PERFORMANCE EVALUATION OF AN ADAPTABLE inVANETS-BASED INTERSECTION TRAFFIC CONTROL

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ABSTRACT

With the recent advances in intelligent vehicles ad-hoc networks (inVANETs), the traditional traffic control problem at intersections is being revisited to cope with the future intelligent transportation systems. In this paper, we introduce the performance evaluation of a centralized inVANETs-based intersection traffic control protocol. Extensive simulations have been conducted using various real traffic scenarios to evaluate the efficiency and the dynamics of the newly proposed traffic control approach that gives the intelligent vehicles full autonomous control of crossing intersections using vehicle-to-vehicle and vehicle-to-infrastructure communications. Simulation results using the tools OMNet++, VEINS, and SUMO showed that the new approach is a viable alternative and addition to the existing traffic control approaches.

KEYWORDS

Smart cities, Intelligent Transportation Systems, Intersection Traffic Control, Distributed Algorithms, Intelligent Vehicles ad-hoc networks (inVANETs)

1. INTRODUCTION

An important part of Intelligent Transportation System (ITS) is the intersection traffic control, as it needs to adapt to the increasing number of congestions as well as emergencies and accidents (Wei 2014), (Srinivasan 2006), (Baras et al. 2017). Many applications for ITS were proposed such as collision avoidance, traffic surveillance which make the way to the next generation of smart cities. Numerous solutions were proposed to control intersections automatically. The conventional solutions mostly concentrated on improving the scheduling of the traffic lights to reduce congestion as well as increasing the vehicles flow on the intersections, (Chen 2010). The new approaches focus on more intelligent scheduling of traffic lights depending mainly on computational intelligence for example like evolutionary genetic algorithm (Chen 2010), (Zhao 2012), machine learning (Gokulan 2010), fuzzy logic (Qiao 2011), (Lertworawanich 2011), (Gokulan 2010), and neural networks (Wei 2014), (Qiao 2011). For more details the readers can read this survey (Bhatt 2010), (Hassan and Elhade¹ 2018), (Saeed and Elhade¹ 2017).

The insufficiencies were shown by Wu et al (Wu 2014) in this approach such as deciding the optimal time for the green light knowing the subtleties of the flow of the traffic. Moreover, the algorithms of computational intelligence consume time thus aren't suitable for real time traffic control. Advanced communication and sensing technologies were proposed in (Srinivasan 2006), (Lee 2010), (Zhou 2010) which are being used to allow real time traffic response for green light traffic control that uses a type of control strategy deduced from preselected logic rules and traffic data to schedule traffic lights. Another approach was the trajectory maneuver has been discussed in (Lee 2010), (Zhou 2010), (Tubaishat 2009), (Glaser et al. 2010). This approach is built on an intersection controller that handles the trajectories of the vehicles knowing the conditions of the nearby vehicles to prevent any possibility for an overlap. In this approach, the vehicles are able to move without the need to stop, and this leads to enhancing the system's efficiency. Numerous ways have been studied in order to calculate the ideal trajectories, such as fuzzy logic (Raravi 2007), merging (Dresner 2008), cell-based (Bulgannawar 1995), scenario-driven (Milans et al. 2010), global adjusting, and exception handling (Srinivasan 2006). There are some insufficiencies in the trajectory maneuver approach such as the trajectory calculation complexity and being reliant on a centralized controller causes this approach to be costly, and likely to single point of failure.

