An Opportunistic Traffic Management System for Vehicular Networks

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Abstract—Road congestion is a serious problem both in terms of costs and time wasted. State of the art traffic management techniques such as traffic light synchronization, dynamic message signs and traffic management decisions are based on vehicle counts at streets and intersections. Vehicular networks could radically transform traffic systems. A peer to peer vehicular network can enable cars to prevent accidents and manage congestion. The use of an opportunistic vehicular network is both efficient and cost effective: cars are in-traffic sensors that provide real-time delay estimates on a fine grained scale of both space and time. A mobility management system should be distributed, act locally, be capable of sharing traffic information fairly among cars and take advantage of typical urban mobility patterns.

In this paper we propose an opportunistic vehicular network system in which vehicles receive local information about traffic towards their destination and dynamically update their routes given this information. We show the performance evaluation results in terms of efficiency and effectiveness on a realistic simulator that models both mobility and wireless network connectivity. We also indicate some results of a real testbed evaluation.

I. INTRODUCTION

According to “The 2007 Urban Mobility Report” by the Texas Transportation Institute, in year 2005 the traffic congestion cost to the nation (in the 437 US urban areas) added up to $78.2 billion. The same report also observes that more and more time is spent in cars due to congestion. A measure of this phenomenon is the increase of the Travel Time Index (TTI), the ratio of travel time in rush hours to travel time at quiet periods, that has steadily risen from 1.09 in 1982 to 1.26 in 2005.

Combating traffic congestion is the main focus of Intelligent Transportation Systems (ITS) which aim at managing traffic flows in routine and emergency situations. Traffic control is enforced mainly through traffic light synchronisation systems and dynamic message signs. Traffic management decisions are taken based on vehicle counts in streets and intersections through the use of movement detection systems such as cameras and induction loops.

These solutions to traffic management and road condition information systems are limited in a number of ways. First of all, a central repository where data is collected for analysis is in place: all the information is computed there and, if needed, redistributed (e.g., for traffic light control), with the usual problems related to scalability of the approach, timeliness of the information delivery and costs related to the communication. Second, the information collected is often quite coarse-grained, as it is usually collected by an infrastructure that monitors only a subset of streets.

On the other hand, the availability of networked vehicles [2], able to both sense road and traffic conditions and to communicate via wireless radio to other vehicles or fixed basestations is rapidly rising. These vehicles are often also equipped with navigation systems which provide knowledge of the exact location of the vehicle and its destination. We argue that opportunistic vehicular networks can improve the ways in which traffic monitoring and management are conducted. A network of vehicles can be established, exploiting the wireless links existing among the cars. This allows the decentralisation of the information system, together with the faster distribution of the information in localised areas.

As indicated in our related work section below, there have been a number of approaches which, in a way or another, tackle issues related to decentralised traffic data gathering, content dissemination, and traffic information management. In this paper we describe an approach that goes beyond the state of the art of traffic monitoring by also offering a solution for distributed traffic management. Vehicles collect information about the local traffic conditions by i) Acting as sensors in the environment, ii) by gossiping the sensed data to others. In brief, vehicles record the traversal time for each road segment and broadcast this information. Neighbouring vehicles receive this and relay it periodically, using a gossip protocol. Each vehicle collects the information relevant to its direction and destination and, based on the navigation system’s knowledge of the area, re-routes the vehicle if necessary. As we shall see in our evaluation section information is up to date and consistent throughout, for instance, the 4 x 7 km map we consider. This is thanks to the ability of gossip to perform well in dense and mobile networks [11]. Since data is locally distributed by many vehicles what is received is very fresh. For the same reasons cheating is difficult unless there is large scale collusion.

Our approach is evaluated using a novel simulation methodology: we combined a network simulator with a mobility simulator, and a realistic flow model of Portland traffic. The performance is compared with other approaches which include having full knowledge and an infrastructure based scenario.

