

Impact of IDM Lane-Changing on the Performance of AODV on VANETs

Mouaz Chamieh, Rand El-Kouatly

Department of Networks and Computer Systems Engineering
 Damascus University
 Damascus, Syria
m.chamieh@damasuniv.edu.sy, rand@ieee.org

Oula Abu-Amsha

Department of Computer Science
 Higher Institute of Applied Science & Technology
 Damascus, Syria
oula.abuamsha@hiast.edu.sy

Abstract — In order to introduce a realistic simulation environment to support the research on vehicular Ad hoc Networks (VANETs), the human behavior must be studied, understood and included in the mobility model representing the vehicles movement. This paper studies the behavior of the driver concerning specifically the decision to change the lane. Our study is based on real world observations and safety driving rules, and introduces a new lane-changing simulator accordingly. This simulator is integrated within Intelligent Driver Model with Intersection Management (IDM-IM) and compared with Intelligent Driver Model with Lane Changes (IDM-LC) as well as IDM-IM mobility models provided by VanetMobiSim framework, concerning their effects on the performance of Ad hoc On Demand Routing Protocol (AODV) and reality imitation.

Keywords – component, VANETs, mobility models, lane changing simulation, performance evaluation, routing protocols

I. INTRODUCTION

The high mobility, scalability and the wide variety of environmental conditions heavily affect the VANETs (Vehicular ad hoc network) performance and make routing operation a complicated task. For the time being, the design of a routing protocol in the VANETs networks relies mainly on simulations. A mobility model tries to imitate the main characteristics of the topology of the network as well as the movement of the nodes through this topology. In the literature, vehicular mobility models are usually classified as either microscopic or macroscopic. When focusing on a macroscopic point of view, motion constraints such as roads, streets, crossroads, and traffic lights are considered. Also, the generation of vehicular traffic such as traffic density, traffic flows, and initial vehicle distributions are defined. The microscopic approach, instead, focuses on the movement of each individual vehicle and on the vehicle behavior with respect to others. (more details on mobility models can be found in [1]). Lane-changing is one of the essential characteristics in a mobility model that could affect the performance of a routing protocol. In fact, a realistic description of VANETs requires a multilane modeling framework, where "mandatory" lane changes as well as "discretionary" lane changes can take place [2]. This is why it is important to have a well designed algorithm that reflects the real behavior of the driver with the ability of changing lanes.

In this work we attempt to give a new analysis of the naturally complex human behavior when a driver makes a decision related to a discretionary lane-changing on highways. We use this analysis to suggest a new simulation algorithm of the lane changing behavior, and then we integrate this algorithm with the IDM-IM mobility model,

and study the impact of the new algorithms on the performance of AODV [3], and compare it with the impact of MOBIL [4], which is a common lane changing model based on a different analysis of the human lane changing behavior, on the performance of AODV as well. We believe that our modeling of the lane changing decision is more realistic than the existing model, MOBIL. We justify our model compared to MOBIL in section V to propose the new algorithm. The new model is a microscopic lane changing model based on real world observations and advised driving behavior during lane changing decision making phase concerning safety issues. It is evolved according to several parameters grouped as position parameters, speed parameters and other parameters such as politeness and the driver desire of speed, where gaining an advantage to maintain or increase the current speed is the motivation to initiate a lane changing process. The new model estimates the needed distances and speeds to succeed a lane changing, and then it decides according to which constraints are satisfied, whether to make the lane-changing immediately or not. The new model shows convergences with MOBIL on the impact on AODV performance, but the reality of our new model is much more better than the reality of MOBIL concerning the number of Lane-Changing maneuvers performed by each model.