In this paper, we are going to evaluate the proposed novel adaptable centralized intersection control for intelligent transportation systems, which relies on inVANETs. The intersection control algorithm that is based on inVANETs contains two tasks: the vehicleTask, and the controllerTask. The two tasks work with each other using the exchange of messages to let the vehicles cross an intersection with no conflicts at all. This work is based on the centralized algorithm that was developed in (Wu 2014) that considers the existence of traffic controller that its role to give the privilege of passing the intersection to the vehicles requesting to cross. The centralized approach considers that if the controller gives the passing to a queue of vehicles on the intersection, then it waits until the release message is received from the last vehicle in the queue, or in real life situations there might be a delay for vehicles due to bottleneck congestion, or accidents, which make using this centralized approach impractical. The traditional scheduling of traffic light overcomes the situation by changing the lights to red for a certain amount of time to allow the vehicles to pass while resolving the situation. The adaptable inVANETs work proposes a solution to solve the weakness in the original centralized approach, which adapts this approach to real scenarios. In the controller-based approach, an algorithm for locks is being used to give or reject access to the intersection the waiting vehicles can cross the intersection when the controller has locked the lanes that are conflicting successfully. When a vehicle reaches the queuing area, it sends a request to the controller to lock the conflicting lanes. The controller, which manages the locks, will reply to the vehicle with a message to give it access to the intersection. The objective of the controller is to guarantee the efficiency of the mutual exclusion as well as maximize the number of vehicles passing in the intersection simultaneously. The paper is organized in this approach. In Section 2, we discuss preliminary definitions, and explain the system model. In Section 3, we discuss the algorithm, the messages, and other details of the new adaptable inVANETs-based intersection control. In Section 4, we discuss the application of algorithm in Abu Dhabi, and in Section 5 we discuss the performance evaluation results. In Section 6, we conclude the paper.

2. PRELIMINARY

The adopted system model was developed by (Wu 2014). Consider this example of an intersection having four directions (Figure 1), and the lanes are numbered from 10 to 17. The *core area* is the area of the small dashed square, and the larger area is the one called the *queuing area*. Each vehicle will have the state of *CROSSING* in the core area, and the state will be either *WAITING* or *QUEUING* in the queuing area. The rules of the traffic intersection state that the vehicles having crossing paths such as l_0 , and l_6 should pass the intersection mutually exclusively. These lanes are supposed to be *conflicting* and represented by $\propto$. The vehicles having non-crossing paths such as l_0 , and l_4 can pass the intersection at the same time. These lanes are considered to be *concurrent* and represented by $\approx$. Using this definition, we have $l_0 \propto l_6$, and $l_0 \approx l_4$. In (Wu 2014) the concurrency and conflict relationships were represented using a graph, which can be used with any type of intersection.

Figure 1. A Typical intersection

It is assumed that each vehicle has its own *ID* and is self-driven. The vehicles count on their sensors, and other devices for navigation, and collision avoidance. In addition, each vehicle is able to detect the core, and queuing areas' limits using the positioning system of the vehicle such as GPS, as well as sensors placed at the limits of the areas. Vehicles have devices for wireless communication that allow the vehicle to communicate in

vehicle-to-infrastructure communication or vehicle-to-vehicle communication. In addition, the vehicles are equipped with wireless FIFO channels. It is assumed that the message transmission is reliable, and the range of transmission is larger than the length of the queuing area. Therefore, all the vehicles in the queuing area creating a one-hop ad-hoc network, which allows any set of vehicles to directly communicate.

In Figure 2 you can see the transition of states of the vehicle. Any vehicle will start in the *IDLE* state if it's outside of the intersection area. The state of the vehicle will change when it enters the queuing area to *WAITING*. When the vehicle is in this state, it will request the access to the core area from the controller and waits for the approval from the controller. When the controller gives the access the vehicle, the state of the vehicles changes to *QUEUING*. The vehicles having the *QUEUING* state cross the core area in a first-in-first-out fashion. The vehicles that are delayed and cannot cross the core area in a specified certain time, their state will change to *WAITING* again. Moreover, the vehicle that change its position to another lane which is conflicting while being the *QUEUING* state, its state will also change to *WAITING*. Then the vehicle needs to send the request to cross again to the controller to cross the intersection. The vehicle state is changed to *CROSSING* when it enters the core area. Finally, when the vehicle crosses the core area, and leaves, the state is changed to *IDLE*.