The novel contributions of the paper can be summarised as follows:

- A decentralised opportunistic system to collect and dis-
tribute vehicular traffic information;
- An adaptive mechanism that aggregates the collected information in order to perform route calculation based on traffic information;
- A novel evaluation system which combines a network and a mobility simulator to allow the dynamic rerouting on cars in the simulation based on the computed estimation.

The paper is structured as follows: Section II discusses existing related work. Section III describes the scenarios which motivate our work and the requirements of a system able to work in those scenarios. In Section IV we describe the approach in details. Section V reports about our evaluation techniques and the performance results, while Section VI discusses the experimental trials we have conducted. Section VII concludes the paper listing possible future directions.

II. RELATED WORK

Traffic congestion is so important in today’s society that it would be impossible to cite all the work carried out on the subject. We will here discuss some of the main contributions to traffic management.

A key role in this area is played by traffic measurement methodologies and by the technologies employed to gather the measurements. One of the oldest and most widely spread technologies is induction loops. Induction loops are placed in the asphalt and provide punctual measurements for speed and traffic flow for that location. This metric suffers from a number of problems that limit its reliability and a more complete analysis of induction loops may be found in [12]. Video cameras are slowly replacing induction loops, but their widespread deployment is limited by their cost. They have the advantage of using end-to-end time rather than a point sample.

The same information can also be gathered using Radio Frequency IDs (RFIDs) placed on vehicles or by monitoring the movement of cellular phone flows [13]. The idea of using vehicles as probes was first introduced in [14]. The advantages of this approach are that it can provide feedback on any street segment, cuts large scale infrastructure deployment costs and if widely deployed provides a high redundancy of information.

Based on the information received by measurement systems control technologies are used to direct and influence traffic flows. The main control technologies that have been deployed to this date are traffic light synchronisation systems, Dynamic Message Signs (DMS), automatic toll systems, Radio Data Systems (RDS), Traffic Message Channels (TMS) and websites. Traffic light synchronisation systems adapt traffic light red and green times to traffic flows. Electronic toll collection systems implement dynamic pricing strategies to shift traffic demand. Such approaches do not in principle attempt to modify the travel routes of cars, but rather back-pressure traffic flows that are approaching congested areas. Real-time information is dispatched using DMS, RDS and TMC. These systems broadcast some brief information on the state of traffic and weather conditions, it is then up to drivers to infer which would be the best alternative route.

More recently, the advent of cellular phone technologies and the opening of GPS for commercial purposes have laid the path to new, commercial, traffic control systems. Commercial products such as Dash.net [15] gather GPS position and speed measurements and upload them through GPRS or WiFi. Such information is then processed and distributed to all vehicles, providing drivers with the three best possible routes to reach a destination.

Examples of vehicular networks helping monitor traffic exist: for instance Cartel [5] allows cars to collect sensed data about road pavement conditions and traffic to route back through the closest access point to a central server. Authors in [3] develop a traffic measurement system capable of identifying congested traffic and accidents from a vehicle. In [4] the problem of reporting traffic conditions in a privacy preserving condition is tackled. However, none of these systems use integrated data collection, local and decentralised distribution and dynamic route correction.

In [6] a system for the dissemination of information in an area is presented: the framework however does not take advantage of topological constraints to drive the dissemination, and only concentrates on notifying a percentage of nodes in a circular area. Works targeting multicast communication in vehicular networks recently appeared in literature [7], [8]. They used different versions of epidemic protocols to constrain the propagation of a message within the given area specified by the publisher. Other works [9], [10] instead define a notion of relevance to enable the routing layer to identify the areas in which the messages should be delivered. With respect to these papers, our work concentrates not only on dissemination in specific areas but on propagation of fresh information along all routes to reach as many vehicles as possible. We show in our evaluation that this large scale gossip is not influencing negatively the performance.

As we said, our testing approach uses real maps and street information to create realistic models of vehicle movement. There is some previous work in this area, a survey of which may be found in [16]. TIGER maps are introduced to spatially restrain traffic flows to urban streets in [18]. A model that considers the state of neighbouring nodes in the motion of a car is shown in [19]. Finally, the case of swarm and group mobility models, which may be best suited for military scenarios, is considered in [20].

