A Model for Traffic Control in Urban Environments

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Abstract—**Wireless technologies can help solve traffic congestions in urban environments, where road infrastructures develop slower than the sometimes exponential growth in the number of cars in traffic. We present a model for traffic control and congestion avoidance developed over a vehicular ad-hoc network created between the cars in traffic and the road infrastructure. We propose a solution for monitoring traffic using not only sensors within the road infrastructure, but also the cars themselves acting as data collectors. The traffic control decision, provided by the road infrastructure, is scalable, load-balanced, and based on correction decisions for the route adjustment based on local areas. We present evaluation results that show the capabilities of the proposed congestion avoidance model.**

Keywords- congestion avoidance, VANETs, traffic control

I. INTRODUCTION

Traffic congestions are realities of urban environments. The road infrastructure capacities cannot cope with the rate of increase in the number of cars. This, coupled with traffic incidents, work zones, weather conditions [1], make traffic congestions one major concern for municipalities and research organizations.

The communication capabilities provided by wireless technologies and mobile devices offer opportunities for developing traffic control applications where cars and devices within the road infrastructure collaborate. Currently traffic lights organize the flow of traffic in intersections. Intelligent traffic lights are adaptive to the traffic and can provide priority to emergency cars, as well as safety to pedestrians and cyclists [5]. The same principle can be applied for congestion avoidance. For example, a traffic light can have sensors (to collect data for traffic) and processing capabilities (to aggregate traffic data and take actions such as updating the time for the change of red or green lights or to log information for an economic pricing model to control congestions). One project [6] is able to determine the number of cars waiting at the traffic light. In addition, it can rely on sensors deployed in various key points within the road infrastructure. However, for congestion avoidance a more appropriate model should reflect the current status of all roads. A system based on sensors collecting data in key points takes decisions that re-route cars from roads where it knows of possible congestions to other roads where it has no information (and, consequently, it thinks there is no congestion).

We propose a model for congestion avoidance and traffic control based on traffic data collected from both sensors within the road infrastructure, and also from monitoring applications running inside cars. The immediate advantage of such an approach is that the cars becomes data sources themselves, and can help collect traffic data from all places.

Such a model is feasible today because of wireless communication technologies. Research projects such as DOLPHIN ([3]) and FleetNet [4] use both Inter-Vehicle-Communication IVC and Road-to-Vehicle Communication RVC to provide intelligence in the transportation system. We propose a hybrid monitoring model based on a hybrid approach. Cars can communicate with each other and with the infrastructure to send the traffic data to ground servers, where data is further aggregated. Cars running the monitoring application collect data and store them temporary until they are able to communicate with an access point and forward the data.

For traffic control the model includes several servers where traffic data is aggregated. To solve scalability issues, each server is responsible for a local traffic zone (a delimited area around a traffic light, for example). A car running a traffic navigation application receives traffic updates only for the traffic zone around the car (based on its current location) at a certain moment. It will receive traffic updates for another zone only when it enters the area of another server. At a higher level, servers are also able to communicate with each others to aggregate data at a global level. Such an approach has several advantages. Consider a scenario where a driver enters a particular destination on its navigator device. The navigator is able to receive feedback from a wireless system about possible congestions and to dynamically adjust its route. So, later on, the navigator receives feedback from the wireless system that on a particular road an event leaded to congestion. This information might trigger an update of the driving route to avoid that particular road segment, even though the alternative might lead to an increased cruising time. This can happen because, in reality, the congestion might be reached only after a certain period of time (sometimes hours of navigation). So the data about a congestion happening now should not always influence the driving decisions, particularly if it is happening too far from the car's current position.

In addition, by using several distributed servers in charge of traffic zones, the model can better support scalability. A service replication scheme can be used. It can consist of several servers that manage fault tolerance. We also present evaluation results obtained in simulation scenarios using the proposed congestion avoidance model.

The paper is structured as follows. In Section 2 we present related work. Section 3 presents the model for congestion avoidance. In Section 4 we present details about the implementation of the model as an extension of a simulator designed for VANETs, experimental results. In Section 5 we give conclusions and present future work.

