Vehicular Ad-hoc Network Application for Urban Traffic Management based on Markov Chains

Ahmed Adart¹, Hicham Mouncif², and Mohamed Naimi¹
¹Faculty of Sciences and Technologies, Sultan Moulay Slimane University, Morocco
²Polydisciplinary Faculty, Sultan Moulay Slimane University, Morocco

Abstract: Urban traffic management problems have taken an important place in most of transportation research fields, hence the emergence of vehicular ad-hoc network (VANET) as an essential part of the intelligent transportation system (ITS), that intervenes to improve and facilitate traffic management also control as far as improve global driving experience in the future. Indeed, the concept of smart city or city of future becomes a new paradigm for urban planning and management, it considered as a complex system made up of services, citizens and resources. On the other hand, ITS concept is implemented to deal with some problems as though traffic congestion, energy consumption and property damage and human losses caused by transport accidents. In this paper we propose an approach for urban traffic management in smart cities based on markov chains implementing all vanet’s technology units to optimize traffic flow simultaneously with real time monitoring of vehicle in urban area from its starting point to the destination.

Keywords: Vanet, smart city, intelligent transportation system, markov decision process, markov chains.

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1. Introduction
In the recent decades the huge usage of vehicles in personal or common transportation has been taken a largest part of attention by academic researchers, industry leaders and governments because of the increased number of road users, which causes frequently road accidents and property damages. Furthermore, the urban traffic management requires the integration of new suitable technologies of communication and control to improve the traffic quality in term of security likewise management and real time monitoring, that’s why researchers get involved in.

Urban traffic congestion problem is considered as a major challenge to deal with in smart city due to huge number of vehicles, for example according to the statistics of Moroccan’s Ministry of equipment, transport and logistics, we note that from 2006 and 2014 the evolution of fleet in circulation has increased by 60.1% while the large city take great percentages [11]. In addition traffic congestion contribute to natural degradation by its responsibility for gas emission especially Carbon Dioxide (CO2).

Intelligent Transportation System (ITS) [7] concept deployed in smart city to solve problems denoted before, it covers multiple fields such as urban management, civil engineering science and communication technologies which include vehicular ad-hoc networks that contains Vehicle to Vehicle (V2V), Vehicle to Infrastructure (V2I) and hybrid communications [3].

Smart city concept services comprise more than those offered by the utilities. Thus, other services that can be improved under smart city paradigm endorse those provided by public safety agencies such as police, ambulance and fire-fighters… in addition of public transport systems as metros, buses and others, garbage collection and recycling services as far as public health system (hospitals and clinics), etc., [5].

2. Previous Work
The vehicular traffic in the whole world especially over urban areas, has taken an important attention recently. Indeed, it’s one of the most popular themes that has been discussed using Vehicular Ad-hoc networks, the aim of too many works in literature, is how to manage traffic in urban areas as well as avoid getting stuck in congestion especially in traffic’s peak hours, by predict congestion level and suggest the most suitable path depending on travelling time and distance which are grouped as markov chain’s parameters. We introduce in this paragraph a brief review of previous work related to our problematic.

Yeon et al. developed in their work a model for travel time estimation on a freeway using Discrete Markov Chain (DMC) [20], based on estimating travel time in spite of the instantly change of congestion level. Where Antoniou et al. [2] present in their paper a methodology for identification and short term prediction of traffic state which combines variable length markov chain, model-based clustering and nearest neighbour classification. An overview of traffic modelling advancements and approaches,
issues of route guidance and information systems as far as specific road and motorway network control systems are presented as an ITS and traffic management by Papageorgiou et al. [13]. Sun et al. [16] developed a method for short term traffic flow forecasting using sampling markov chain with incomplete data by modelling the traffic flow as high order markov chain, while the transition probability to transit from one state to other is approximated by Gaussian Mixture Model (GMM) [16]. In other hand, a markov chain approach towards dynamics of vehicular traffic characteristics method presented by Olaleye et al. [12] focused on traffic management in the urban intersections also short and long-term daily traffic prediction for incoming and outgoing traffics in order to reduce pressure on intersections. Abdel Hafeez et al. [1] presented their analytical model with the intention of performance analysis and enhancement of the DSRC [17] for Vehicular Ad-hoc Network (VANET) safety applications based on several factors such as average number of vehicles in the range of the transmitter, distribution of vehicles on road and the impact of mobility on the link availability between the transmitter and the receiver [1]. To apply any new approach that has a relation with vehicular ad-hoc network, researchers decide to use a good simulator in order to validate their works, a realistic vehicle tracking and infotainment service provisioning in vehicular networks is presented using VanetSim [8] including its characteristics for both V2I and V2V communications.

