An Infrastructure-Free Traffic Information System for Vehicular Networks

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Abstract— **Vehicular networks are the major ingredients of the envisioned Intelligent Transportation Systems (ITS) concept. An important component of ITS which is currently attracting wider research focus is road traffic information processing. This has widespread applications in the context of vehicular networks. The existing centralized approaches for traffic estimation are characterized by longer response times. They are also subject to higher processing requirements and possess high deployment costs. In this paper, we propose a completely distributed and infrastructure-free mechanism for road density estimation. The proposed solution is adaptive and scalable and targets city traffic environments. The approach is based on the distributed exchange and maintenance of traffic information between vehicles traversing the routes. The performance analysis of the proposed mechanism shows the accuracy of the algorithm for different traffic densities. It also gives insights into the promptness of information delivery in the mechanism based on delay analysis at road intersections. This promptness is a necessary condition to various applications requiring reliable decision making based on road traffic awareness.**

Index Terms—**Vehicular Ad hoc Networks, Road-Traffic Estimation, Performance measurements.**

I. INTRODUCTION

A study in [1] provides results regarding the awful side-effects of road traffic. This study shows that traffic congestion accounted for huge losses in additional delays and wasted fuel in 75 urban areas in the U.S. Over 6 million crashes occur each year in the U.S., resulting in over 40000 fatalities and an estimated $150 billion in economic loss [2, 3]. Most of these incidents could be averted by providing timely and appropriate information to the driver or to the vehicle.

Vehicular networks are a cornerstone of the envisioned Intelligent Transportation Systems (ITS). By enabling vehicles to communicate with each other via Inter-Vehicle Communication (IVC) as well as with roadside base stations via Roadside-to-Vehicle Communication (RVC), vehicular networks could contribute to safer and more efficient roads by providing timely and accurate information to drivers and other concerned authorities. One of the most important components of the Intelligent Transportation System (ITS) is the road traffic information handling (monitoring, transmission, processing and communication). The existing traditional ITS traffic information systems are based on a centralized structure in which sensors and cameras along the roadside *monitor* traffic density and *transmit* the result to a central unit for further *processing*. The results will then be *communicated* to road users. These systems require substantial public investment in sensing, processing and communication equipments. Moreover, such systems are characterized by long reaction times and thus are not useable by all the applications requiring reliable decision making based on accurate and prompt road traffic awareness.

The objective of this work is to provide a completely decentralized mechanism for the estimation of traffic density in city-roads (IFTIS – Infrastructure-Free Traffic Information System). This decentralized approach is based on traffic information exchanged, updated and maintained between vehicles in the roads. The estimated road traffic density information is useful for several ITS-related applications. Particularly, the proposed mechanism is suitable for integration to real-time traffic congestion warning systems, leveraging on the proposed distributed mechanism that provides updated traffic information to drivers. It may also be used as a critical metric for determining optimal vehicular data routing paths in Vehicular Ad Hoc Networks (VANET).

The reminder of the paper is organized as follows: Section 2 discusses the main existing approaches realized for density estimation in vehicular environment and their disadvantages. The detailed description of our traffic information system is provided in Section 3. Section 4 describes the simulation setting and results. It is followed by a discussion of relevant applications of the system in Section 5. Finally, Section 6 concludes the paper depicting future research directions.

II. RELATED WORK

Most traffic information systems are based on a centralized architecture focused around a traffic management centre that collects data from the street network, via sensing devices, and processes them. The resulting traffic information is made available to the drivers via broadcast service or alternatively on demand via cellular phones. The centralized approaches are dependent on fixed infrastructure which demands public investments from government agencies or other relevant operators to build, maintain and manage such infrastructure: a large number of sensors are needed to be deployed in order to monitor the traffic situation. The traffic information service is then limited to streets where sensors are integrated. Besides, centralized designs have the disadvantage of being rigid, difficult to maintain and upgrade, require substantial computing/communications capabilities, and are susceptible to catastrophic events (sabotage or system failures).