II. RELATED WORK

The problem of finding the optimum route for a destination in a crowded city has been previously approached in several research projects (*e.g.* [7], [8]). Still, previous approaches considered that cars are equipped with navigators able to receive feedback from traffic to dynamically adjust their routing paths. Optimality is addressed regarding to time (compute the routes such that to decrease the time cars spend in traffic) or distance (compute the routes such that to decrease the length of the paths considering that cars pollute). We argue that a more correct traffic decision should be made on a global scale. By letting cars control and choose their routes a situation where all cars see the same congestion roads and decide on the same alternative road – which will eventually congest the alternative road – is easily encountered.

Projects such as [7] approached the problem of computing optimal adjacent routes using learning techniques. After running on a route, the driver manually inputs the time spent in traffic, and in the future he/she will be able to select the best route depending on the average speed associated with known routes. However, such applications are limited, because they consider that traffic conditions are static. They also ignore events such as different weather conditions, accidents, etc, that are considered by many authors the roots of congestions [1]. Alternative solutions (*e.g.* [8]) process data received from various sensors within the road infrastructure (infrared cameras, asphalt integrated sensors, etc.) and compute the route dynamically, based on the traffic conditions (as opposed to using a classical Dijkstra algorithm). The authors present results showing that the alternative expert system is able to calculate a shortest path, but it also needs a large amount of data for computing the route. Also, the integration of sensors in every city intersection and/or road is costly, an aspect which can negatively influence the large-scale adoption of such a solution. At the moment, applications based on such types of sensors are used mainly on highways, and the services they provide are limited to traffic flow adjustment.

In [5] we previously proposed a solution based on communication between cars, wireless traffic lights and a central server. In our approach cars collaboratively collect and send data about the traffic, and receive feedback that is used to dynamically adjust routing decisions based on traffic conditions. The experimental results showed promising results ([5]). However, we also noticed that our solution suffers from a drawback: the central server, which manages the data about the roads, becomes a bottleneck and a single point of failure.

WAZE [13] is a free social traffic and navigation application that uses real-time road reports from drivers improve the navigation decisions. Similar to our approach, WAZE uses a social layer, where drivers work together to report and receive the most relevant traffic information available at any given moment.

In this we propose a model which relies on the data also collected on a social basis from the traffic participants (cars traveling), but also combined with data from sensors within the road infrastructure, to take traffic decisions. Unlike WAZE, we propose an approach where data is automatically collected by the mobile devices and aggregated, such that to take higher level decisions (such as the average speed cars are moving on a particular road segment). Also, by making use of alternative sources (sensors) and combining our approach with security solutions we previously proposed ([14]) we solve many of the problems that social networks have (intruders for example). We also propose several novel solutions. We use a number of distributed servers that are in charge of different traffic zones. Such an approach has advantages on communication (the traffic data is aggregated locally), processing (data is collected from a smaller area, so the amount of data is reduced compared to [5]), and scalability.

III. A MODEL FOR CONGESTION AVOIDANCE

The proposed model assumes the existence of (some) vehicles equipped with wireless capabilities (smart-phones, laptops or the car's computer having communication capabilities) and road-sided wireless equipments installed in major intersections within a city. Cars are running a monitoring application that collects data about the current traffic conditions (the data can consist of sampled speeds or can be augmented with information about the acceleration if such a sensor exists locally). The data is stored locally and sent to a server whenever possible. The model also considers the existence of road-sided wireless equipments. The traffic lights can be equipped with wireless communication capabilities (for the rest of the paper we will refer to the road-sided wireless equipment as Wireless Traffic Light, or WTL[1]).

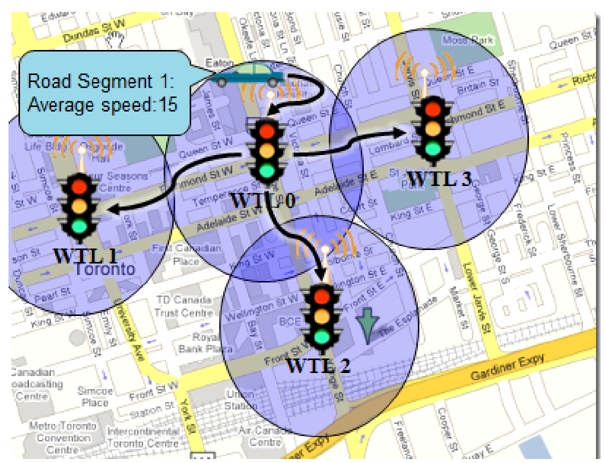

Figure 1. The proposed model for traffic control.