3. Vehicular Ad-hoc Network in Smart City

Communications deployed to VANET’s networks can be applied to an existing telecommunications infrastructure, or take place directly between vehicles to improve driving, the management and operation as well as to bring new services to users. Furthermore, these applications can be classified into two categories: one dedicated to the road safety called oriented vehicle (alerts in case of accidents, alerts for abnormal slowdown, jams, parking lots, collaborative driving,) and other one dedicated to comfort applications called user-oriented (internet access, network games,..).

The VANET is the core of ITS [7] with the primary objective: ensure the road security and the flow of data between vehicles in real time. We can define two categories of equipment: Internal to vehicles (On Board Unit: OBU) [15] and external (Road Side Unit: RSU). The “OBU” is an installed unit in vehicles that can record, calculate, locate and send messages over a network interface. In the other hand, the “RSU” [15] is a placed unit on roadsides which can inform nearby vehicles while disseminating traffic and weather conditions, or those specific to the road (maximum speed, overtaking permission, etc.,). They can also play the router role between vehicles. These devices form a system called Dedicated Short Range Communication (DSRC) [9].

As shown in the Figure 1 below, many types of architectures exist to facilitate communication between all network’s part, we can find inter-vehicles communication or V2V, vehicle to roadside communication or V2I and hybrid communication that rely both of the two precedent architectures. As shown in the Figure 1 above, many types of architectures exist to facilitate communication between all network’s part, we can find inter-vehicles communication or V2V, vehicle to roadside communication or V2I and hybrid communication that rely both of the two precedent architectures.

![Figure 1. Vanet's architecture components.](image-url)
location and direction to make a good decision. The approach is to use information provided from near RSU that has already the path from EV’s source to destination and compare with its path, so if there is a match in the present section, the road user must make a way.

- **Avoidance of Traffic Jams**: To avoid traffic jams in urban areas both of communications are necessary for information’s gathering to know the level of road congestion before arriving to the next sub-path to destination, if that is the case road user must decide which section is better based on statistics given by near RSU on road.

- **Warning of Road Works**: In urban areas we frequently find construction sites and temporary maintenance working areas on road, that affect the quality of traffic also cause accidents and road congestion, so the communication between infrastructure and vehicles is the solution to inform vehicles in its scope varied information like road works, parking positions, restrictions, instructions or other advises.

### 4. Markov Chains for Urban Traffic Management

#### 4.1. Definition

Markov decision processes [14] are defined as controlled stochastic processes satisfying the Markov property, assigning rewards to state transitions. Are defined by a tuple \((S, A, T, P, R)\) where \(S\) is the state space within which the process \(A\) is the space of actions that control the dynamics of the state, \(T\) is the space of time, \(P()\) is the transition probabilities between states, \(R()\) is the reward function of the transitions between states. \(T\) the field of decision steps is a discrete set, considered as a subset of \(N\), which may be finite or infinite and constant throughout the process.

The transition probabilities characterize the dynamics of the system status. For a fixed share, \(P(s'|s, a)\) represents the probability that the system goes into the state after executing the action \(a\) in state \(s\). The distributions \(P()\) satisfy the fundamental property that gives its name to the Markov decision process considered in Equation (1) below:

\[
P(S_{t+1} | s_0, a_0, s_1, a_1, \ldots, s_t, a_t) = P(s_{t+1} | s_t, a_t)
\]

Let \(A(i)\) all possible actions in state \(i\), can be defined by:

\[
A = \bigcup_{i \in S} A(i)
\]