II. RELATED WORKS

Mobility models plays a significant role in determining the protocol performance, hence, it is desirable that these models emulate the movement pattern of targeted real life applications in a reasonable way. Otherwise, the observations made and the conclusions drawn from the simulation studies may be misleading. One of the most difficult aspect of the driver behavior that researchers think it has to be taken into account, the process of lane changing decision making. Many works have been done towards modeling and simulating the driver lane-changing behavior,

one of them is MOBIL [4], which is discussed more in detail in section IV, and which is based on a game-theoretical modeling that evaluates gains and losses related to a lane changing decision. Another model is proposed in [5]. Here a new microscopic lane-changing behavior for urban traffic is done based on Hidden Markov Models (HMM) and cognitive factors, and it takes advantage from many previous works and concentrated on lane-changing decision making phase according to parameters grouped as position parameters, speed parameters and other parameters such as traffic rule for lane-changing, politeness and desired acceleration. After making the needed calculation for distances and speeds, the model will decide to make the lane-changing immediately, adapt the speed to make the lane-changing, follow the current lane, or follow the current lane but notify the vehicle on the target lane asking for enough space for a future lane change action. On the other hand, many works [6] [7] [8] [9] have been done to evaluate the performance of VANETs routing protocols based on different mobility models. For example, in [6] the performance of three MANET reactive routing protocols is studied while using different VANETs mobility models produced by VanetMobiSim [10], and through varying the number of nodes and nodes maximum speed.

III. STUDIED ROUTING PROTOCOL

Routing protocols in Ad hoc networks are usually separated into two main kinds: proactive and reactive routing protocols. Proactive routing protocols require that all nodes maintain a routing table for routing to other hosts, in order to update the routing tables, huge amount of information exchange is needed making the large overhead a burden for the network. In high mobility network like VANETs the overhead is even larger because of the increased routing table update failure probability. As for their counterpart, reactive or on-demand routing protocols discover and establish routes only there is a need. This kind of routing protocols save unnecessary information exchange and thus bring down the overhead costs. This section introduces a common reactive routing protocol Ad-hoc On-demand Distance Vector (AODV) Protocol, the routing protocol used in our study.

In AODV [3], when a source node has data to be sent to a destination node, it first initiates a route discovery process. In this process, the source node broadcasts a Route Request (RREQ) packet. Neighbor nodes which do not know an active route for the requested destination node, forward the packet to their neighbors until an active route is found or the maximum number of hops is reached. When an intermediate node knows an active route to the requested destination node, it sends a Route Reply (RREP) packet back to source node in unicast mode. Eventually, the source node receives the RREP packet and opens the route.

IV. STUDIED VEHICULAR MOBILITY MODELS

Obviously mobility models deeply affect the simulation results, so it is important to choose a realistic mobility model in order to obtain results that could reflect the real world

performance of VANETs. In our study, We choose two extensions of the well-known mobility model IDM [11]. In fact, IDM is able to reproduce all the essential traffic dynamic phenomena observed on freeways, and we are interested in studying the effect of lane changing behavior on the performance of routing protocols in such environment. We briefly describe here the studied mobility models in this paper. More details could be found in [12].

A. Intelligent Driver Model with Intersection Management (IDM-IM)

This model is a longitudinal macroscopic car-following model that adapts a vehicle speed according to other vehicles driving ahead, thus falling into what so-called car following models category [1]. IDM-IM model uses a quite small set of parameters, which can be evaluated with the help of real traffic measurements. This model extends the IDM model [11] in order to include the management of intersections regulated by traffic lights and stop signs [12]. IDM-IM inherits the car-to-car interaction description of the IDM basic model and provides vehicles with the capabilities of handling intersections. It can manage crossroads regulated by both stop signs and traffic lights. In both cases, IDM-IM only acts on the first vehicle on each road, as IDM automatically adapts the behavior of cars following the leading one.

B. Intelligent Driver Model with Lane Changes (IDM-LC)

This model extends IDM-IM model, it allows vehicles to change lane and overtake each others. IDM-LC [12] adopts one of the following behaviors when a vehicle approaches a crossroad:

- If the lane the vehicle is currently moving on is also present in the next road on its path, then it moves through the intersection and keeps traveling on the same lane in the next street;
- If the lane currently used by the vehicle does not exist in the next road, then it tries to merge to its right as it approaches the junction. If merging is not possible, e.g. because the lane to its right is very crowded, the vehicle stops at the intersection and waits until a spot becomes available.