[1] We make the observation that alternative road-sided communication equipments can be used as well.

The WTLs receive data from cars and aggregates it to form a traffic road map. A WTL can also communicate with other neighbor WTLs (the adjacent WTLs in each direction of the intersection) and can send them its knowledge of the traffic map and the cost associated with the road segments it knows about.

A representation of the model is presented in Figure 1. According to the model, a road is composed of road segments. The data is collected and average traveling speeds are computed for each particular data segment. This is a natural approach for situations where as cars approach the end of the road or an intersection they slow down, while for a straight road cars accelerate – so for the same road you see different speeds. The model associates a cost to each road segment, representing the estimated time a car would transit it considering current known traffic conditions.

For each road segment we aggregate all known costs that the WTL is aware of. In the beginning each road segment is associated with a default speed value. As vehicles and sensors collect data for that specific road segment, they provide feedback. Vehicles send back their measured average traveling speeds. Based on these values the average speed associated with a road segment is modified accordingly, using a moving average algorithm. The cost related to the road segment represents a division between the road segment length and its relative speed, thus resulting an approximate time a vehicle spends to pass the road segment. However, the algorithm for the cost estimation is flexible, and we are currently experimenting with solutions to eliminate statistical deviations such as cars parking for example. Also, attackers might negatively influence the traffic conditions by reporting wrong data. However, the model can cope with such situations by using a model for trust computation based on collaboration between cars (such as the ones presented in [10]).

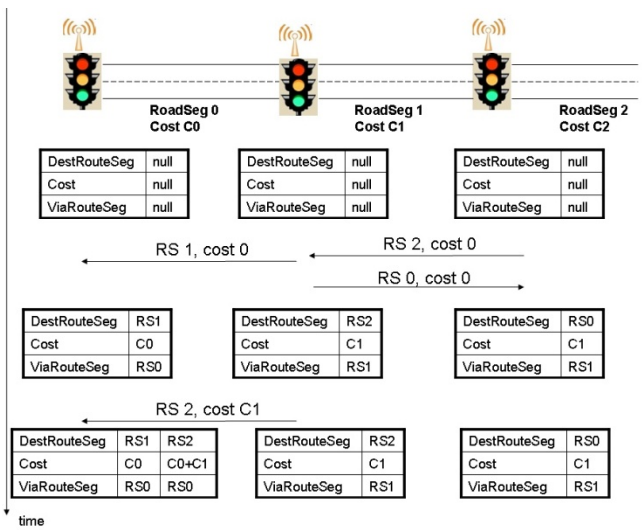

Figure 2. The distance-vector routing for route exchanges.

A WTL communicates and computes routes similar to a distance-vector routing RIP protocol ([9]). It employs a distance-vector routing algorithm, where WTL act as routers, communicating with their neighbors and offering their local knowledge about the network, as well as computing the best route for each road segment, consisting only of the "next hop", which is also a WTL (corresponding to the next traffic zone). When a vehicle asks for the best route towards a destination, the road-sided wireless equipment offers only the route necessary for the vehicle to reach the “next hop”. As the vehicle then enters the next zone, it makes another inquiry towards the WTL in charge of the new area.

All road-sided wireless equipments use three lists: 1) the known route segments, 2) the costs associated with each road segment, and 3) the the road segments that a vehicle must go to for particular destinations (located on a route segment from the first list). In the beginning these lists are empty. Every WTL advertises to its neighbors that it can reach the route segments directly connected to it with a null cost. When a neighbor receives such an advertisement, it checks that the advertised route segment is not directly connected, and if not, it adds the route segment to the “routing table”, putting the associated cost of the route segment that must be passed to reach the neighbor who advertised the route segment. Once a WTL receives information about a route that was not present in its local “routing table”, it will send this information to all its neighbors through another advertisement. This action is performed several times, until the system reaches a state of convergence (see Figure 2). Furthermore, all WTLs will continue to advertise the route segments that are directly connected to it, to provide a fresh perspective to its neighbors and to force them to recalculate (if necessary) the cost associated with all the routes that required to pass through the traffic zone.

