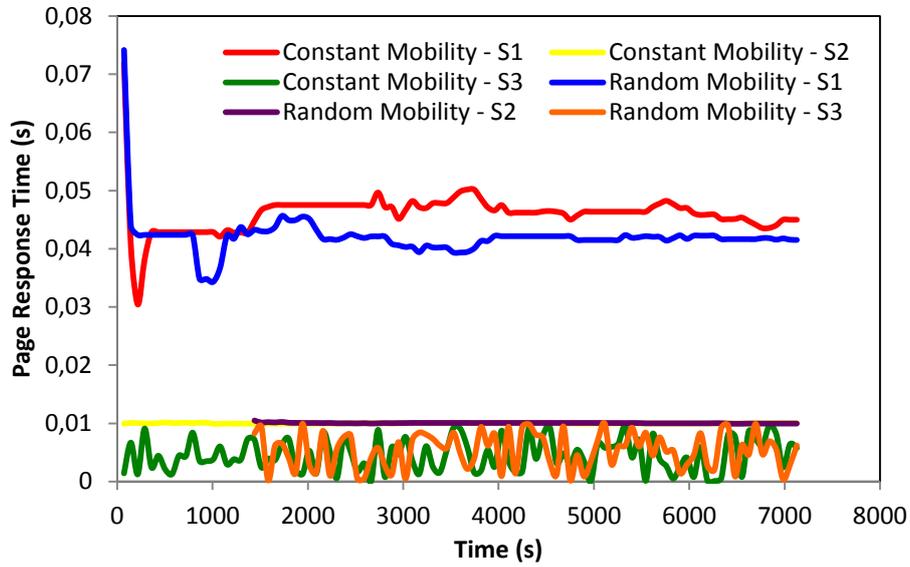


Figure 14. Page Response Time

6.6. Retransmission Count

Figure 15 shows the total number of TCP retransmissions in the network. They represent the messages written when data are retransmitted from the TCP unacknowledged buffer. We can see that higher values are obtained in S1 scenarios (which end at around 2700 TCP retransmissions), while lower values are obtained in S3 scenarios (but they are quite similar to S2 scenarios). This happens because S1 scenarios have more groups and the network is more congested.

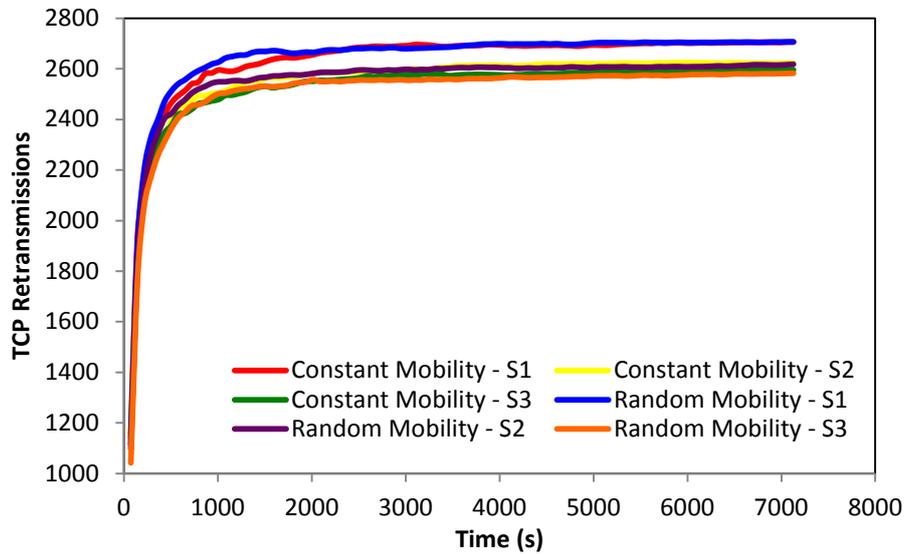


Figure 15. Retransmission Count

6.7. Data Dropped (Retry Threshold Exceeded) (bits/sec)

Figure 16 shows the total higher layer data traffic (in bits/sec) dropped by the all the WLAN MACs in the network as a result of consistently failing retransmissions. This statistic reports the number of the higher layer packets that are dropped because the MAC couldn't receive any ACKs for the (re)transmissions of those packets or their fragments, and the packets' short or long retry counts reached the MAC's short retry limit or long retry limit, respectively. The worst cases are given in S1 scenarios, while the best cases (that is the ones with less data dropped) are given in S3 scenarios.