Let \(P\) the transition function describing the dynamics of the environment:

\[
P: E \times A \times E \rightarrow [0,1]
\]

\[
(i,a,i') \rightarrow P(i,a,i') = P[i_{t+1} = i', i_t = i, a_t = a]
\]

Where \(R\) is the reward function defined by:

\[
R: E \times A \times E \rightarrow IR
\]

\[
(i,a,i') \rightarrow R(i,a,i') = E[\tau^t]_i = E[i', i_t = i, a_t = a]
\]

#### 4.2. Environment Representation

The model that will be used to represent the environment is one of the grid layout showed in Figure 2, in which the environment is fully discretized in a regular grid whose size roughly corresponds to that of the urban road networks.

A transition probability may be associated with each element of the grid. The advantage of such representation is that it directly uses the sensor data (RSU) fixed at intersections of the sections of the grid, in order to update the transition probabilities of the vehicle connected to the same RSU.

![Figure 2. Example of real grid urban road network.](image)

Each RSU mentioned by red spots covering an area of intersection of two or more sections communicates with passengers vehicles while they are still within reach of V2I communication, if they get the information from the vehicles coming from the intersection as a V2V communication.

#### 4.3. Definition of Transition Probabilities

Consider a dynamic system that is observed at moments \(t = 1, 2 \ldots\). At any moment \(t\) the process state is denoted by \(X_t\), where \(X_t\) is a random variable with values in a set of states \(E\). If process is in state \(i\), a controller chooses the action a where:

\[
a \in A(i) = \{1,2, \ldots, m(i)\}
\]

The action selected at time \(t\) can be considered as a random variable \(A_t\). If the system is in state \(i\), and action \(a\) is chosen, then regardless of the history of the process, the result as follow:

- \(R_{ia}\) is a reward acquired immediately.
- The system switches to another state \(j\) with a transition probability:

\[
P(i,a,j) = P_{iaj}
\]
The probability of going from state $i$ to state $j$ in $n$ time steps is:

$$P_{ij}^{(n)} = P(X_n = j | X_0 = i)$$  \hspace{1cm} (7)

Where:

$$P_{ij} = P(X_{k+1} = j | X_k = i)$$  \hspace{1cm} (8)

As defined in Equations (6), (7), and (8) the $n$-step transition probabilities satisfy Chapman–Kolmogorov [10] equation, that for any $k$ such that $0 < k < n$ in a state space $S$ of markov chain:

$$P_{ij}^{(n)} = \sum_{r \in S} P_{ir}^{(k)} P_{rj}^{(n-k)}$$  \hspace{1cm} (9)

### 5. Proposed Approach and Results

#### 5.1. Approach and Proposed Algorithm

In this section, we will try to treat the navigation problem of vehicles equipped with OBU in a random unknown urban environment that undergo a number of constraints from source to destination, such as road congestion, emergency transportation priority or inactive sections of road because of work construction or maintenance.

**Algorithm 1: Approach for urban traffic management**

Data:
- Vehicle’s initial position.
- Destination’s position.

1- Put all positions in the free states.
2- Put the destination position to the goal state.
3- Detect link’s states that surround the requested RSU.
4- Update the observed link’s states.

for $k$ times do
5- Calculate the optimal strategy.
for $k'$ times do
6- Vehicle movement to next step after executing the optimal action.
7- Detect link’s state surround requested RSU.
8- Update observed link’s states.

Until reach destination or instant trouble

The initial position of active vehicle and its destination is known by the nearest RSU, while the same representation of urban grid network showed in Figure 2 will be used without knowing other links state treated by other RSU in the grid. It’s assumed that the vehicle can detect the state of links surround the RSU using the closest RSU’s calculation.

The first approach (Algorithm 1) will be used to assume that in the beginning all link’s state surround an RSU are free i.e., the three or four sub paths from the closest RSU to the next one that the vehicle may use it to reach its destination, then the RSU calculates the optimal strategy with the Value Iteration [4] algorithm by introducing always the final destination as stopping criterion. After it sends results to the vehicle in order to move in the optimal trajectory until arriving to next intersection and go through the same procedure till the destination requested initially.

