

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

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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.

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 [1]. In addition traffic congestion contribute to natural degradation by its responsibility for gas emission especially carbon dioxide (CO₂).

ITS 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 [2].

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. [3].

2. 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 vehicular Ad hoc Network (VANET) is the core of ITS[5] 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) [4] 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. On the other hand, the "RSU" [4] 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 DSRC [6] (Dedicated Short Range Communication).

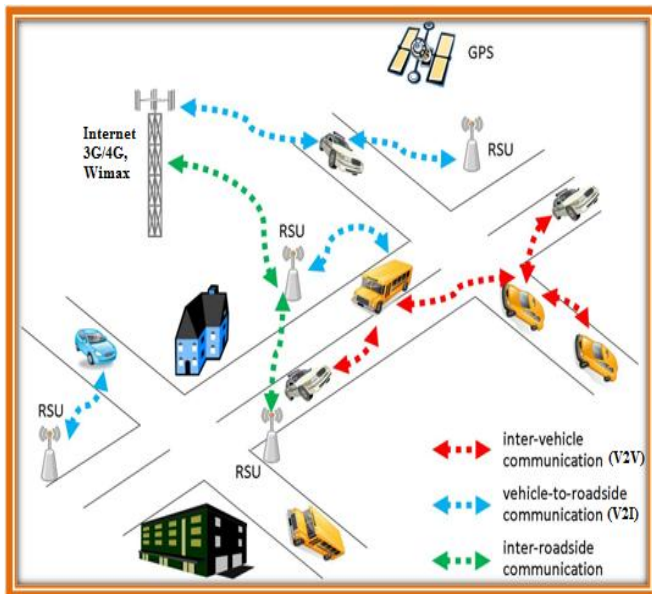


Figure 1 : Vanet's architecture components

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.

The VANET in a set of communicating entities organized according to communication architecture; the

architecture of vehicle to vehicle (V2V) which is a particular case of MANET. This type of communication is performing than a communication via an operator network. And the architecture of vehicle to infrastructure (V2I), whose network uses cellular gateways and wireless access points. It serves to the exchange between vehicles and infrastructure. A major objective of V2I is to avoid the traffic accidents. The hybrid architecture uses both approaches V2V and V2I [4].

The challenges and issues related to VANETs networks still need original and consistent solutions, namely the high mobility, signal attenuation, diversity of density and the security aspect which has a crucial importance.

Smart city approach comes to encompass many cases in each city to enhance daily lives based on technological researches that scientists achieve in recent years. Use cases that can be covered by smart city approach are:

- **Emergency transportation:**

Road users must make way for all emergency vehicles like ambulance or police cars after hearing the siren, but they don't know which way as a result the ignorance of its 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 advises.

3. Markov chains for urban traffic management

3.1 Definition

Markov decision processes [7] 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 $\mathbb{N}$, 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 here.

$$P(S_{t+1} | s_0, a_0, s_1, a_1, \dots, s_t, a_t) = P(s_{t+1} | s_t, a_t) \quad (1)$$

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

$$A = \bigcup_{i \in S} A(i) \quad (2)$$

And let P the transition function describing the dynamics of the environment:

$$P: E \times A \times E \rightarrow [0,1] \\ (i, a, i') \rightarrow P(i, a, i') = P[i_{t+1} = i' / i_t = i, a_t = a] \quad (3)$$

Where R is the reward function defined by:

$$R: E \times A \times E \rightarrow IR \\ (i, a, i') \rightarrow R(i, a, i') = E[r_t / i_{t+1} = i', i_t = i, a_t = a] \quad (4)$$

3.2 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

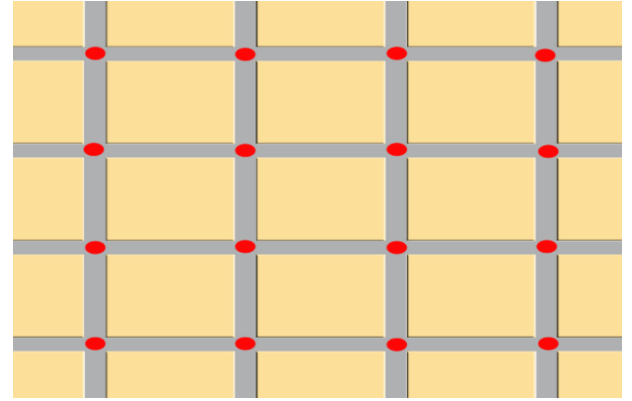


Figure 2: Urban road network grid

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.

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.

3.3 Definition of transition probabilities

Consider a dynamic system that is observed at moment $t = 1, 2 \dots$ 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:

$$a \in A(i) = \{1, 2, \dots, m(i)\} \quad (5)$$

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

$$p(i, a, j) = P_{iaj}$$

state j with a transition probability:

The probability of going from state i to state j in n time steps is:

$$P_{ij}^{(n)} = P(X_n = j | X_0 = i)$$

$$\text{Where: } P_{ij} = P(X_{k+1} = j | X_k = i) \quad (7)$$

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

$$P_{ij}^{(n)} = \sum_{r \in S} P_{ir}^{(k)} \cdot P_{rj}^{(n-k)}$$

4. Proposed approaches and results

4.1 Definition of transition probabilities

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.

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.

Algorithm 1:

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.

Repeat

- 5- Calculate the optimal strategy.

Repeat

- 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.

Until reach destination.

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 [9] 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 showed 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.

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.