To overcome the disadvantages of centralized schemes, initiatives towards decentralizing traffic information systems began to appear. In the work described in [4], the authors propose a simple time-dependent solution for road congestion estimation. The solution is based on an opposite stream vehicle communication approach where each vehicle exchanges information about the average entry-exit times (travel times) of segments with their neighbors in the opposite streams. This updated traversal times, which are assumed to be stored at the street segments, could help the driver as descriptive network information to re-evaluate current routes and to possibly produce new routes. To avoid the redundancy, it is strictly considered that only vehicles traversing in opposite directions will exchange information (the vehicles closely moving in same directions will maintain similar information). A second viable decentralized approach named as SOTIS (Self-Organizing Traffic Information System) was proposed in [5]. The traffic condition is evaluated in terms of average velocity for traffic segments. Then, the vehicles (SOTIS equipped) periodically exchange and update their current position and traffic information (average velocity), in order to inform the surrounding vehicles about the individual knowledge. As another car receives this information, it is compared with a '*knowledge base*' to establish whether the information is more accurate/updated than the existing information. Entries in the '*knowledge base*' are associated with geographic coordinates and are combined with a digital '*local map'* and displayed as warnings/indicators on an in-car display. Another decentralized solution is proposed as part of the e-Road project [6], which aims to achieve a scalable communication infrastructure for IVC (Inter-Vehicle Communications). As part of this project, they propose a system called TrafficView [7], which aims at disseminating and gathering information about vehicles in the road. Using such a system, the vehicle driver will be aware of the road traffic, which helps in driving through foggy weather or for determining optimal route in a long distance trip. The system works based on frequent message broadcast based on the information provided by the GPS receiver (like location, speed, current time and direction of the vehicle). The received neighborhood information is validated to avoid conflicting information and is then moved and merged with existing validated dataset. Periodically, the system displays the data from the validated set. The basic idea behind the information dissemination in TrafficView system is data aggregation.

The decentralized mechanisms for traffic density estimation presented above do not provide a scalable and accurate solution for dynamic traffic density estimation as required by vehicular networking applications. The associated time lag for the update information and inaccuracy of information in case of sparse networks renders the work presented in [4] unsuitable for many vehicular networking applications. Moreover, there is no collaborative processing of information in SOTIS that takes place between vehicles, and there is no attempt to identify abstract traffic events by interpreting the sensor data. The aggregation techniques exploited in TrafficView does not explicitly site the issues related to information exchange and processing. The success of data aggregation methods depends on the frequency of the update messages and could saturate the IEEE 802.11 capabilities, thereby imposing different problems in the system. Both SOTIS and TrafficView are designed for highways, and are not adapted to city environments, and in particular to downtown areas. A better adapted mechanism for road density estimation is required with improved accuracy and promptness of delivery, where scalability is a primary constraint so that it does not saturate the system capacity.

III. INFRASTRUCTURE-FREE TRAFFIC INFORMATION SYSTEM

A. Preliminaries

In IFTIS, we assume that each vehicle participating in the cooperative road traffic information processing knows its own geographic position using a Global Position System (GPS). Moreover, we consider that such vehicles are equipped with digital maps to determine which road they are in. Therefore, the available traffic information can be visualized and stored based on road identifiers in the digital map. We also assume that each vehicle is equipped with at least one wireless transceiver. Finally, each vehicle is required to maintain a neighbour table in which position, velocity and direction of each neighboring vehicle are recorded. This table is built and updated thanks to the periodic exchange of hello packets by all vehicles. Additionally, the vehicles also record the identity of the traffic route in which their neighbors are traveling (represented as road ID).

B. Group Formation

Our solution revolves around the core idea of information relaying between groups of vehicles rather than individual vehicles. More precisely, vehicles are arranged into location-based groups. This brings us to the group formation primitive we adopt in our approach. In fact, each road (section of street between two intersections) is dissected into small fixed area cells, each defining a group. Note that the cell size depends on the transmission range of vehicles (around 250m) and the cell ID depends on the road ID. Cells, and hence groups, overlap in such a way that any vehicle moving from one cell to the next belongs at least to one group. The closest vehicle to the cell center is considered as the group leader for a given duration. This is illustrated in Fig. 1 where group leaders are vehicles which are within the circular regions around cells' center.

We make the following observations that motivate the location-based group concept applied in our solution.

- Vehicles in geographical proximity often share redundant information such as road and traffic conditions.
- A vehicle will automatically know to which group it belongs and whether it is a group leader or not.

- A group leader will know easily the traffic information within a cell using its neighbouring table (number of its neighbours within the cell, average velocity of its neighbours…).

To achieve the above advantages, the only additional cost involved in this type of group formation is the cell-based dissection of the maps by each vehicle. But this can be easily done using GPS information. In other words, cells could be directly identified by the GPS coordinates of their center. Hence, cell centers can be computed according to a common set of simple rules using cell radius and road intersection coordinates. Cell IDs and Road IDs can be easily derived using GPS Information.