The main advantage of grid urban road network is that vehicles can be controlled through four actions: move forward, turn right, and turn left or return to the last intersection as shown in the Figure 3. Where red spots are road side units located between every road intersections, blue arrows showing the possible path that can be taken by vehicles after getting the right calculations results from the closest RSU.

![Figure 3. Vehicles position in urban road network grid.](image)

These actions can be easily programmed as instructions on RSU’s to inform active vehicle. We can even add pause or stop action if there is no path to destination or the appearance of an obstacle on the way, also if there is a critical weather’s condition.

According to the (Algorithm 1), we can simulate the approach by a sequence diagram (Figure 4), which represent the procedure to guide a vehicle equipped by an OBU since his departure to the requested destination, ensuring vehicular to infrastructure communication as far as between infrastructure and database server.

![Figure 4. Sequence diagram of proposed approach.](image)

#### 5.2. Simulation Tool Description

During our work, we decided to implement our approach compared to existing approaches especially Dijkstra algorithm in the VanetSim, which is an open source simulator as well as one of the most used software for similar studies. It is an intuitive tool that...
aims to ensure the vehicular communications in order to analyse the security and privacy concepts in VANETs as far as simulate an important number of road vehicle’s type and scenarios. By using VanetSim we were able to evaluate our proposed approach to improve traffic management in urban areas especially in road intersections.

This simulator like any other one, covers a several features to researchers in this field, moreover it provides other availabilities that distinguish it from other simulation software, such as [18]:

- **Realistic Maps**: vanetSim has the ability to simulate traffic on real road maps due to its importation tab in the graphical interface for importing maps from OpenStreetMap project [19]
- **Extensibility**: the code source structure supports easy adaptation and extension of features to add or edit any simulation depending on user’s need.
- **Platform-Independence**: the simulator has been developed in java 6, so it supports and run on most operating systems and hardware platform.
- **Security**: vanetSim offers to software’s user the possibility to verify the security concepts thanks to its strong focus on security field.
- **Visualization**: vanetSim guaranteed a good use due to its graphical interface which is composed with: Simulation, edit and report tabs as far as many integrated components.
- **Micro-Simulation**: vanetSim offers a realistic simulation due to the possibility to simulate each vehicle individually and report any information depending on selected vehicle on road.
- **Extensive Scenario and Map Editor**: possibility of creation and alteration of maps as well as scenarios creation and edition are guaranteed.
- **Integration of Privacy-Enhancing Technologies**: For empiric investigations, four techniques to improve privacy in vehicular ad hoc networks: mix zones, promix zones as well as silent periods and slow are implemented [18].

### 5.3. Approach Illustration and Results

We suppose that the environment seen previously is a macro-model composed of sixteen intersections, each one of them is a macro-state. In our case we are going to work with 16 states, each state has three possible actions as an orientation’s direction mentioned previously in Figure 3.

If we suppose that the environment to be modelled is a directed graph from the source to the destination with just two actions, we obtain the following graph (Figure 6) with transition probabilities between each connected state:

![VanetSim main graphical interface.](image)

![Modelled graph with transition probabilities.](image)

We want to minimize travelled distance by a vehicle from its source to destination, however the travelled distance depends on the position of the intersections, while the choice of the right intersection to cross depends on action to execute. The data for problem modelling are the following:

- The states are: [1, 2, 3…..16].
- The possible actions are: move forward (1), turn right (2), turn left (3).
- The reward function illustrated in Equation (11).

Indeed, to solve reaching overall goal problem, active vehicle must reach the local goal i.e., reaching the next macro-state that is the closest in term of distance to the final destination, after determining of the shortest path from source to destination using Dijkskra [6, 19] algorithm mentioned in Figure 7 as follow:

![Optimal trajectory obtained using Dijkstra algorithm.](image)

To calculate the various transition probabilities for each road to next intersection in our approach, we
conducted to use the proposed transition probability Equation (10).

\[
P_{ij} = \begin{cases} 
0 & \text{if no path exist} \\
1 & \text{if only one path or goal achieved} \\
\frac{1}{m} \sum_{k} \frac{C_k}{\sum_j C_j} & \text{if not}
\end{cases}
\] (10)

The proposed transition probability is based in our case on three constraints: Traffic density, Weather condition, Road state. Where:

- \( C \): set of used constraints.
- \( m \): number of related sub-path associated to RSU.