III. SCENARIO AND SYSTEM REQUIREMENTS

Every day millions of vehicles flow from residential areas to business areas in the morning and back in the evening. As we have seen in Section II, various traffic measurement systems are deployed to support smart vehicular routing around accidents or heavily congested areas. The main flaw of such systems is that they monitor only a very small subset of roads, thus providing limited and coarse grained traffic information.

We envision a future where each vehicle will be able to continuously assess and correct its prediction on the best route to reach its destination. To do this each vehicle will be equipped with a NAVSAT system capable of: (a) sensing
information about traffic (i.e., other cars present in the street being currently traversed; (b) providing/receiving this information to/from neighbouring vehicles; (c) estimating the best route to destination from the current position, based on the information gathered and received. The NAVSAT system is then much more than a simple topology based routing system. A NAVSAT system becomes an element of a distributed system that cooperatively collects and exchanges traffic conditions and a sophisticated traffic estimator, based on the collected information. Moreover, users will be encouraged to provide destination information by the ability of receiving updates on traffic and best routes.

Such a system would be useful in many traffic scenarios. Primarily, such system is useful when infrastructure-based traffic monitoring systems are not deployable for various reasons. This is in fact quite common, only a few cities around the world (e.g., Los Angeles, London, etc.) have installed a coarse grained monitoring system able to advise drivers. Even in these cases it is only for a subset of arterial roads and highways. A number of basic characteristics identify a system able to offer the solution just described:

1) Traffic Sensing. The system should be able to sense traffic conditions. To monitor what is sensed, traffic metrics should be defined. Speed, traffic volume, traffic density and trip time are the most commonly used metrics;
2) Traffic Information Dissemination. Each piece of traffic information should reach the right vehicles at the right time. Excessive redundancy risks to congest the feedback channel, too little can lead to wrong decisions;
3) Traffic Estimation. Questions about how traffic information and the absence of information should be interpreted need to be answered. This interpretation has a fundamental impact on the performance of the system.
4) Performance Evaluation System. It is not possible to satisfy any of the previous requirements without being able to evaluate the consequences of each design choice on performance. The complexity and the scale of the real system makes “on field” evaluation prohibitive. There is a need for tools capable of producing a realistic traffic emulation and handling dynamic routing, i.e., the assessment of collected data and the correction of the mobility of the vehicles at run time.

IV. CATE: Computer Assisted Travelling Environment

In this section we introduce CATE, a Computer Assisted Travelling Environment.

CATE collects travel time samples relevant to the navigation system’s route and dynamically chooses the best route given the information received. CATE is completely decentralised. It is composed of various modules: a traffic sensor component, which collects data about the time needed to drive through road segments, a traffic dissemination component, which helps the diffusion of the sensed data collected, a traffic estimation component, to allow the estimation of the time to destination given the information about traffic received by other vehicles.

In Figure 1 we describe the various interactions of the modules. We now illustrate the components in detail.

A. Traffic Sensing Module

Every vehicle can be seen as a mobile traffic sensor i.e., every vehicle collects traffic information. It is obvious that there are many ways to collect such information (e.g., coarse/fine grained samples, speed samples, density estimations, average speeds). We selected a simple, yet efficient way: We model the street topology as a directed graph, where each link connects two intersections. This choice is consistent with the majority of map databases (e.g., [17]) and navigation systems. Therefore, it is easy for existing navigation systems to collect information about traversed road segments and the same information can be used by other vehicles to estimate traffic conditions. Note that in this model a two-way street is modelled with two directed links, each direction having its own link ID.

We choose the delay incurred in driving through a road segment as an estimate of the traffic conditions. This is the information drivers are most interested in. By correlating the samples that are generated by different vehicles, we will show that it is possible to compute and track, in real time, the trip time for each vehicle.