For the implementation, a vehicle (client) periodically broadcasts messages containing data recorded while passing the last few road segments and the vehicle’s destination. It gets a reply once it enters the traffic zone of a WTL; in this case the response makes it aware that the broadcast message has been received. The response message, in the simplest implementation, contains the route segment(s) that the WTL has associated with the route segment associated with that particular destination. An alternative is for the WTL to also predict future congestions and compute the next route using on a load-balancing metric. In both approaches, the WTL directs the car to the next WTL, where the vehicle will also again be notified of another route, until it reaches its destination.

Because the WTL does not compute the entire route of the car it uses fewer CPU-intensive operations. In this case the WTL simply checks if a point on the map is located on any of the road segments that are in its local database, and if a match is found, it immediately send the response message with the corresponding entry in the database.

The simple computation is also important because a car must receive a response before it passes through the intersection (so in many occasions quite fast). Also, by not computing the entire route for a car can prove to be suitable for a city scenario where the traffic conditions are very dynamic and a route may not be the best available in only a few minutes after it had been computed.

It often happens that a particular road segment gets very congested, so all vehicles passing through consequently report slow traffic speeds. This introduces a higher cost associated with the road segment, which will lead to the routing of cars on possible alternative routes. And it also happens that. after a period of time in which vehicles are not routed through that particular road segment anymore, the road segment becomes free and cars might pass very quickly, with a low cost. But because there is no car to pass through the system does not know the state of the road segment. To prevent such problems, a periodical adjustment is made to all speeds (and costs) of all road segments of the map. This adjustment tries to draw the speed of a road segment near its standard speed, creating the possibility to reduce the cost of a road segment that has developed a very high one. The frequency of this operation is set so as to not create a false cost to a road segment. Its only purpose is to help road segments with high cost regain their "credibility" (lower their cost) once no vehicles pass through.

IV. Experimental Results

We evaluated the proposed traffic control model in a simulated environment. For that we extended the VNSim simulator [12], a generic VANET traffic simulator that uses both the microscopic and macroscopic models in order to accurately evaluate the performance of a wide range of VANET technologies.

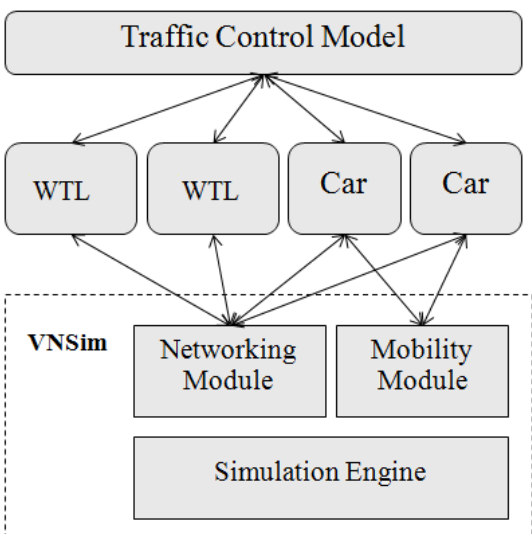

Figure 3. The extension to VNSim.

On top of the already provided mobility and network models ([12]), we added the components and mechanisms previously described (see Figure 3). To evaluate the performances of the model we used a scenario consisting of 10 roads, 25 intersections with wireless equipments, and 60 road segments (see Figure 4).

The scenario considers as main roads the ones that intersect in the center. In these experiments cars enter at three of the ends of the main roads, and go towards the fourth (cars come from west, north, and south and go to east). Using these conditions we conducted several experiments with different traffic flows. We were particularly interested in the number of vehicles that reach their destination in a specific amount of time in the simulation, the average time needed by the vehicles to reach their destination, the average fuel consumption, in liters/100 kilometers, and finally the total emissions resulted from the engines of the cars. For the last results the VANET simulator uses the model proposed by Akcelik and Besley for fuel consumption estimation [11]. To evaluate and compare the emissions of the vehicles, we chose to study the carbon dioxide, which is one of the four categories of toxic emissions of vehicles. The carbon dioxide is stated as kilograms/hour/car.