Figure 2. Vehicle State transition diagram

In (Wu 2014), they showed the intersection traffic control like a vehicle mutual exclusion for intersections (VMEI) problem, which says that at the intersection, each vehicle sends a request in whatever direction it desires. Therefore, the vehicles queue up at the equivalent lanes in the queuing area. The vehicles can pass the intersection in the same time if they are in the same lane or concurrent lanes. Also in (Wu 2014), the correctness properties are summarized in order to give any solution to the problem as in the terms of *safety*, *liveness*, and *fairness*, shown below.

Safety (mutual exclusion): at any given moment, in the core area, no conflicting vehicles can be in it. If there was more than one vehicle, these vehicles should be concurrent with each other.

Liveness (deadlock free): any vehicle in waiting state will be given the access to the core area in a finite time.

Fairness (starvation free): each vehicle should be able to pass, after a finite number of vehicles pass the intersection, and all the lanes share the same priority.

3. AN ADAPTABLE INVANETS-BASED INTERSECTION TRAFFIC CONTROL ALGORITHM

In (Wu 2014), the first algorithm that was developed to solve the VMEI problem was called the centralized algorithm. It considers the existence of a controller which its role to give privilege to requesting vehicles to pass the intersection. It is shown that the algorithm mentioned in (Wu 2014) does not satisfy the properties of safety, liveness, and fairness. There is an error in the locking mechanism that does not satisfy the safety property. This algorithm considers the existence of traffic controller that its role to give the privilege of passing the intersection to the vehicles requesting to cross. The centralized approach considers that if the controller gives the passing to a queue of vehicles on the intersection, then it waits until the release message is received from the last vehicle

in the queue, or in real life situations there might be a delay for vehicles due to bottleneck congestion, or accidents, which make using this centralized approach impractical. The traditional scheduling of traffic light overcomes the situation by changing the lights to red for a certain amount of time to allow the vehicles to pass while resolving the situation.

The adaptable inVANET work proposes a solution to solve the weakness in the original centralized approach, which adapts this approach to real scenarios. In the controller-based approach, an algorithm for locks is being used to give or reject access to the intersection the waiting vehicles can cross the intersection when the controller has locked the lanes that are conflicting successfully. When a vehicle reaches the queuing area, it sends a request to the controller to lock the conflicting lanes. The controller, which manages the locks, will reply to the vehicle with a message to give it access to the intersection. The objective of the controller is to guarantee the efficiency of the mutual exclusion as well as maximize the number of vehicles passing in the intersection simultaneously.

The controller preserves one lock per lane, therefore, for the intersection shown in Figure 1 eight locks are going to be used. Since the safety property was not satisfied by (Wu 2014), the locking mechanism was improved and correcting, and still relies on the same idea of locking two conflicting lanes.

Table 1. The lane-locking scheme

Vehicle's lane	0	1	2	3	4	5	6	7
Lanes to be locked	0	1	1	0	1	2	3	1
	5	3	2	3	3	5	5	4
	7	6	7	5	4	7	6	7

The inVANETs-based intersection control algorithm consists of two parts: the *vehicleTask* and the *controllerTask*. The following representation $state_i$ which designate the state of the vehicle which has the state *IDLE*, when the vehicle is outside the area of intersection, the state *WAITING*, when the vehicle sent a request to the controller to cross the intersection and still waiting for the controller reply to cross, the state *CROSSING*, which shows that the vehicle is crossing the intersection area, and finally, the state *CROSSED* which shows that the vehicle crossed the intersection. $Lane_i$ represents the lane of the vehicle. *crossingLists* denotes the list of vehicles that the controller accepted their request message and is allowing them to cross the intersection. Any vehicle in that list can move and then cross the intersection area.

These five messages are exchanged between the *vehicleTask* and the *controllerTask*:

- *<REQUEST, i, lane_i>*: The vehicle *i* sends this message to the controller to indicate its lane and that it wants to cross the intersection.
- *<CROSS, lane, vehiclesList, duration>*: message sent by the controller to order waiting vehicles in *vehiclesList* to cross the intersection within the specified *duration*.
- *<DELAYED, i, lane_i>*: vehicle *i* sends this message to inform the controller that it failed in crossing the intersection within the specified duration.
- *<NEWLANE, i, lane_i>*: vehicle *i* moved into a new lane that conflicts with its old position.
- *<CROSSED, i>*: vehicle *i* informs the controller that it crossed the intersection.