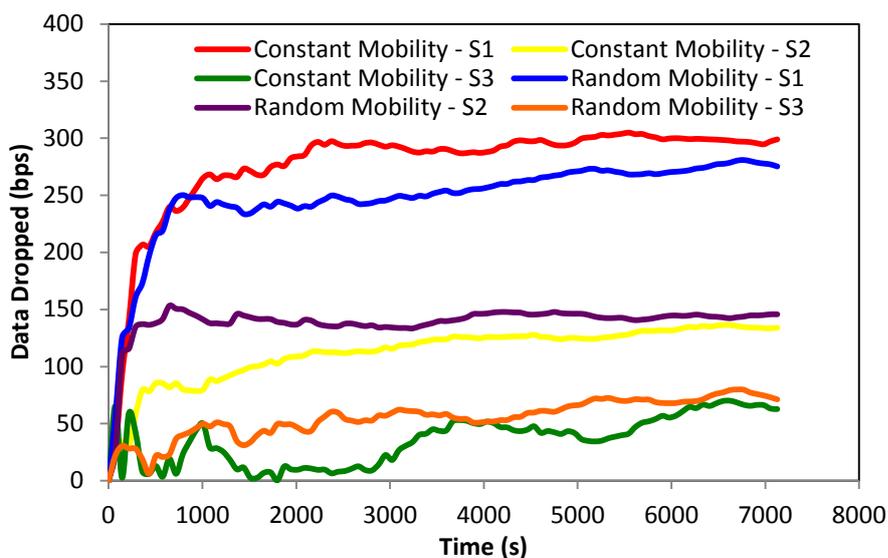


Figure 16. Data dropped

6.8. Delay (sec)

Figure 17 shows the end to end delay of all the packets received by the wireless LAN MACs of all WLAN nodes in the network. This delay includes medium access delay at the source MAC, reception of all the fragments individually, and transfers of the frames. The values obtained are quite similar for all scenarios. The highest delays have been obtained for the cases of S1 scenario.



Figure 17. Delay

6.9. Load (bits/sec)

Figure 18 shows the total load (in bits/sec) submitted by all higher layers in all WLAN nodes. We can see that the load is higher when the number of buses in the network is higher, because there are more groups, and thus more number of bits/sec in the network. The load is less unstable in S1 cases than in the other cases. Moreover, in S3 cases, is almost lineal. This happens because there are fewer changes in the network. The highest average values has been obtained in random mobility S1 with 123650 bits/s, and the lowest value has been obtained in constant mobility S3 with 95421 bits/s