In our implementation every time a vehicle exits a link it creates a sample of type \{\text{linkID, delay, timeStamp, carID}\}. The linkID should be unique per street segment and direction throughout the vehicular network. The delay is measured as the time spent by the vehicle on the link with the given linkID. The timestamp is the GPS time. The carID, inserted to ensure that samples may be uniquely identified, can introduce privacy concerns. For this reason the NAVSAT system can use a random number instead.

B. Dissemination Module

Our aim is to design a simple but effective dissemination technique. We will devote a few lines in Section VII to the
numerous possible optimisations that could be added to this dissemination module.

The primary objective of the module is to disseminate the collected information throughout the vehicular network. It should:

1) Collect as much information as possible for each link on the map;
2) Propagate the most recent information;
3) Limit traffic overhead.

Previous studies [23] [22] show how the performance of traditional ad hoc routing protocols, in terms of goodput, is heavily affected by vehicle density in urban environments. Gossip-based ad hoc routing is proven [11] to be very effective in disseminating large amounts of information in dense networks. For this reason we implement gossip-based routing in CATE. Periodically, each vehicle selects a subset of the sample information in its buffer (notice that the buffer contains both the vehicle’s generated information and information collected by other vehicles) and broadcasts this information to every neighbour.

A key element of the dissemination module is the sample selection algorithm (i.e., which part of the information that a vehicle keeps should be broadcasted to the neighbours, assuming that we can only transfer a fraction of a vehicle’s knowledge). Therefore, when a packet is built, it needs to include only the tuples \{linkID delay timeStamp carID\} that provide high utility in terms of map coverage and sample freshness. Even though a limited amount of information can be propagated per each link, accuracy of information should be preserved. In our implementation we use a simple utility metric that maximises both coverage and information freshness. We select, in round robin fashion on links, the newest sample that was not already selected in the previous round, until the sending buffer is filled. As we shall see in Section V, even this simple approach provides good results in a realistic urban scenario. There are numerous optimisations that can improve the information dissemination procedure (e.g., some type of information aggregation, or utility functions that include topology information to disseminate only information that is related to the dissemination area).

C. Traffic Estimation and Routing Module

Each vehicle receives messages from the dissemination module in the form \{linkID delay timeStamp carID\}. This information is then used by each vehicle to compute the shortest path (in terms of time required) to destination. Such choice has been shown [1] to be non-optimal in minimising the total trip time. In order to minimize aggregated trip time, each vehicle should follow the path that minimises the sum of delays and the delay increments generated by its choice of following such path. The estimation of this second quantity is still an open research topic which is beyond the scope of this paper. For this reason we implement a routing algorithm that chooses the shortest delay path to destination. This is performed on a local (selfish) basis.

To select the route of the vehicle we use a pure Dijkstra-like algorithm on a weighted graph that represents the map with the current known traffic conditions. Therefore, before running Dijkstra we generate weights per each link based on the collected information. We tested a few simple solutions to evaluate their impact on traffic patterns:

- **Most Recent Estimate:** for each link we select the freshest sample (in terms of the time when the sample was taken, not received by the current vehicle): \(W_{\text{linkID}} = \text{Delay}(\text{linkID}, \text{mostRecent})\). This approach is obviously subject to fluctuations, given that samples can vary rapidly or be erroneous. As we shall see in Section V, however, this solution still improves performance and adapts well to the bursty nature of vehicular traffic.

- **Bayes Estimate:** We use a simple Bayesian estimator to predict the traffic conditions using a large number of samples taken at different time instances: \(W_{\text{linkID}} = (1-c) \cdot \text{BayesWeight}_{\text{linkID}} + c \cdot \text{DefaultWeight}_{\text{linkID}}\). Where \(c\) is an ageing factor calculated by: \(c = \frac{\text{Min}(\text{carTime} - \text{RecentsampleTime}, \text{maxAge})}{\text{maxAge}}\).

- **Default:** The weights are determined by the speed limit for this segment: \(W_{\text{linkID}} = \frac{\text{MaxLength}}{\text{SpeedLimit}}\). This weight is also used in all previous methods when there is no collected information about this link.

