Decreasing Greenhouse Emissions Through an Intelligent Traffic Information System Based on Inter-Vehicle Communication

Allan M. Souza\textsuperscript{1}, Azzedine Boukerche\textsuperscript{2}, Guilherme Maia\textsuperscript{3}, Rodolfo I Meneguette\textsuperscript{1}, Antonio A. F. Loureiro\textsuperscript{3}, Leandro A. Villas\textsuperscript{1}

\textsuperscript{1} University of Campinas, Campinas, SP, Brazil
allanms@lrc.ic.unicamp.br, \{ripolito, leandro\}@ic.unicamp.br
\textsuperscript{2} University of Ottawa, Ottawa, ON, Canada
boukerch@site.uottawa.ca
\textsuperscript{3} Federal University of Minas Gerais, Belo Horizonte, MG, Brazil
\{jgmm, loureiro\}@dcc.ufmg.br

ABSTRACT
Traffic congestion is an urban mobility problem, which generates stress to drivers and economic losses. In 2012, greenhouse gas emissions from transportation accounted for about 28\% of total U.S. greenhouse gas emissions. Intelligent transportation systems can assist in the identification and reduction of vehicular traffic congestion. In this context, this work proposes an intelligent traffic information system based on inter-vehicle communication to avoid vehicle traffic congestion. The main goal of the proposed solution is to decrease CO\textsubscript{2} emissions, the average trip time and fuel consumption by avoiding congested roads. Simulation results show that our proposed solution can reduce the average trip time, and the overall CO\textsubscript{2} emission and fuel consumption. In particular, the trip time was decreased approximately 86\%, the fuel consumption 40\% and the CO\textsubscript{2} emission 55\%. This shows the potential of the proposed solution.

Categories and Subject Descriptors
C.2 [COMPUTER-COMMUNICATION NETWORKS]: Network Protocols; H.4 [Intelligent Traffic Information System]: Miscellaneous

Keywords
VANETs; Greenhouse Emissions; Intelligent Traffic Information System; Data Dissemination

1. INTRODUCTION
The transportation sector is responsible for the second largest atmospheric greenhouse gas emissions in the United States.

For instance, in 2012, greenhouse gas emissions from transportation accounted for about 28\% of total U.S. greenhouse gas emissions [6]. Therefore, over the past years, worldwide authorities have started implementing regulations to decrease global pollution. However, as the number of vehicles on the roads grows, we have more traffic congestion [12].

Traffic congestion has several negative impacts for society, such as, the inability to forecast travel times accurately, which results in wasted times for both motorists and passengers. Moreover, blocked traffic may interfere in the passage of emergency vehicles while they are answering urgent calls. It also leads to an increase of the overall fuel consumption and carbon dioxide emissions, due to long idle periods and frequent acceleration and braking.

There are four fundamental ways to reduce the carbon emissions from the transportation sector. The first one is to reduce the transportation activity itself, by encouraging people to use alternative transport systems, such as bicycles. The second one is to substitute current energy sources by alternative fuels that are less carbon intensive, such as bioethanol. The third is to increase the energy efficiency of transportation vehicles. The last one is to increase the efficiency through which transportation systems provide mobility [7]. In this work, our goal is to increase the mobility efficiency in transportation systems.

Intelligent Transportation Systems (ITS) are management systems that aim to improve the efficiency of transportation by integrating information, communication, sensors, control and computer technologies. An efficient and promising research area for ITS is VANETs (Vehicular Ad hoc Network). In VANETs, vehicles are equipped with embedded sensors, processing units and wireless communication interfaces to enable communication with other vehicles and roadside units (RSU), thus, allowing the creation of a spontaneous network while vehicles move on the roads and highways [14]. Preventing accidents, improving safety on roads, and reducing pollution and congestion are some of the goals of VANETs.
Several approaches have been proposed to detect and reduce congested areas in highways scenarios [2, 5, 16]. Those studies are based on evaluating the traffic density, vehicle's speed or traveling time. Wireless communications have been used between roadside units and vehicles to collect vehicle's speed, location and destination. Although using this technique seems attractive, it actually faces many network communication challenges, such as, redundant data and bandwidth flooding [15], late and wrong congestion level evaluation [16], and reliability problems [9]. Moreover, the proposals are limited to specific scenarios, since they depend on the infrastructure (roadside units) in the monitoring areas.

In this work, we propose an intelligent traffic information system based on inter-vehicle multi-hop communication to minimize vehicle traffic congestion by taking into account the aforementioned network challenges. In particular, to overcome them, we use our efficient and robust data dissemination protocol for highway environments with different traffic conditions (DRIFT) [13] to disseminate accident warnings on the road. Such dissemination proposal eliminates the broadcast storm and maximizes the data dissemination capacity among network partitions with little delays and low overhead. Moreover, our solution can avoid road traffic congestion and decrease CO2 emissions, the average trip time and fuel consumption.