The MOBIL (Minimizing Overall Braking Induced by Lane change) model [4] is employed in IDM-LC [12] to manage the overtaking process. As its name indicates, the MOBIL model -by following a game theoretical approach- computes the advantage that a vehicle gains if changing its lane and compares it with the gain loss caused to vehicles in the destination lane. If the own advantage is much higher than the disadvantage caused to other vehicles, the lane change is performed. Such requirement is fulfilled when the following two conditions are fulfilled:

$$a^l - a \pm a_{\text{gain}} > p(a_{\text{cur}} + a_{\text{new}} - a_{\text{cur}}^l - a_{\text{new}}^l) + a_{\text{loss}} \quad (1)$$

$$a_{\text{new}}^l > -a_{\text{safe}} \quad (2)$$

Where a is the current acceleration of the vehicle, a^i is the equivalent acceleration computed in the case the vehicle moved to an adjacent lane i . Similarly, a_{cur} and a_{cur}^i describe the acceleration of the car which currently follows the vehicle we are considering in the case the vehicle under study stays on its lane, or in the case it moves on another lane. Finally, a_{new} and a_{new}^i represent the acceleration of the car which would become the new back vehicle if the car under study changed its lane to, before and after a possible lane change of the latter. In Eq. 1 the left hand side of the inequality is the advantage that the lane change would bring to the car under study and the right hand side represents the disadvantage brought by the same movement to the back cars in the current and new lanes. The P factor models the driver's politeness, while the acceleration threshold a_{thr} prevents lane hopping phenomena in borderline conditions and a_{thr} can be adjusted to differentiate movements to the left or to the right. Eq. 2 introduces a safety condition on the braking deceleration of the back car in the new lane.

V. REALISTIC LANE CHANGING

In this section a new lane changing model is proposed, this model simulates human discretionary lane changing behavior on highways. This model is integrated with IDM-LC instead of MOBIL because MOBIL is based on an approach tends to optimize the lane changing decision process by reducing the overall braking operations on simulated movements, and we believe that this strategy doesn't reflect the reality. In addition, the driver doesn't only consider the two vehicles and two gaps behind him on the current and the target adjacent lanes as it is modeled in MOBIL, but the driver also considers the two vehicles and two gaps in front of him on the current and the target adjacent lanes [13]. Moreover, the driver consciousness takes into consideration the surrounded vehicles velocity rather than their accelerations. In addition, our suggested model adds a mean of desire to represent the willingness to change lane, where the driver can initiate a lane change if the front vehicle brakes him from achieving his desired speed, which is the speed that IDM estimates for each vehicle. Our new model respects an optimal safety distance to be left as a gap between two successive vehicles on a highway. This safety distance is calculated according to the 3_second rule [14], which is the distance that the back car can traverse in 3 second and this could be calculated according to the following motion equation:

$$3_second\ rule\ distance = 3\ sec * back\ car\ velocity \quad (3)$$

Also, our model sets the minimum distance required to avoid collision with the preceding vehicle in case of perfect conscious driver is the passed distance while applying the maximum deceleration which value is located within the range [7, 8]m/s² [15] and could be calculated according to the following motion equation:

$$minimum\ distance = \frac{car\ velocity^2}{2 * maximum\ deceleration} \quad (4)$$

A new politeness factor p is proposed here, and is used to define the reference gap, which is a desired distance to be left by the driver while lane changing process is being performed, this factor takes a value within the range [0, 1] and determines the reference gap which must take a value within the range [minimum distance, 3-second rule distance] according to the following equation:

$$Reference\ Gap = p * (3_second\ rule\ distance - minimum\ distance) + minimum\ distance \quad (5)$$

The new simulator tries to make lane changing to the left side first then if no possibility found it tries to check the right side and follows the following conditional Algorithm:

if((velocity of $v_s >$ velocity of v_f **and** $Gap\ f <$ distance according to equation (5)) **or** (velocity of $v_s \approx$ velocity of v_f **and** velocity of $v_s <$ desired velocity)) **then**

if(($Gap\ af >$ distance according to equation (5)) **or** ($Gap\ af >$ minimum distance **and** velocity of $v_s <$ velocity of v_{af})) **then**

if(($Gap\ ab >$ distance according to equation (5)) **or** ($Gap\ ab >$ minimum distance **and** velocity of $v_s >$ velocity of v_{ab})) **then**

if($Gap\ b >$ distance according to equation (5) **or** velocity of $v_s >$ velocity of v_b) **then**

Do lane changing

We refer to this new model integrated with IDM-IM as IDM-RLC (*Intelligent Driver Model with Realistic Lane Changes*).