V. Evaluation

To evaluate CATE a sophisticated tool was required, one capable of producing a realistic traffic emulation and handling dynamic routing. The tool need to perform this testing on a very large scale. In this section we first describe our novel evaluation environment and then we report on the performance of our system.

Our novel evaluation environment builds upon two simulators, a vehicular mobility simulator, MobiDense [21], and a telecommunication network simulator, QualNet [24]. These two simulators constantly interact: future mobility decisions are influenced by the network dissemination (e.g., collected information), and the network dissemination is influenced by the mobility patterns (location of the vehicles). A depiction of the interactions between the two tools is shown in Figure 2. We will now describe the implementation in more detail.

A. MobiDense

MobiDense [21] is a mobility simulator which combines topology and traffic flow information to generate a mobility file. MobiDense requires the following topology inputs:

- Intersection positions;
- Street descriptions, which define the properties of streets that connect intersections;
- Intersection stop probabilities.
Traffic light definitions, where traffic light positions, timings and phases are given.

The flow of each street segment is tuned by adapting intersection stop probability and red/green time phases of traffic lights. If a vehicle stops is the first in queue, it waits for one second at the intersection and recomputes whether it should stop for one more second or move on. Queues propagate backwards at ingress streets such that a vehicle cannot enter a full street segment.

Traffic flows are constructed by providing a source-destination file that defines the origin and end positions for each vehicle and the time at which a vehicle begins its journey. The streets traversed by each vehicle depend on the routing algorithm that is implemented. MobiDense allows interchangeable "behaviours" for the vehicular re-routing and the traffic data aggregation. In our testing process these behaviours are part of the CATE traffic estimation modules. These estimate the traffic given the received data and recompute the best route (see Section IV).

B. QualNet

QualNet and MobiDense continually provide information to each other. MobiDense provides position and speed updates to QualNet, acting as a GPS device. The positions are used to place the vehicles in the network simulation area.

QualNet implements CATE's network and dissemination modules. Each vehicle selects the information to be propagated. This information is a subset of the information that has been collected from the vehicle itself (acting as a sensor) plus information received from other vehicles through the wireless network. When new information is available (either by local observation or through the network), it is stored in a shared database as this information can affect the future mobility decisions of this vehicle.

C. Evaluation Settings

For our evaluation we used a detailed map of Portland, Oregon. The area is approximately 4 x 7 km and includes downtown Portland, (a map is depicted in 5). Start and end points of the journey of each vehicle are created from the traces generated at the Los Alamos National Laboratories, using TRANSIMS. More details about how the traces are derived can be found in [22]. The realism of these traces lies in the fact that they were created using real activity location information. Activity location information, such as information on where residential areas and business areas are, is used to define start and end points of traffic flows at a particular time. The traces generated with TRANSIMS, for example, see a good amount of cars flowing in the morning from the suburbs to downtown Portland. We also analyse TRANSIMS traces to derive topological information about Portland, such as traffic lights position/delay, intersection stop probabilities, speed limits and road capacities. We here demonstrated the potential benefits of ad-hoc dissemination in terms of trip time minimisation for a more realistic and more complex scenario than those we introduced before.

The performance results aimed at evaluating the impact of the algorithms presented in Section IV. The main performance measure is the total vehicle’s trip time, but there are also other factors that should be considered. For example, it is important to understand (a) how long the chosen routes are compared to the shortest routes (in seconds); (b) how information delay affects trip delays; (c) what amount of network traffic such system produces.

D. Traffic Information Evaluation

As we described before, each vehicle receives a number of traffic samples and stores them, grouped by linkID, in a local buffer. In case no information is known about a link, all the strategies we implement assume that there is light or no traffic on such link (we assume that vehicles travel using the speed limit of that link).

We here compare the 3 different traffic estimation algorithms described in Section IV: (a) Most Recent Estimate; (b) Bayes; (c) Bayes with Ageing. Additionally we will compare these strategies with the case where no information is disseminated and we just use speed limits to select the shortest route to vehicles’ destination.