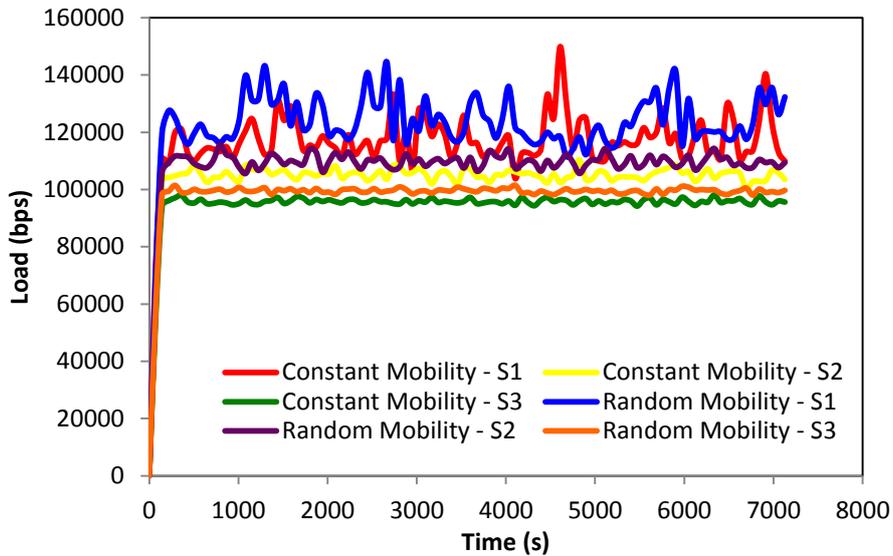


Figure 18. Load

6.10. Media Access Delay (sec)

Figure 19 shows the global statistics for the total of queuing and contention delays of the data, management, delayed Block-ACK and Block-ACK Request frames transmitted by all WLAN MACs in the network. For each frame, this delay is calculated as the duration from the time when it is inserted into the transmission queue, which is arrival time for higher layer data packets and creation time for all other frames types, until the time when the frame is sent to the physical layer for the first time. The highest peaks and the most unstable graphs have been obtained for S1 scenarios (the highest one was constant mobility). The most stable graphs and with less peaks were S3 scenarios (the lowest has been the random mobility case).

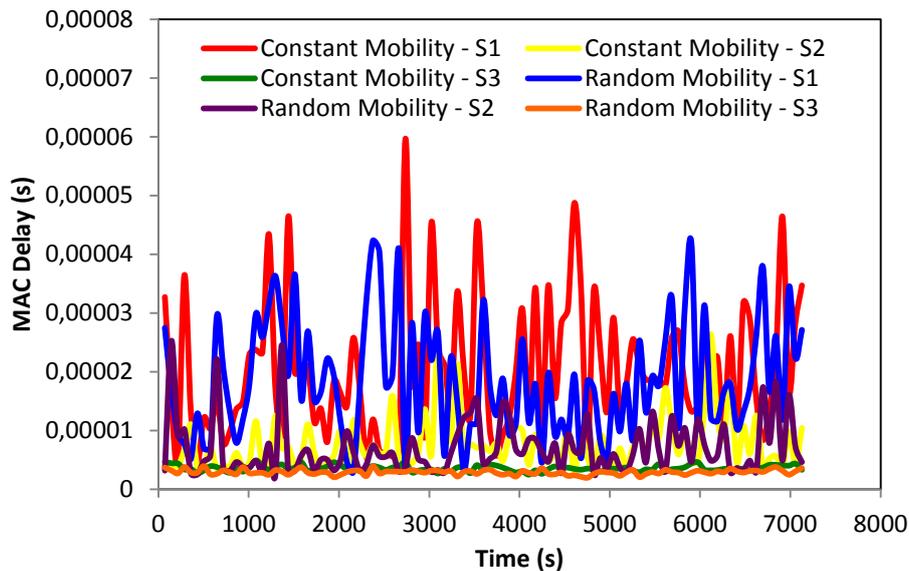


Figure 19. Media Access Delay

7. Conclusions

In this paper we propose a group-based protocol and mobility model for vehicular ad hoc networks (VANETs). Each public transport vehicle forms a group of vehicles. Our proposal let car co-drivers and passengers access Internet with a considerable probability of success only taking into account a public transport company. Moreover car devices could consult any Internet service in order to provide the most accurate information to the driver about routes, traffic congestion, weather, etc.

We have designed the protocol and algorithms to achieve our purpose. Each vehicle can move inside the group and can leave and join any group at will, while all groups are moving. Our main research contribution is the design and simulation of a new mobility model based on groups, where nodes inside each group are moving, so groups have different sizes and number of nodes, while they are moving.

We have studied the probability of having Internet access in order to demonstrate that it is a feasible proposal and we have compared our system for several group densities. We have also simulated a study case based on real values in order to study the performance of our proposal in terms of several network parameters such as the number of hops per route, the network traffic, number of packets dropped, the total route requests sent, the page response time, retransmission count, the data dropped, the network delay, and the network load.

We believe that if all public transport vehicles (from other bus enterprises) allow Internet access by using a system like the one explained in this work, the probability of having Internet access elsewhere for any vehicle will be increased very much, thus it will contribute to the Internet access ubiquity. Moreover, the system could be enhanced if we add to our system some private vehicles that offer Internet access freely.

In our future works we will study the impact of vehicle velocity and density over a VANET configuration in order to extend the coverage of each group by means of network aware vehicles along their trip. Moreover, we will include geographic routing in order to improve the message forward direction and provide fast and reliable routing mechanisms [28]. Furthermore, we will add the combination of symmetric and asymmetric cryptography in order to provide authentication, data integrity and message encryption, like we have added in our previous work [29].

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