The remaining of this paper is structured as follows. In Section 2, we provide a general overview of the existing approaches for decreasing greenhouse emissions of the transportation sector. Our proposal for decreasing greenhouse emissions through an intelligent traffic information system based on inter-vehicle communication is described in Section 3. In Section 4, we present a detailed performance evaluation and the simulation results. Finally, Section 5 concludes the paper with remarks and future work.

2. RELATED WORK
The aim of this work is to reduce the trip time, fuel consumption and gas emissions using a vehicular ad-hoc network (VANET) as a distributed intelligent traffic information system. In this context, there are several studies in the literature that deal with this problem. Most of them focus on the communication of vehicles with traffic lights at intersections. For instance, by optimizing the traffic light timing, Rakha and Kamalanathsharma [10] and Barba et al. [1] aim to reduce the time that vehicles spend on red traffic lights in order to smooth the traffic flow. Those studies predict when traffic lights will change the light state allows for smoother deceleration/acceleration of vehicles, and also for turning off the engine of vehicles when waiting for the traffic light to turn green [1], thus helping to reduce fuel consumption.

Some authors propose to use a microscopic vehicular traffic model to measure vehicle consumption and CO2 emission when a vehicle approaches a traffic light. Then, using a traffic light signal (TLS) application combined with a geocast protocol, it delivers TLS data to all vehicles in selected geographical areas. Therefore, these vehicles can calculate economically and environmentally friendly speeds to avoid inefficient stopping and accelerations, thus reducing CO2 emissions and fuel consumption. With the same idea, Rakha et al. [10] and Barba et al. [1] use a TLS application with signal phasing and timing to estimate fuel consumption and manage vehicle’s speed, decreasing CO2 emissions and fuel consumption.

Wei-Hsun Lee et al. [8] create a decision-tree based on green light driving to reduce CO2 emissions. The idea of that work is to allow traffic lights built-in with roadside units to send broadcast messages to nearby vehicles. Those messages contain countdown and queuing related information. When the on-board units (OBU) of nearby vehicles receive those messages, they can determine the best driving speed. Doolan and Muntean [4] introduce EcoTrec, a novel eco-friendly routing algorithm for vehicular traffic that relies on vehicle to vehicle (V2V) communications. EcoTrec considers road characteristics and existing traffic conditions to improve fuel consumption and reduce gas emissions. For that, vehicles disseminate their routes and fuel consumption while on trip. EcoTrec uses that information to determine the best routes and redirect the vehicles accordingly.

In summary, application for road traffic control in VANETs can be broken down into identifying, minimizing and preventing congestion. The identification of road traffic congestion tries to effectively characterize congestion on roads. The minimization corresponds to an attempt to reduce the detected congestion and, finally, congestion avoidance is a complex approach, since it needs to manage flows of vehicles on roads to prevent the onset of congestion. While many studies in the literature aim to identify and minimize congestion, our work aims to prevent congestion. In this context, this paper proposes an Inter-Vehicle Communication (IVC) algorithm to prevent congested roads caused by accidents.

The next section describes our proposed solution.

3. PROPOSED SOLUTION
The goal of our approach is to notify drivers of existing accidents, and, consequently, congested street segments, through a cooperative multi-hop dissemination process. To disseminate an accident warning, we used our efficient and robust data dissemination protocol for highway environments with varying traffic conditions (DRIFT) [13]. In summary, DRIFT is a distributed protocol for data dissemination in highway environments, which does not require any infrastructure support, i.e., it uses only the V2V (vehicular-to-vehicular) communication technology. The main objective of such protocol is to guarantee data delivery to all vehicles located in an area of interest, under several traffic conditions, by incurring low overhead and short delays. Apart from that, and differently from many solutions found in the literature, vehicles using DRIFT do not need to build a neighbor table, which is a desirable feature when we consider the dynamic nature of VANETs. For this end, DRIFT defines a preference zone to eliminate the broadcast storm problem and uses a store-carry-forward technique to deal with disconnections under sparse scenarios. Vehicles that are inside this preference zone and are moving in the same direction as the source have a higher priority to retransmit data messages. Conversely, vehicles moving in the opposite direction of the source vehicle are responsible for storing and carrying the messages (for more details, see [13]).

In the proposed intelligent traffic information system, when there is an event detection (e.g., accidents or road conges-
Figure 1: An example of a route change

Algorithm 1: Performs the accident warning dissemination and decides to change vehicles’ route or not

**Input**: N // Set of vehicles within the area of interest
1 Source // Vehicle that starts the accident warning dissemination
2 Warning // Accident warning message
3 (s_x, s_y) // Emitting vehicle coordinates
4 (r_x, r_y) // Receiving vehicle coordinates