3.1 VehicleTask Operations

In Figure 3 we show the main steps on the *vehicleTask* as it communicates with the *controllerTask*. When a vehicle *i* enters the queuing area it sends a request message to the controller *<REQUEST, i, lane_i>* to the controller to get permission to cross the intersection (Step 1.1), the vehicle *i* state updates to *WAITING* which means that the vehicle is waiting for the reply from the controller that gives the vehicle the access to the intersection. While the vehicle is waiting to get the access from the controller, the vehicle may transfer to another lane that is conflicting with the old position that was sent earlier to the controller, so in that case, the vehicle sends the message *<NEWLANE, i, lane_i>* to the controller to notify it about the change (step 1.5). Any vehicle *i* can be in the intersection area while crossing or outside of it after crossing or in the queuing area, and as a result of that, the vehicle state changes correspondingly.

When any vehicle *i* receives the message *<CROSS, vehiclesList>* and *i* is in the *vehiclesList*, only then the vehicle can cross the intersection. It was assumed in (Wu 2014) that when the controller grants the cross to a list of vehicles, the controller has to wait until it receives a message from the last vehicle in the list to confirm that every vehicle crossed which can lead to delays in real life scenarios if a slow driver is driving the vehicle or a congestion happened in the intersection. To solve this problem, a duration period was added, which is set by the controller after which the vehicles that are delayed will not get access to the intersection until the controller decides based on the waiting list. When this period elapses, any vehicle *i*, which was delayed and was not able to cross the intersection, this vehicle will receive the delayed message *<DELAYED, vehiclesList>* in order to be

notified by the controller that this vehicle has been changed to the waiting state again. In addition, in order to solve the situation where a vehicle may have changed its lane to a conflicting one after sending the *REQUEST* message, in the *CROSS* message, the lane that was given access to the intersection was added.

In (Elhadeif 2015), (Wu 2014), it was assumed that the last vehicle in the vehicles list to cross the intersection is the vehicle that will notify the controller by sending a message noted as *RELEASE*. When taking into consideration that the vehicles may get delayed and aren't able to cross the intersection in the specified period of time, the algorithm was changed to make the vehicle send the *CROSSED* message to the controller when it crosses the intersection (step 1.6), and in that way the controller will know which vehicles already crossed the intersection, and which vehicles were delayed because they will send the *DELAYED* message.

Algorithm 1 *VehicleTask*

Initialization //tasks performed by vehicle *i*

State_i = *IDLE*; *crossingList* = $\emptyset$;

CoBegin

1.1. Vehicle *i* enters the queuing area:

Send (*<REQUEST, i, lane_i>*, *Controller*);

oldLane_i = *lane_i*;

State_i = *WAITING*; // wait for message *CROSS* from Controller

1.2. Vehicle *i*'s GPS position changed:

if (*i*'s position in *IntersectionArea*) *State_i* = *CROSSING*;

else if (*State_i* = *CROSSING* & *i*'s position out
IntersectionArea)
State_i = *CROSSED*;

1.3. Receive (*<CROSS, vehiclesList>*) from controller:

if (*State_i* = *WAITING* & *i* ∈ *vehiclesList*) {
State_i = *QUEUING*;
crossingList = *vehiclesList*;
 Move and cross the intersection; }

1.4. Receive (*<DELAYED, vehiclesList>*) from controller:

if (*State_i* = *QUEUING* & *i* ∈ *vehiclesList*)
State_i = *WAITING*;

1.5. Lane change detected:

if (*State_i* = *QUEUING* & *oldLane_i* ≠ *lane_i*) {
 Send (*<NEWLANE, i, lane_i>*, *Controller*);
oldLane_i = *lane_i*;
State_i = *WAITING*; }