VI. PERFORMANCE EVALUATION

In this section, the study of the impact of the IDM mobility model lane changing algorithms on the performance of VANETs routing protocols is introduced.

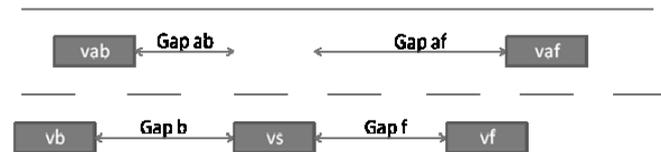


Figure 1. General snapshot of vehicles positions on a highway with two lanes:

- 1- vs: subject vehicle, vb: vehicle at back, vf: vehicle at front, vab: vehicle at adjacent back, vaf: vehicle at adjacent front.
- 2- Gap f: Gap at front, Gap b: Gap at back, Gap af: Gap at adjacent front, Gap ab: Gap at adjacent back.

C. Simulation Setup:

In order to evaluate the impact of IDM's lane changing models MOBIL and the new algorithm on the performance of AODV routing protocol we used VanetMobiSim framework [10]/NS-2.33 [16] simulation environment. In all simulations the source and destination nodes are static and the distance between them is located within the range [1.5, 2]km. In our simulated scenario, vehicles travel in a 4000 m X 4000 m highway topology that includes few intersections managed by stop signs. The roads created in the simulation have four lanes per direction and vehicular movement occurs on a single direction in each lane.

The minimum speed of the vehicle is 80km/h and the maximum speed is 120km/h, the Maximum Safe Deceleration is 7.5m/s^2 [15] and the Safe Headway Time is 0.5s, other mobility parameters are given in Table 1. By aid of NS-2 the nodes were enabled to communicate with each other using IEEE 802.11 MAC operating at 2 Mbps, other simulation parameters are given in Table 2. For all simulation results in this paper, each experiment with same number of vehicles is repeated five times on five different topologies, starting with 60 vehicles and increased by 20 vehicles for every other experiment. We repeated each experiment on five different topologies after we find that the statistics on these topologies are sufficiently close.

D. Metrics:

- Average end-to-end Delay: It refers to the time needed for a packet to be transmitted across a network from source to destination, and this metric describes the packet delivery time. The lower average end to end delay the better the network works, we studied this metric against both nodes number and politeness factor.

Table 1
MOBILITY MODEL PARAMETER

Parameter	Value
Maximum Acceleration	0.6 m/s ²
Comfortable Deceleration	0.9 m/s ²
Vehicle Length	5 m
Politeness Factor	Constant at 0.5 for first type of experiments and variable for the second type of experiments, while its impact is being studied
Jam Distance	2 m

Table 2
NS-2 PARAMETERS

Parameter	Value
Simulation Time	1000 s
Channel Type	Wireless Channel
Antenna Type	Omni Directional
Propagation Model	TwoRayGround Model
Transmission Range	250 m
Traffic Type	CBR
Data Payload	512 Byte/Package
Packet Rate	1 Packet/Sec

- Packet Delivery Ratio – it represents the ratio of overall received packets by the destination node over the overall sent packets by the source node. The higher packet delivery ratio the better the protocol performs. Also here we studied this metric against both nodes number and politeness factor.
- Number of Performed Lane Changing Maneuvers: This evaluates how the model does approach the reality.

Also we studied the effect of politeness factor on the end-to-end delay and PDR for both IDM-RLC and IDM-LC, here we fixed the nodes number to 100 and started to increase the politeness factor from 0 to 1.