We used the traffic traces from the Portland scenario to vary the density by removing vehicles but keeping the characteristics of the original Portland traces. We simulated very low density scenarios (33% traffic) to normal traffic scenarios (100%) that are directly extracted from the traces.
As we see in Figure 3, when density increases the trip times escalate quite quickly going from 400 seconds (7 minutes) to 1200 seconds (20 minutes) in average. When CATE is used, the trip times are significantly shorter, especially in cases where there are traffic congestion problems. This happens because CATE is able to assist drivers to find routes that are less congested and, thus, to avoid the major traffic hotspots. For example, under normal traffic conditions the average trip time was 29% faster, which is a significant improvement.

In terms of weight calculation algorithms, we observe that using the most recent information and Bayes strategies provides the best results for this simulated environment. The main reason is that collected information is rather accurate and high correlation of information is not required. Bayes with ageing is still better than no-information but worse than the other two methods due to the fact that conditions are not rapidly changing in road traffic.

Figure 4 presents a histogram of the trip times gain/loss for normal traffic conditions when CATE is used. Negative values represent improvement in trip times. As we observe, there is a large number of vehicles (34%) that had between 1 and 25% reduction in trip time. There were also luckier vehicles able to avoid big traffic queues and completed their journey two or three times faster. However, at the same time, we see that some of the drivers actually required more time when CATE was used. This is due to some of the traffic is diverted into smaller roads which become busier as a consequence. However, we can clearly observe that far fewer drivers have their time increased rather than decreased and their trip times are not more than 1.5x longer. In total 23% of vehicles were not really affected (+-10% trip time), 17% needed an additional 10% time to finish their trip, and 60% of the vehicles saved at least 10%.

To further investigate this behaviour, we created a coloured map that represents the difference between the speed limit and the actual speed of the vehicles (Figure 5). As we see, when no information is disseminated there are areas that are congested but when CATE is used, traffic is diverted away from these hotspots. However, other areas that were not previously congested show some traffic slowdown.

**E. Traffic Information Dissemination Quality**

It is important to understand the suitability of gossip for traffic information dissemination. An unfair dissemination of samples can lead to groups of vehicles making erroneous traffic decisions that will then affect their journey. Inconsistencies in distributed traffic information may be due, for example, to different densities of vehicles or to the topological characteristics of the map.

We estimate the quality of the information that is received using gossip dissemination by comparing it to the amount of information that would be available in an ideal case, where all information would reach all cars at the instant it is produced. We call this infinite bandwidth/zero delay scenario, full knowledge. We observe the variation in aggregated average traffic trip time, between a fleet of vehicles that gossip information and a fleet of vehicles that receive all the available information immediately. Note that this mode is obviously an artefact of the simulation where global knowledge is present. We should also notice that this is not the globally optimal case as every vehicle’s reaction is still independent. We just compare with the ideal dissemination algorithm for this application.

Graph 6, shows the results for the same traffic estimation methods used before, yet now the information is not collected with the dissemination protocol (gossip) but all the collected information is instantly available when a vehicle requires to
run the routing algorithms. The first thing we can observe is that the same trends appear as when CATE is used. The comparison with Figure 3 reveals that trip times are slightly smaller as more (and newer) information is available to the vehicles. However, the trip times that CATE achieved are very close to this, revealing that a simple vehicle-to-vehicle dissemination protocol can provide sufficient information to the vehicles.

In terms of information freshness, gossip is quite efficient in spreading the collected information quickly. Figure 7 shows a zoomed area of the map (near the middle bridge). In this graph, we plot the average age of the collected information about the bridge highlighted with the (yellow) arrow. As you can see, in areas near the entry points of the bridge the information is less than one minute old. Vehicles that are further away (2km) will use information that is about 3 minutes old. In fact, in the whole simulation area we could rarely find vehicles that were using information that was more than 15 minutes old. This further explains why CATE can perform close to full-knowledge: traffic trends (i.e., congestion) builds up slower than the speed of the disseminated information giving the vehicles enough time to react.