1.6. *State_i* = *CROSSED* //Vehicle *i* crossed the intersection:

Send (*<CROSSED, i>*, *Controller*);
State_i = *IDLE*;

CoEnd

Figure 3. The *vehicleTask* in VANETs-based intersection control algorithm

3.2 ControllerTask Operations

The *controllerTask* main steps are shown in Figure 4 *locks_i* represents the set of lanes that are going to be locked for vehicle *i* (refer to Table 1) and *locked* represents the set of lanes that are already locked by the controller at any certain point of time. When the controller receives *<REQUEST, i, lane_i>* from the vehicle *i* which is sending a request in order to cross the intersection (step 2.1), first, the controller examines if the set of lanes to be locked for this vehicle are already locked by the controller then at that time *i* is added to the *crossingList* of vehicles which are given the access to the intersection, and then the controller broadcasts the cross message *<CROSS, crossingList>* to the vehicles in the *crossingList* to notify them that they are able to cross the intersection. However, if the controller didn't lock any lane then vehicle *i*, and the other vehicles on concurrent lanes with vehicle *i* can cross the intersection. Else, in that case, the controller adds vehicle *i* to the *waitingList*. The controller also sets the *crossingTimer* to certain duration, and hence giving the access to the intersection for a period that is limited. Also, the controller may receive the new lane message *<NEWLANE, i, newLane>* from the vehicle that changed its lane. Then the controller updates its information. If the vehicle sending this message changed its lane to a conflicting one with the old one, which has been granted access to the intersection and is

in the *crossingList*, then the vehicle i is moved from the *crossingList* to the *waitingList*. (Step 2.2). When the controller receives the message *crossed* $\langle \text{CROSSED}, i \rangle$ which informs the controller that the vehicle i crossed the intersection, and after that the controller updates the information in the *crossingList*, and when it the *crossingList* becomes empty then the controller gives access to the intersection to the first vehicle in *waitingList*.

The controller uses the *crossingTimer* for the implementation of fairness property. The fairness property means that any vehicle will have the chance to cross the intersection after a finite amount of time (step 2.4). When the timer finishes, the controller examines first if there are waiting vehicles. If there is, the controller checks if the vehicles that were given access to cross the intersection crossed the intersection or not. If some of these vehicles were delayed the controller will send them the delayed message $\langle \text{DELAYED}, \text{crossingList} \rangle$ to notify these vehicles that they need to wait up until the next round. In order to manage the situation of a vehicle being currently in the intersection, then the timer waits for another *crossingDuration* before giving the access to other vehicles to cross the intersection. If there are no vehicles waiting then the controller extends the duration for crossing to delayed vehicles.

Algorithm 2 *ControllerTask*

Initialization //tasks performed by the controller

crossingList = *waitingList* = *locked* = $\emptyset$;

CoBegin

2.1. Receive $\langle \text{REQUEST}, i, \text{lane}_i \rangle$ from vehicle i :

```

if ( $\text{locks}_i \subset \text{locked}$ ) {
    crossingList = crossingList  $\cup \{i\}$ ;
    Broadcast ( $\langle \text{CROSS}, \text{crossingList} \rangle$ );
}
else if ( $\text{locked} = \emptyset$ ) {
    locked =  $\text{locks}_i$ ;
    crossingList = all vehicles in waitingList and on lanes concurrent to  $\text{lane}_i$ ;
    broadcast ( $\langle \text{CROSS}, \text{crossingList} \rangle$ );
    SetTimer(crossingTimer, duration); }
else waitingList = waitingList  $\cup \{i\}$ ;

```

2.2. Receive $\langle \text{NEWLANE}, i, \text{newLane} \rangle$ from vehicle i :

```

if ( $i \in \text{crossingList} \ \& \ \text{lane}_i \neq \text{newLane}$ ) {
    crossingList = crossingList -  $\{i\}$ ;
    waitingList = waitingList  $\cup \{i\}$ ; }
Update  $\text{lane}_i$  in waitingList using newLane;