E. Analysing Results:

For the three models IDM-RLC, IDM-LC and IDM-IM Fig 2. which describes the end-to-end delay against the number of nodes, shows that the greater the number of vehicles the higher the performance of VANETs is. Moreover, Fig 3. shows the effects of the changes of politeness factor values, which affects the lane changing decision for IDM-LC according to inequality (1) and for IDM-RLC according to Eq. (5), on end-to-end delay for both IDM-RLC and IDM-LC, this factor doesn't affect end-to-end delay too much and although the conceptual differences between politeness factors for both models, they show a proximity of effect on end-to-end delay. Fig 4. which describes the Packet Delivery Ratio (PDR) against the number of vehicles shows that the greater the number of vehicles the higher the performance of the VANETs, Fig 5. shows the effects of the changes of politeness factor values on PDR, this factor hardly affects the PDR and thus the network connectivity as well, but also here we see a proximity in both models concerning politeness factor. The effect of node number on these two performance metrics makes sense since the connectivity of the network increases as the number of nodes increases, so its performance increases as a result. Moreover, these two metrics show that the three models are close to each other and the performance is barely affected by the lane-changing maneuvers when the politeness factor value is fixed for both IDM-RLC and IDM-LC. In fact this is the case because the experiments are tested on highway topologies with no congestions, continuous traffic and high speed vehicles, which make the lane-changing factor has limited effects. However; the performance is obviously affected by the driver's politeness and the value 0.3 is the best value, which increases the PDR and decreases the end-to-end delay. The big difference between IDM-RLC and IDM-LC is shown in Fig 6., which describes the number of lane-changing maneuvers done by both models, and this metric shows how the model reflects the reality. For instance, during about 16 minutes of simulation, for IDM-RLC at nodes number 100 the mean value of left lane-changing maneuvers is about 120 and 60 for right maneuvers while IDM-LC for same number of nodes the mean value of right lane-changing maneuvers is about 800 and 500 for left maneuvers. This shows that IDM-RLC is much more closer to reality concerning the number of lane-changing maneuvers according to [17] and [18] after

taking into consideration the parameters adaptation, knowing that our model gives the advantage to left lane-changing maneuver whereas IDM-LC gives it to right maneuvers.

VII. CONCLUSION

With this study we introduced a new lane changing algorithm trying to simulate the behavior of the real world driver on the highway, the new algorithm is integrated with IDM-IM producing a new model which is compared with IDM-IM as well as IDM-LC. Many more details and fields should be studied to improve this model such as mandatory lane changing, urban details and some advanced methods to collect information and behave accordingly. We aim to introduce a comprehensive accurate model for human behavior on the road, which will be an infrastructural product for all future VANETs researches.