F. Infrastructure vs Infrastructureless Probing

In this scenario we compare with existing solutions that use cameras or induction loops in selected street segments and where information is disseminated using cellular network (e.g., 3G). With these current systems where vehicles can access fresh and accurate information but only for a subset of the street segments. In CATE, however, information is collected by all the vehicles (and, thus, from all street segments and very fine granularity) but information is not as fresh as in those systems. Additionally each vehicle has different views of the traffic situation (e.g., has collected different information). For our simulations, we selected 10% of the streets to use these cameras and the information is then instantly propagated to all the vehicles without any more delays (which, again is a very optimistic assumption).

Figure 8 shows the trip times when different amount of infrastructure is used. It is obvious that CATE is able to outperform most of the existing solution just because it collects far more information using each vehicle as a mobile sensor. Information might be delayed as reported in previous graphs, but it is fresh enough to avoid congestion hotspots. The graphs also reports about the full knowledge mode.

G. Gossip Network Overhead

We measured the dissemination protocol network overhead in order to estimate the communication network congestion. In our simulations we used a gossip interval of 10 seconds and a 2000bytes transfer buffer. Figure 9 presents the transfer rates experienced by each node. As it can be observed, there is plenty of capacity for more data in the medium. Vehicles only receive data at 23kb/sec. This is about 1.5Mb/minute or 90.000 samples per minute.

VI. ON THE ROAD PRELIMINARY EXPERIMENTS

In order to assess the feasibility of an actual deployment of the CATE system we performed preliminary experiments using the UCLA Campus Vehicular Testbed (C-VeT) [25]. The UCLA testbed, provides a platform for researches to develop and evaluate applications and protocols for vehicular networks. In particular, C-VeT offers both Vehicle-to-Vehicle and Vehicle-to-Infrastructure connectivity, a virtualized shared environment to perform experiments (similar to planet), and a number of tools to assess the record system behaviour and
A. Experimental setup

On July 23-26, 2008, we performed several experiments to assess the feasibility of CATE in an actual vehicular network. In particular we designed two classes of experiments aimed at studying the effectiveness of content dissemination. Furthermore we performed basic connectivity experiments to evaluate the amount of data that can be transmitted across two vehicles that cross each other in the opposite directions in a urban scenario. The experiments were performed in the UCLA campus (Los Angeles, CA). In the experimental setup each vehicle is equipped with an industrial grade PC equipped with an of the shelf Zyxel AG-225H card (compliant to IEEE802.11a/b/g), and a GPS sensor powered by a SIRF III chipset. We performed experiments with two and eight vehicles. While the number of vehicles is not representative of the city vehicle density it can be used to assess how a dissemination system like CATE can perform in a very sparse environment. During the experiment the the wireless cards were set to work on Channel 11 and operate in IEEE802.11g only with no rate fallback. The area around UCLA is populated with a large number of access points that range in all the channels. In particular a war-drive performed with Netstumbler [26] and GPS showed that on average at any point it is possible to receive signals from about 40 different APs. No RTS/CTS mechanism was employed during the experiments, and the hosts were assigned a static IP as well as a predefined SSID. The SSID was publicly broadcasted and beaconing was enabled.

B. Mobility

The mobility patterns used during the experiments were designed to emulate the city traffic. The experiments have been carried out during daylight on regular business days and the mobility has been affected by the regular traffic of the Westwood area - this includes business and residential traffic. Each driver participating in our experiments has been instructed to perform a specific path across the Westwood village as depicted in Figures 10-a for the two car experiment and by Figure 10-b for the eight car experiment. The driver were requested to repeat the path throughout the experiments.

C. Experiment setup

We performed the following different experiments:

- **basic connectivity**: this experiment aims at evaluate the ability to deliver traffic under different mobility conditions. The experiment was performed using Iperf injecting UDP traffic[27].
- **mobile dissemination**: content dissemination in a fluid traffic condition.