```

2.3. Receive $\langle \text{CROSSED}, i \rangle$ from vehicle i :

```

crossingList = crossingList -  $\{i\}$ ;
if (crossingList =  $\emptyset$ ) {
    Let  $j$  be the first vehicle in waitingList;
    locked =  $\text{locks}_j$ ;
    crossingList = all vehicles in waitingList and on lanes concurrent to  $\text{lane}_j$ ;
    Broadcast ( $\langle \text{CROSS}, \text{crossingList} \rangle$ );
    ResetTimer(crossingTimer, duration); }

```

2.4. Timeout of *crossingTimer*:

```

if (waitingList  $\neq \emptyset$ )
    if (crossingList  $\neq \emptyset$ ) {
        Broadcast ( $\langle \text{DELAYED}, \text{crossingList} \rangle$ );
        Wait(crossDuration); }
    Let  $j$  be the first vehicle in waitingList;
    locked =  $\text{locks}_j$ ;
    crossingList = all vehicles in waitingList and on lanes concurrent to  $\text{lane}_j$ ;
    Broadcast ( $\langle \text{CROSS}, \text{crossingList} \rangle$ );
    ResetTimer(crossingTimer, duration); }
else if (crossingList  $\neq \emptyset$ )
    ResetTimer(crossingTimer, duration);

```

CoEnd

Figure 4. The *controllerTask* in VANETs-based intersection control algorithm

4. APPLICATION OF AN ADAPTABLE inVANETS-BASED INTERSECTION TRAFFIC CONTROL ALGORITHM ON A REAL-LIFE INTERSECTION IN ABU DHABI

In this section, we will discuss the application of the algorithm on a real-life intersection in Abu Dhabi. Mainly, Abu Dhabi City has intersection has around 4 lanes in each road, so the intersection will have around 15 lanes, as seen in Figure 5, and Figure 6. Therefore, when applying the locks table, we will get this locks table for 16 lanes.

Figure 5. An intersection in Abu Dhabi

Each lane will lock its lane with 4 conflicting lanes, but we need to take in consideration that some of the lanes are “twins”, which means that these lanes are *identical* which means they are *concurrent* with each other, and concurrent with the same lanes, as well as conflict with the same lanes on the road. Referring to Table 2, In order to solve this issue, the twin lanes will have the same locks, and when 1 lane of the twin requests to lock it will mean the other twin lane is concurrent and shares the same locks. For example, when a vehicle i in l_0 requests the access to the intersection from the controller, and the controller locks l_0 locks, it means that it will allow a vehicle j on l_1 to cross as well since it shares the same exact locks with l_0 which are l_{10} , l_{11} , l_{14} , and l_{15} . Similarly, like Table 1. If a vehicle i is concurrent with the lane that the controller already has its locks it will get access to the intersection, for example like $l_0 \approx l_2$. Also, if vehicle i is on a conflicting lane then the controller will request it to wait. For example, like $l_1 \propto l_4$.

Figure 6. View of an intersection in Abu Dhabi

5. SIMULATION RESULTS

In order to check the performance of the developed algorithm, we analyzed simulation results generated on different metrics that depend on mainly on the traffic of vehicles in the simulation.

5.1 Simulation Environment

We developed our algorithm based on VEINS, an open source framework for the simulation of vehicular networks in which it uses Omnet++, and SUMO to simulate the vehicular networks. We used a map of a real intersection in the city of Abu Dhabi, and it was created using Open Street Map, which is a geographic data tool. In Figure 7, we can see the traffic in the simulation generated.

We ran our algorithm on nine simulations generated with different scenarios. In figure 8, we can see that the vehicles are distributed in an almost non-uniform fashion on four different roads.