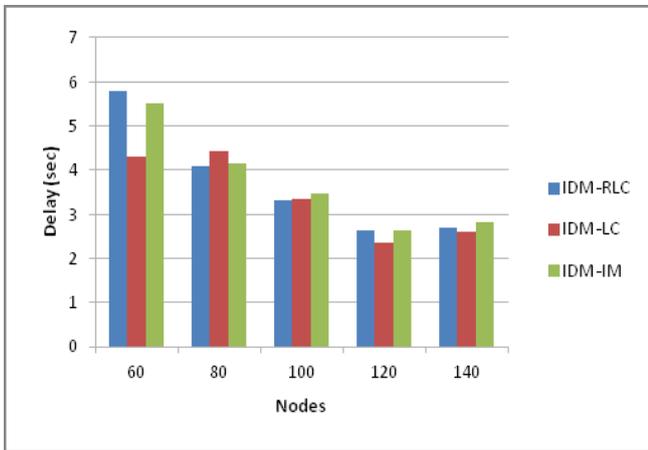


Figure 2. End-to-End Delay vs Number of Nodes

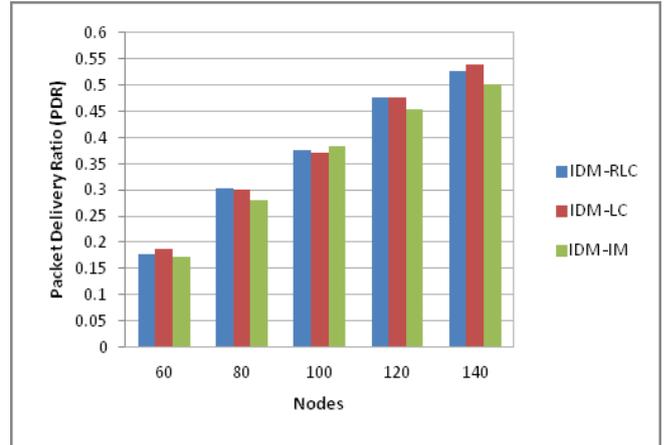


Figure 4. PDR vs Number of Nodes

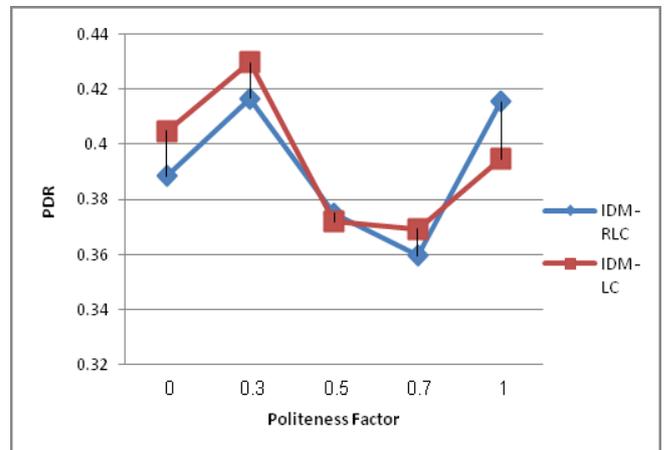


Figure 5. PDR vs Politeness Factor

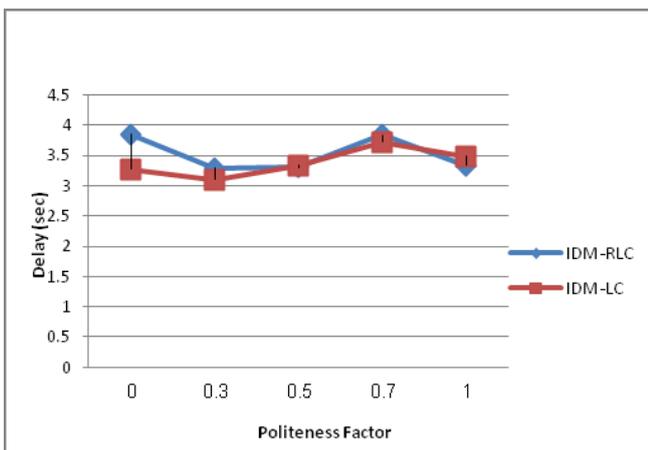


Figure 3. End-to-End Delay vs Politeness factor

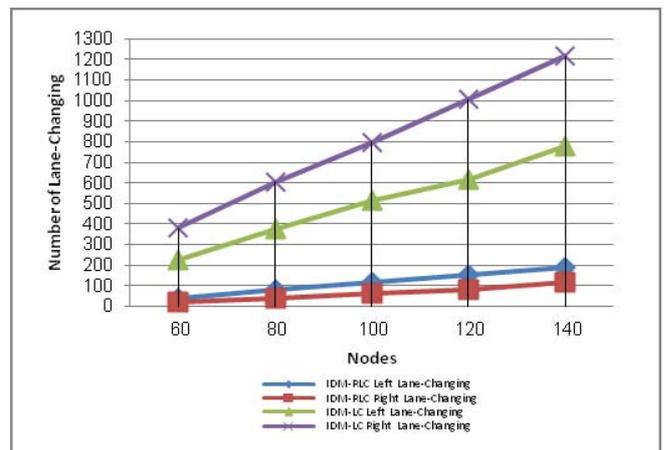


Figure 6. Lane-Changing Maneuvers vs Number of Nodes

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