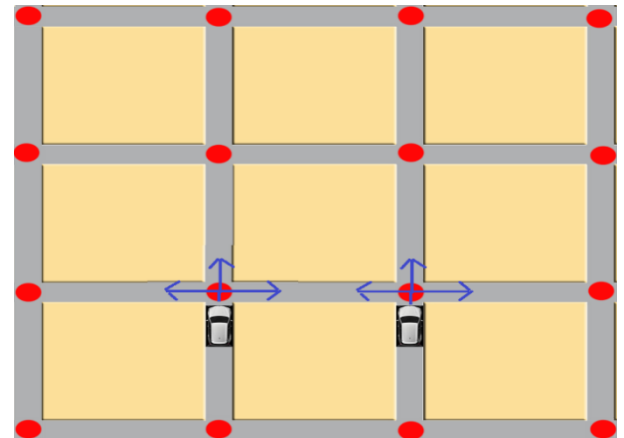


Figure 3: Vehicles position in urban road network grid

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.

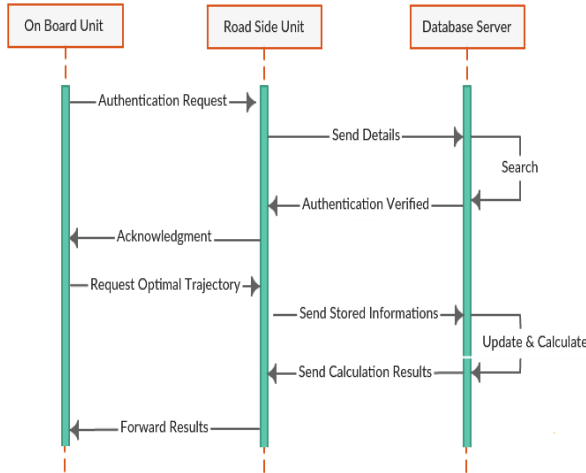


Figure 4: Sequence diagram of proposed approach

4.2 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 modeled is a directed graph from the source to the destination with just two actions, we obtain the following graph "figure 5" with transition probabilities between each connected state:

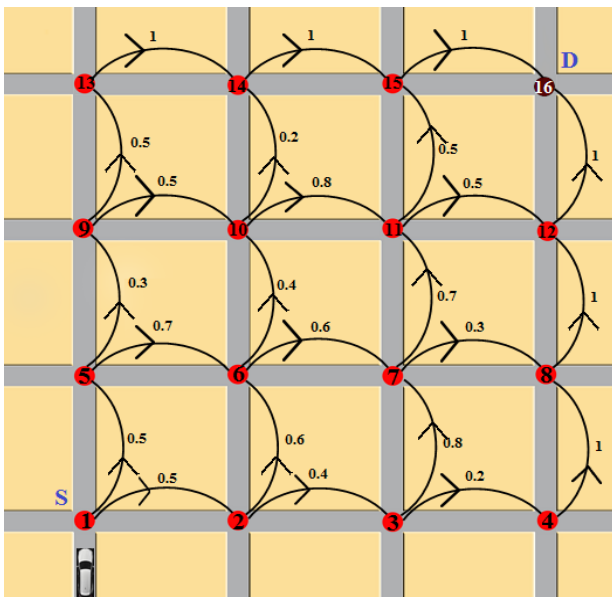


Figure 5: modeled graph with transition probabilities

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 modeling 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 (10).

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 Dijkstra [10, 11] algorithm mentioned in figure 6 as follow:

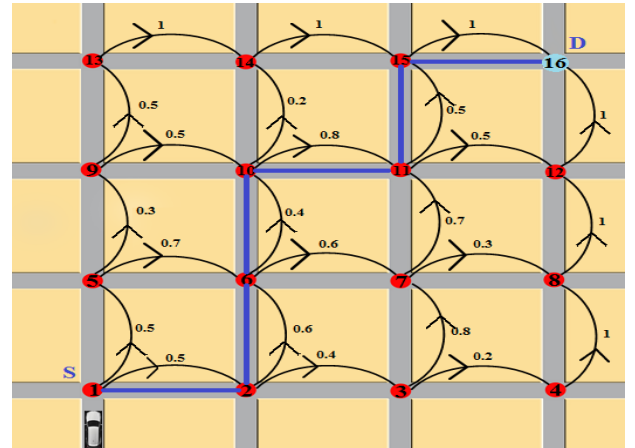


Figure 6: Optimal trajectory using Dijkstra algorithm

The reward function mentioned in equation (10), 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.

$$\pi(s, a, s') = \begin{cases} +1 & \text{if path to macro - model goal} \\ +r & \text{if path to good macro - state} \\ -1 & \text{if path to bad macro - state} \\ -r & \text{if exist an obstacle in path} \end{cases} \quad (10)$$

Where π is the reward function obtained while vehicle moves from state s to next state s'

executing the action **a**. reward function can determinelocal 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 7” with all actions to execute during the trip.

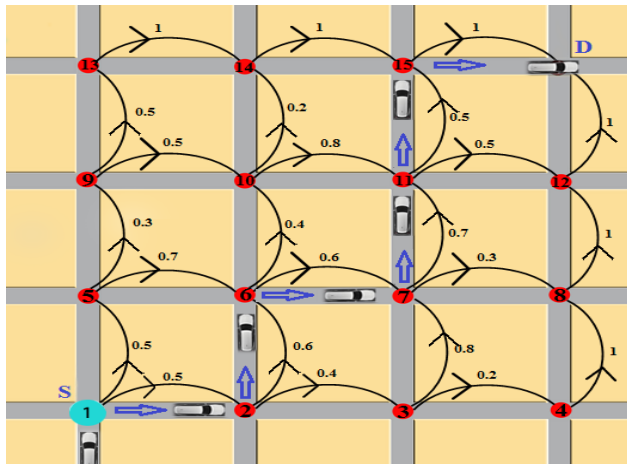


Figure 7: Optimal trajectory using proposed approach

Conclusion& perspective

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 modeling. 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 modeling decision process for strategies enhancement and road user's real monitoring.

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