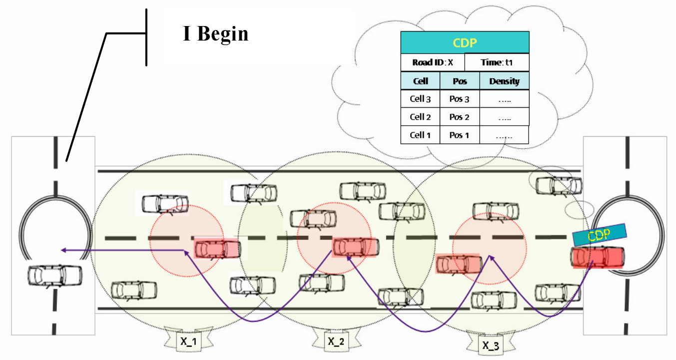

Figure 1 - Location-based groups -

C. *Generating, Forwarding & Analysing CDP*

After realizing group formation, we introduce in the following the distributed mechanism for the estimation of road-traffic density. This one is based on the use of specific Cells' Density[1] data Packet (CDP). The CDP provides the cell density of a given road. As illustrated in Fig. 2, CDP also contains fields identifying the road ID, transmission time[2], and the list of route anchors (position of cells center).

<table>
<tr><th colspan="3">Cells Data Packet (CDP)</th></tr>
<tr><td colspan="2"><i>Road ID</i></td><td><i>Time</i></td></tr>
<tr><td><i>Cell ID</i></td><td><i>Cell 's Center (Position)</i></td><td><i>Cell's Density</i></td></tr>
</table>

Figure 2 - CDP message format -

The CDP is generated by vehicles which have already been group leaders. In other words, only a vehicle which has already updated a CDP message will generate the new CDP. It only does so when it reaches a road intersection (i.e. before leaving the road). This is to control the generation of CDP messages, avoiding scalability issues. When initiating the CDP, such vehicle records the road ID, the transmission time and a list of anchors[3] through which the packet has to pass while traveling to the other intersection. Then, it sends it backward.

The CDP header includes a limited list of anchors corresponding to the position of the cells' centers. Then, the CDP is forwarded towards the first anchor on the basis of greedy forwarding (the forwarding vehicle selects among all its neighbours the closest vehicle to the next anchor). When it is reached, the group leader (closest vehicle to the cell center) updates the CDP by including the density of the corresponding cell (the number of its neighbors which belong to the corresponding road) and then forwards it towards the next anchor, and so on. When the last anchor (the destination intersection) is reached, the CDP is propagated to vehicles which are around the intersection.

Arriving at the opposite road intersection, the CDP packet contains the information of the cell-density of all the traffic groups in the road. Having this information is advantageous for determining if the cell is over-populated, for example, due to a traffic jam or accident. Perhaps, the overall traffic density will not be high for the road, but for a particular cell, the density level maybe very high, indicating some traffic problem. IFTIS allows identifying that. Actually, there are two main implications for the results evolved from the CDP packet depending on the applications. If the application requirement is demanding overall density information for the road, the mean and variance of the cells density will provide the result. On the contrary, if the application requirement is segmented traffic density information, then, the group density information as such could be exploited.

IV. SIMULATIONS AND RESULTS

In this section, we present the performance evaluation of IFTIS. To this end, our proposed mechanism was implemented within the Qualnet [8] simulation tool. The main objective of this section is to discuss whether or not IFTIS can provide traffic information with a reasonable delay and accuracy.

A. *Simulation Setting*

The scenario presented in this paper simulates a 2500 m long, straight road, with two bi-directional lanes (Fig. 3). This section of road is dissected into five overlapping cells. In the middle of the third cell, we introduce a traffic light as a perturbation source. Substantially, the effect is to create stop-and-go waves in the traffic stream.

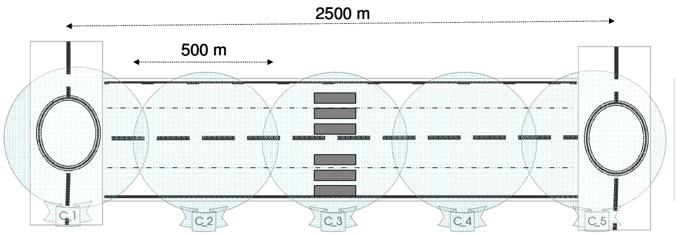

Figure 3 - Simulation scenario -

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[1] By density, we mean the number of vehicles within the cell.

[2] Note that all the vehicles are synchronized by GPS.

[3] Including the list of anchor points is not mandatory as all the vehicles are able to re-compute them. This list is used for CDP forwarding and update.

For the movement pattern, we used Vanet-Mobisim[9], a realistic vehicular mobility generator which uses the car-following and lane-changing models to determine the movements of cars on the roads. Hence, cars are initially distributed over the road and start moving on both directions considering both macro-mobility (road topology, street characterization, car class dependent constraints, traffic signs, etc.) and micro-mobility (car-to-car interactions, car-to-road interactions, acceleration and deceleration, overtaking, etc.).