The reward function mentioned in Equation (11), is positive if there is a path to the good macro-state, while it’s equal to -1 if there is a way to bad macro-state or even an obstacle. Initially, more the macro-state is closer to the goal, more the reward function should have a great value. Whereas if the transition function is deterministic, a gain function provides optimal policies according to shortest path’s criterion.

\[
\pi(s, a, s') = \begin{cases} 
+1 & \text{if path to macro-model goal} \\
+r & \text{if path to good macro-state} \\
-1 & \text{if path to bad macro-state} \\
-r & \text{if exist an obstacle in path}
\end{cases}
\] (11)

Where \( \pi \) is the reward function obtained while vehicle moves from state \( s \) to next state \( s' \) executing the action \( a \). reward function can determine local and final goals to achieve. “s” is the current state or macro-state while “s’” is the next state or macro-state and \( r \) is a reward unit that depends on distance to final destination. We obtain as a result the optimal trajectory from source to destination (Figure 8) with all actions to execute during the trip.

The graphs (Figures 9, 10, 11, 12, and 13) below show a comparison between our approach and Dijkstra algorithm after several simulations in order to obtain average values, including the five parameters used in our simulations, which are: travelled time, delay expressed in minutes, Travelled distance expressed in kilometres, congestion rate, finally, the number of vehicles in tail.

6. Conclusions and Future Perspectives

The increased demand of road traffic control due to new conception of smart cities and huge number of road users necessitate more researches in traffic engineering practice also in integrated network technologies. Our paper focused on urban traffic management based on vanet technology and simulated as a markov decision process to help road users that have vehicle equipped by an OBU to reach their destinations rapidly avoiding road congestion as far as facilitate traffic control using V2I communication.

Unfortunately, our approach doesn’t cover all complex scenarios, we are stuck to a simple case of modelling. However, it can be extended by using other markov decision process algorithms to enhance our approach which provide a way to improve urban traffic management and fluidity.

As future work, a new amelioration of proposed approach by including other modelling decision process for strategies enhancement and road user’s real monitoring.

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Figure 11. Proposed approach vs. dijkstra approach congestion rate.

Figure 12. Proposed approach vs. dijkstra approach vehicles in tail.

Figure 13. Proposed approach vs. dijkstra approach travelled delay.

References


Ahmed Adart obtained his Master degree in computer science in 2014 from the faculty of Science and Technology, Beni Mellal. Currently, he is a PhD student at the Center of Doctoral Studies in the faculty of Science and technology of Beni Mellal. His research interest includes wireless networks, vehicular ad hoc network and network security, intelligent transportation systems algorithms and applications and security protocols.

Hicham Mouncif received his BS degree in mathematical and computer science from the Faculty of Sciences and technology Beni Mellal in 1999, and the MS degree in mathematical and computer science from the University of Ben Msick, Casa-Blanca in 2001. He received his PHD in computer science from the Faculty of Sciences and technology Mohammedia, Morocco in 2005. He is currently, a professor at the Polydisciplinary Faculty, University Sultan Moulay Slimane, and his research interests include special databases, manet and vanet security, intelligent transportation systems, algorithms and applications and mobile-GIS.

Mohamed Naïmi, is a professor of mechanical engineering at the Faculty of Sciences and Technics in Beni-Mellal, Morocco. Actually, he is the Associate Dean of the Polydisciplinary Faculty in Beni-Mellal. He received his national doctorate (INPL, Nancy, France) and a doctorate of state (Cadi Ayyad University, Marrakesh, Morocco), in 1989 and 2001, respectively. He is a teacher researcher, with the degree of higher teaching Professor as far as Director of the Flows and Transfers Modeling (LAMET) at the Faculty of Sciences and Technics of Sultan Moulay Slimane University (Beni-Mellal, Morocco). His research interests include natural, double diffusive and capillary convections in non-Newtonian fluids. He has published about 70 research papers in international journals.