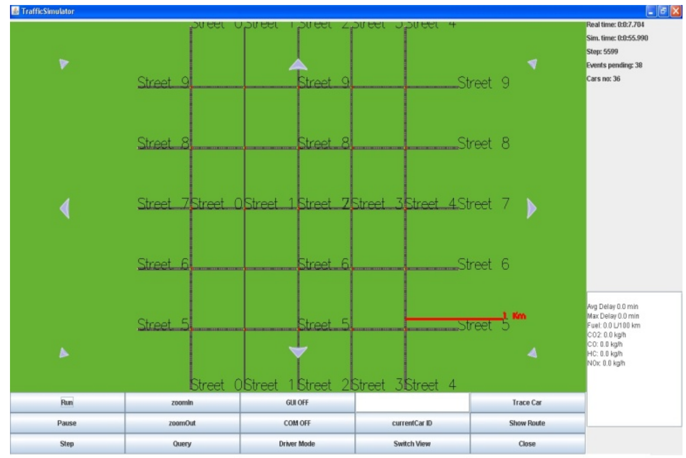

Figure 4. The scenario used in the simulation experiments.

The results in Figures 5-8 were obtained for the case involving a mobility flow of 150 cars/lane/hour. The results show an increase in the number of vehicles reaching the destination before the end of the simulation - as high as 45% increase in performance, from 327 to 484 cars. The results also show the average time cars need to reach their destination decreases with approximately 30%. We made comparisons between sets of experiments conducted without the use of the proposed model (the standard series) and the same experimental scenarios conducted using the traffic control model proposed in this paper.

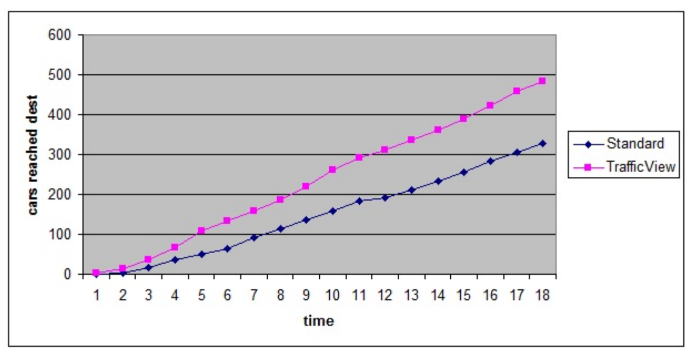

Figure 5. Results for the cars reaching their destinations in a predetermined period of time.

Cars with petrol driven internal combustion engines are a constant source of air pollution. Road transportation is responsible for the emission of carbon monoxide, carbon dioxide, hydrocarbons, nitrogen dioxide, metals and many other organic compounds into the environment. These chemicals produce great damage not only to our health (e. g. respiratory diseases, irritation to the eyes), but also to the entire nature (e. g. global warming, acid rains). As presented, the proposed traffic model also has the potential to reduce fuel consumption (as well as air pollution). Figure 8, for example, shows a decrease of up to 14% in the emissions, from 1931 to 1646 kilograms of carbon dioxide/hour.

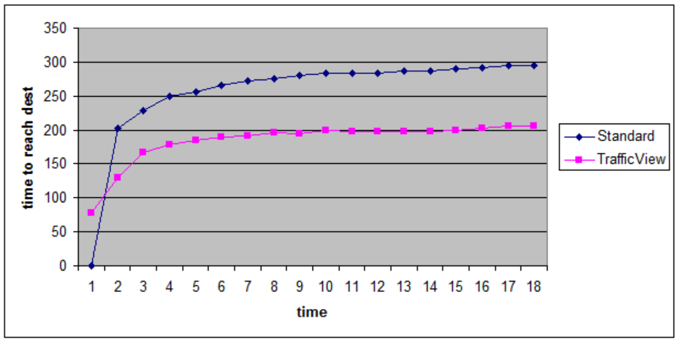

Figure 6. Results for the average time needed to reach destinations.