1) **Basic Connectivity**: in order to assess the basic connectivity of mobile nodes in traffic we performed two different experiments. First, using Iperf, we measured the throughput achieved by two stopped nodes thus defining the best case, then we performed the measurements with two cars travelling in opposite direction at 30Mph (or 13.4m/s). An high gain omnidirectional antenna was installed in the vehicle rooftop and the range in line of sight was on average 250 meters\(^1\).

We repeated the experiment 10 times and averaged out the results. The achieved throughput computed at the UDP layer is 30.004 Mbit/sec, on average, with a peek throughput of 30.3 Mbit/sec, and a minimum of 28 Mbit/sec for the still scenario. In the mobile scenario two cars \(\alpha\) and \(\beta\) started from being out of range on a straight road. The vehicles were then driven towards the same point at a constant speed of 30Mph. Once \(\alpha\) and \(\beta\) are detected to be radio range (this is performed by the OS and IP stack)an Iperf stream of UDP packets from \(\alpha\) to \(\beta\) is started. We measured transferred data during each inter-contact. On average \(\beta\) received 7.24MBytes. The connection between \(\alpha\) and \(\beta\) in this scenario lasted about 15 seconds.

2) **mobile dissemination**: we implemented the basic mechanisms behind CATE in our testbed to investigate its applicability to a real vehicular network. In particular we implemented a basic hello protocol to discover the neighbourhood and a dissemination protocol that delivers the data to all the neighbourhood. This approach has been chosen to emulate the behaviour of a DSRC that offers acknowledged broadcasts

\(^{1}\)Unfortunately in urban scenarios the radio propagation conditions change too frequently to perform precise measurements
as well as high speed broadcast [28]. We performed several experiments using eight vehicles along the path shown in figure 10-b. Each vehicle had a set of information to be disseminated to all the other vehicles via gossiping. The application had been developed in Java and deployed in all the cars. The application transmits hello packets at 1Mbit/s with no acknowledgement while the data packets are transmitted at the nominal rate of 54Mbit/s with the standard layer two acknowledgement mechanism. We performed two different set of experiments:

Single Hop gossiping: Each vehicle had a set of information to be disseminated to all the other vehicles using our gossip mechanism. The application had been developed in Java and deployed in all the cars. In this experiment we measured the average amount of data transmitted during an encounter between vehicles; We achieved 2.35MB per encounter. This value is lower then the experiment with two cars, and is mainly due to two factors: (a) channel load (each car is transmitting to 2-3 neighbours on average), (b) the mobility pattern created a long tail distribution of contact times ranging from three seconds to 30 seconds. The peak data transfer achieved has been 3.35 MB and the lower limit has been 1.76 Mbyte.

2MB chunk dissemination: In a second set of experiments we used only one car as data source for a 2Mbyte data chunk. The experiment aims at estimating the average delay to deploy data to the whole population of eight nodes. The chunk size has been chosen according to the application requirements and the eight nodes mobility pattern is the same as that used for the previous experiment. On average a 2MB chunk can be deployed in 125 seconds. The first vehicle receives the data in less than 20 seconds, the majority of the vehicles (5 out of 8) receive the data in 72.5 seconds, and the later two vehicles receive the data in 118 and 125 seconds respectively.

While the preliminary experiments described in this section are far from a realistic scale and scenario, they show that the proposed application is actually feasible in a real vehicular network with today’s off the shelf equipment and the computation power available in any SatNav or PDA device.

VII. CONCLUSION

In this paper we have described a decentralised approach to road traffic management, one which takes advantage of the existence of in vehicle connectivity and sensing. The approach allows the recalculation of the best routes to destination while on the road, based on the collected information. We also presented our novel testing framework, which allows realistic movement to be considered and to account for vehicle rerouting during the simulation.

There are numerous future works which can spawn from this paper, most importantly, studing the optimisation of gossip dissemination. One possible approach is that of publish-subscribe [6]. We also want to study techniques for the intelligent distribution of information, in order to avoid the secondary congestion generated by the dissemination of identical information (e.g., avoiding a closed road can congest the obvious second best road).

REFERENCES

[27] http://www.dart.nlanr.net/Projects/Iperf/