All the key parameters of our simulation are summarized in Table 1.

Table 1: **Simulation setup**

SIMULATION / SCENARIO		MAC / ROUTING	
Simulation Time	400s	MAC protocol	802.11 DCF
Road length	2500 m	Pause Time	3 à 6 s
Mobility Model	VanetMobisim	Trans. Range	~266 m
Vehicle velocity (city)	40-60±5 Km/h	CDP sending rate	2 s
Number of vehicles	60-120	Red Zone Radius	40 m

B. *Simulation Results and Analysis*

The results shown in the following figures have been obtained on the 2500 m road shown in Fig. 4. The number of vehicles is set to 60 (Low Density, LD) and 120 (High Density, HD).

Figures 4, 5 & 6 reports the estimated and the real densities in the first, second and forth cell respectively over time.

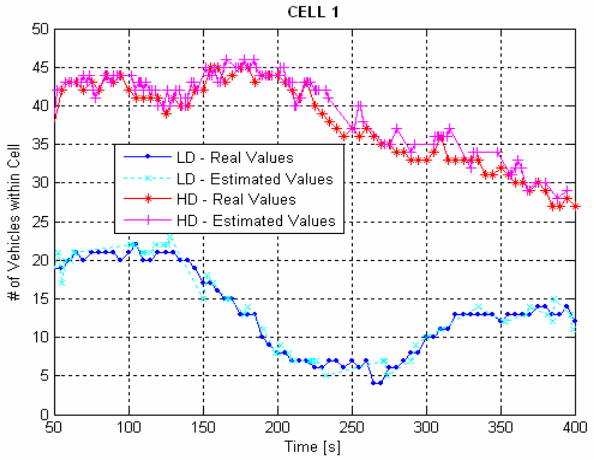

Figure 4 – Number of vehicles within Cell 1 versus time (for Low and High Density scenarios)

Fig.4 shows the behaviour of the number of vehicles (both real and estimated) within cell 1, which is the first one in our road segment scenario. Defining the relative error as $|N_{estimated} - N_{real} / N_{total}$, the relative errors observed are between 0% and 3% for the low density scenario and between 0% and 4% for the dense network, which are very low.

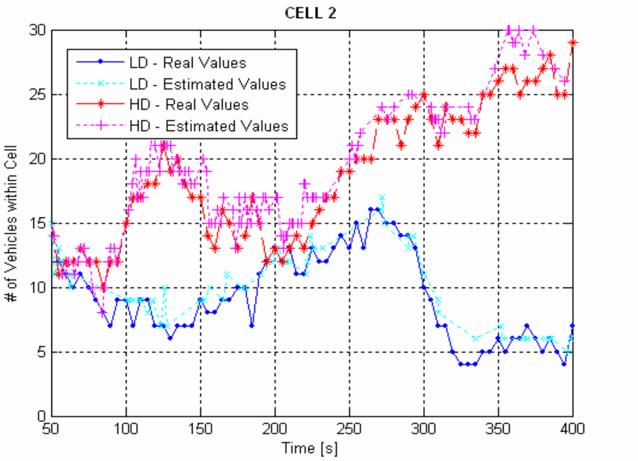

Figure 5 – Number of vehicles within Cell 2 versus time (for Low and High Density scenarios)

Fig. 5 & 6 give the same type of information relative to cell 2 and 4, which are the cells localised before and after the stop. It can be noticed that the pause time and consequently the slowdown imposed at cell 3 creates stop-and-go waves in cell 2 and 4. Also, in this case, errors are quite low (less than 8%). It is worth noting that the system succeeds in becoming aware in quantifying in real-time the anomalous situations where traffic parameters change abruptly.

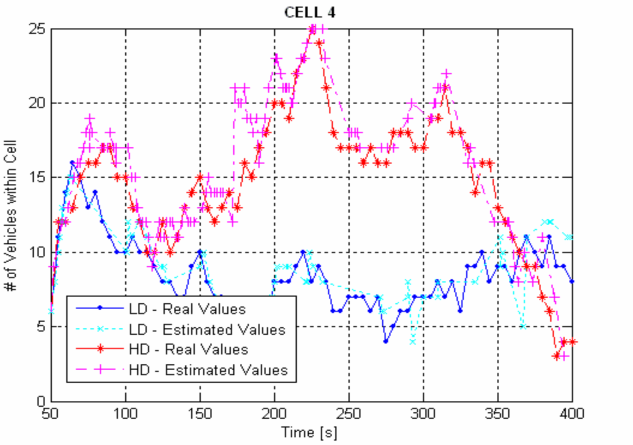

Figure 6 – Number of vehicles within Cell 4 versus time (for Low and High Density scenarios)