Table 2. The lane locking scheme for an intersection in Abu Dhabi

Vehicle's lane	0	1, 2	3, 4	5	6, 7	8, 9
Lanes to be locked	0	(1,2)	(3,4)	5	(6,7)	(8,9)
	6	13	8	11	3	1
	7	14	9	12	4	2
		18	16		18	13
		19	17		19	14
Vehicle's lane	10	11,12	13, 14	15	16, 17	18, 19
Lanes to be locked	10	(11,12)	(13, 14)	15	(16, 17)	(18, 19)
	16	3	6	1	8	3
	17	4	7	2	9	4
		8	18		13	11
		9	19		14	12

Figure 7. Simulation on Omnet++ and SUMO

Figure 8. Distribution of vehicles on roads on scenarios

5.2 Simulation Metrics

The size of the intersection that we are using is 200m * 200m. The transmission reaches up to 510m, and we use IEEE 802.11p for the communication in the network since it is a wireless communication protocol environment that are vehicular. The algorithm was used on different scenarios having different numbers of vehicles ranging between 0 to 50. The simulation time varies depending on the number of vehicles as it is from the range of 51s to 150s. We will show the results based on these performance metrics:

- *Average message cost*: Average number of messages that is sent by each vehicle from the time it entered the queuing area till it crosses the intersection.
- *Average queue length*: Average number of waiting vehicles in queue area.
- *Average waiting time*: Average duration that each vehicle stays from the time it entered the queuing area till it crosses the intersection.
- *System throughput*: Number of vehicles that crosses the intersection in each minute.

5.3 Average Message Cost

In Figure 9, we can see the different messages sent on the network whether they are from the vehicles or the controller. Each vehicle is allowed to send one request message to the controller, and then the controller decides which vehicles that will get the permission to cross based on the locking mechanism and send a cross message to the vehicles who are allowed to cross based on that mechanism. The vehicles then cross the intersection and send the crossed message to the controller. In addition, the controller has a crossing timer that will allow the waiting vehicles to get a chance to cross the intersection; therefore, in that case, it will send the delayed message to the vehicles in order to give the permission to other vehicles to cross the intersection.

Figure 9. Messages on the Network

Figure 10. Average Message Cost

In figure 10, we can see the average message cost in the network, we can notice as we increase the number of vehicles in each simulation, the average messages increases steadily.

5.4 Average Queue Length

We can see in figure 11, the Average Queue Length, we notice that the queue length depends on the scenario itself, so we can see it might increase or decrease depending on the real traffic generated by the scenarios we have. We can notice that there is no steady increase in this figure.

5.5 Average Waiting Time

In figure 12, the simulation results show that the Average Waiting Time depends on the Average Queue length of the scenario, so if the scenario has a longer queue, the vehicles will have a longer waiting time, so the waiting time does not increase steadily, but instead increases or decrease based on the traffic generated by the scenario.

Figure 11. Average Queue Length

Figure 12. The Average Waiting Time

5.6 System Throughput

The simulation results shown in figure 13 display the system throughput throughout the different simulations we have generated. When we notice previous graphs, we can see that the throughput is in relation with the Average Queue Length and the Average Waiting Time, the scenarios that have longer queues, and waiting times have less system throughput, but in general there's an increase in the system throughput using the algorithm we created.

Figure 13. System Throughput 1/M

6. CONCLUSION

In this paper, we discussed developed novel adaptable centralized intersection control for ITS (Intelligent Transportation Systems) which depends on inVANETs (Intelligent Vehicular ad-hoc Networks). The intersection control based on inVANETs contains two main parts: the vehicleTask, and the controllerTask. These two tasks exchange message and cooperate to make the vehicles able to cross the intersection without suffering from any type of conflicts.

In addition, we also, applied the algorithm on an intersection in Abu Dhabi, and explained the improvements necessary in order to be applied with no issues, since the intersections in Abu Dhabi are much larger than the intersection proposed in the algorithm.

We also performed extensive performance evaluation of the algorithm and displayed the results for this evaluation. The traffic in the scenarios were in a non-uniform fashion, we showed statistics involving the message cost, the queue length, the waiting time, and the throughput in each scenario of these different scenarios.

ACKNOWLEDGEMENT

This work is supported by ADEK Award for Research Excellence (A2RE) 2015 and office of Research and Sponsored Programs, Abu Dhabi University.

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