Scenarios involving a lower traffic flow provided results that show an increase in the total number of vehicles that reach their destination before the end of the simulation as high as 15%, and also a shorter average time in which cars reach their destination, with a decrease of over 40%. The fuel consumption registers a slight decrease, which can prove to be very significant, considering that these scenarios involve a large number of cars. Regarding the average emissions, a decrease of about 20% has been registered.

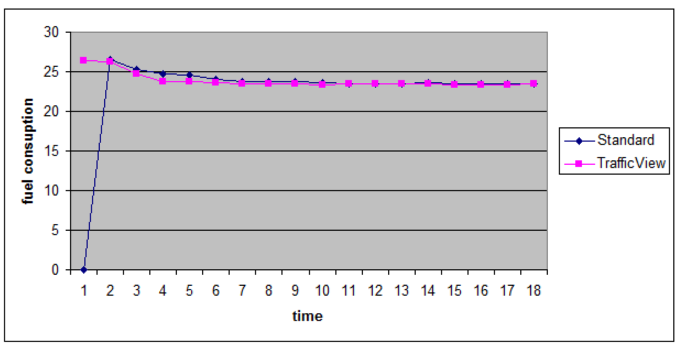

Figure 7. Results for the average fuel consumption.

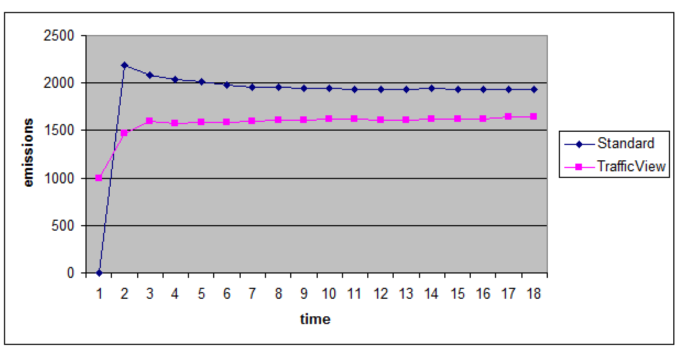

Figure 8. Results for the average emissions (carbon dioxide).

We tested the same scenarios using also an adaptive traffic light system [11], to provide a comparison between the two solutions. Results showed that when using a high traffic flow, the adaptive traffic light system offered better results, while our solution provided better results when lower traffic flows are imputed into the simulator. We also tried to use the two systems together and reached much better results than using them separately. These models, running concurrently, provided an increase in the total number of vehicles that reached the destination before the end of the simulation that exceeded 100% while testing scenarios involving a high flow of vehicles.

V. CONCLUSION

We presented a model for traffic control and congestion avoidance in urban environments. Various studies ([1][2]) previously showed the important role played by the transport infrastructure in modern economies. It is estimated that only in Europe traffic congestion affect approximately 10% of the existing transport network, with significant financial implications. Such reports recognize that the development of new infrastructures is not a reliable solution as compared to investing in technologies based on intelligent transport systems (ITS) and Vehicular Ad-Hoc Networks (VANETs).

In this we proposed a traffic model for solving congestions by collecting traffic data from the road, aggregating it and providing feedback to cars similar to ideas from networking protocols. The model is based on the use of cars to collect traffic data and several WTLs that are able to aggregate and take decisions as to how to influence the routes the cars are driving. Whenever a road segment starts to provide lower average speeds for vehicles passing through, a routing algorithm provides alternatives routes, less congested and providing better times to reach destinations.

We evaluated the model in a series of simulation experiments. We demonstrated that the average time needed for vehicles to reach their destinations registered a significant decrease of up to 40% compared with the time needed for vehicles to reach their destination using predefined static routes. The average fuel consumption also registers economies up to 1 liter per 100 kilometers, which is a major advantage considering the fact that in a city with millions of vehicles the fuel saving can be quite high. The total emissions also show a high decrease because of less fuel consumption and the fewer accelerations and brakes that vehicles need to apply. The emissions' decrease varies from 14% to 40%.

The model is currently in the development stage and we experiment with different alternatives to controlling traffic such that further balance traffic or include trust management models.

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