Fig. 7 depicts the average time it takes for a CDP packet to traverse the road segment. It is observed that the delivery delay in the sparse network is higher than in the dense network. This is because at higher density, the problem of local optimum (the forwarding vehicle might be the closest to the next anchor) is encountered rarely. While the network is sparse, the CDP packet is often carried by the forwarding vehicle, which leads to longer delays. This is confirmed when comparing Fig. 7 with Fig.5 & 6. Indeed, the instants we have delay peaks (Fig. 7) correspond to the instants we have a small number of vehicles within the cell 2 and 4 (Fig. 5 & 6).

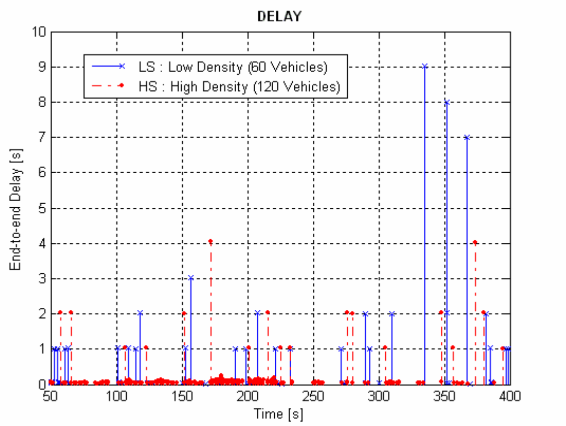

Figure 7 –End-to-end Delay over time (for Low and High Density scenarios)

Also, it is observed that longer delays might cause more errors while estimating the number of vehicles within some cells. For example, the highest delay in the scenario with high density happens at t = 170s. At the same time, we note an error of 5% between the estimated values and the real values within cell 4. This is confirmed in the low density scenario as well, where the highest error in cell 4 (8.3%) happened at t= 367s, instant for which we have a high delivery delay (7s).

In general, simulation results show a good level of accuracy and promptness for both low and high density scenarios.

V. DISCUSSION

The dynamic traffic density information estimated using IFTIS has various potential applications. Particularly, the proposed mechanism is suitable for being a critical metric for determining vehicular data routing paths or maybe adopted to use in a real-time traffic congestion warning system.

In [10], we presented an intersection-based geographical routing protocol, GyTAR, which was shown to be capable of finding robust routing paths within city environments. GyTAR relies on the concept of identifying anchor paths of high connectivity, considering real time vehicular traffic variation and urban environment characteristics. While selecting intersections through which packets has to traverse in order to reach the destination, GyTAR chooses the intersection with the highest score attribute, where this score is a function of the distance and the vehicular traffic metrics. GyTAR assumes the existence of an accurate traffic-information system that it requires. IFTIS answers this requirement. Hence, vehicles around an intersection receiving a CDP packet, based on its content, will be able to calculate the score corresponding to the road density.

The density information disseminated in the traffic route serves the purpose of determining real-time traffic congestion for vehicular networks. Depending on the road traffic density, the driver can choose alternate paths to avoid the congested routes. The traffic density information can also be utilized at the road intersections to give the drivers an indication of the expected road traffic density in the route ahead of their journey. Apart from having the overall information about the traffic congestion, the notion of cell-based density estimation helps to record localized congestion problems and thus give early indications to drivers regarding accurate problem locations in traffic routes. This would help the drivers to control the vehicular speeds, thus avoiding possible traffic collisions, which are quite common in city environments.

VI. CONCLUSION AND FUTURE WORK

In this paper, we presented a completely distributed and infrastructure free mechanism to determine the vehicular traffic density in city environments. The distributed mechanism is a scalable mechanism that makes efficient use of the vehicles traversing the intersections to optimally manage and drive the traffic density estimation process. The performance analysis of the proposed mechanism depicted the accuracy of IFTIS and the promptness of information delivery based on delay analysis at the road traffic intersections. The analysis, conducted for different density values indicates that IFTIS can scale well enough to adapt to changing traffic conditions. Thanks to its distributed nature, IFTIS is well suited for accurate road traffic congestion warning systems and also for multi-hop vehicular communication protocols. We are currently studying the impact of IFTIS approach in vehicular ad hoc routing protocols to analyze the performance gains. We are also fine tuning our approach to identify performance loopholes and extend the mechanism to be applied to highway scenarios.

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