**Output**: Decision to change vehicles route or not and the set of vehicles which will continue the accident warning dissemination

```
foreach r ∈ N do
    accidentPoint ← getCongestedEdge(tfSource, ySource);
    // Set of edges of the route of vehicle r
    route ← getRoute();
    if accidentPoint ∈ route then
        // Vehicle r changes its route
        alternativeRoutes ← getRoutes().exclude(accidentPoint);
        newRoute ← shortestPath(alternativeRoutes);
        changeRoute(newRoute);
    end
    // Vehicle r continues the accident warning dissemination
    if First time receives Warning message then
        distToSender = (s_x − r_x)^2 + (s_y − r_y)^2;
        defaultDelay = 0.01 × communicationRadius;
        if Inside zone of preference then
            // Waiting time for priority 1
            Delay = defaultDelay + random(0, 0.01);
        end
        else
            // Waiting time for priority 2
            Delay = defaultDelay + random(0.02, 0.05);
        end
        // Vehicle r schedules the transmission
        r.ScheduleMessage(Delay);
    end
    else
        if Scheduled message then
            if Dist(r, Source) < Dist(s, Source) then
                Cancel message scheduled;
            end
            Discards the received message;
        end
    end
end
```

Initially, each intended recipient, represented in Algorithm 1 by r (Line 5) and identified in Figure 2(a) by the numbers 1, 2, 3 and 4, receives the accident warning message broadcasted by the Source (Line 1). Then, each vehicle verifies whether the accident happened on a road in its planned route (Lines 6–8). If the condition is satisfied, then the vehicle r computes an alternative route. To calculate an alternative route, vehicle r first checks all possible routes to its destination, excluding the routes that cross the accident area. In possession of such alternative routes, vehicle r selects the shortest one. Finally, vehicle r can take the alternative route and avoid the congested area.

Figure 1 shows an example of a route change made by vehicles that would have to pass through an accident area. In that figure, we can see an accident that closed a road, thus creating heavy congestion. Therefore, the source vehicle starts an accident warning dissemination to notify drivers about it. Eventually, such information arrives to distant drivers who have not entered the congested road yet. Then, the vehicle confirms that the accident is on a road in its planned path (represented by a red line in the figure). Consequently, the vehicle calculates a new route (represented by the green line in the figure) to avoid the congested road and continues with its trip without any further problems.

After receiving the warning dissemination and deciding whether to change the route or not, each vehicle r proceeds with the dissemination process to notify further drivers (Lines 12–3). For that, vehicle r verifies whether it is the first time that it has received the warning (Line 13). If it is, then r calculates its distance to the emitter of the warning, and using such distance, it computes a default delay ((Lines 14 and 15), which will be used to compute the final delay to retransmit the message. Thereafter, r checks whether it is inside the preference zone or not. Vehicles inside the preference zone are assigned shorter delays when compared with vehicles that are outside that zone, i.e., they have a higher priority to retransmit the warning. Either way, r computes the final waiting delay and schedules to retransmit the message. While waiting to retransmit, if r overhears a duplicate of the warning from a distant vehicle, it cancels its retransmission, otherwise, the retransmission proceeds. Such process continues until the whole are of interest has been covered. For instance, in Figure 2, at time instant 1 (Figure 2(a)), vehicle 5 is the source of the warning, so it creates a message.
and broadcasts it to its neighbors. Then, at time instant 2 (Figure 2(b)), vehicles 1, 2, 3 and 4 schedule to retransmit the message. Since vehicle 2 is inside the preference zone of vehicle 5 and it is the farthest vehicle, it will rebroadcast first. Therefore, vehicles 1, 3 and 4 cancel their rebroadcasts, avoiding redundant retransmissions. The process goes on until all vehicles in the area of interest has received the warning.

4. PERFORMANCE ANALYSIS

This section describes the scenario and performance assessment of the proposed solution by means of simulation experiments using the OMNeT++ 4.3 network simulator, an event-based network simulator. We also use the Simulator for Urban MOBility 0.17.0 (SUMO) [3] to build the scenarios and the vehicle mobility model. Furthermore, the experiments rely on the network framework Veins 2.1 [2], a well-known tool in the research community that implements the IEEE 802.11p protocol stack, signal attenuation caused by obstacles and other features used in our analysis. In order to calculate CO2 emissions and fuel consumption, we use the EMIT model integrated in SUMO. EMIT is a simple statistical model for instantaneous emissions and fuel consumption of vehicles based on speed acceleration that is derived from the Handbook Emission Factors for Road Transport (HBEFA) [3] formula.

4.1 Scenario Description

In this work, we use a realistic scenario for the simulations, taken from the OpenStreetMap [4]. We considered 30 km of the SP-065 Highway (Dom Pedro I Highway), which is a state of São Paulo highway – Brazil (see Figure 3). It is one of the most modern highways of the country and links the Anhangüera and Presidente Dutra highways, serving the cities of Campinas, Atibaia and São José dos Campos. The vehicles can move in two opposite directions of the highway. Moreover, vehicles are inserted at the opposite edges of the highway at a constant rate (1000, 2000, 4000 and 8000 vehicles/hour).

In order to ensure a near to a real overtaking, three types of vehicles are inserted into the network. The first one consists of vehicles capable of reaching a maximum speed of 120 km/h and a size of four meters, while the second one consists of vehicles capable of reaching a maximum speed of 90 km/h and a size of 14 meters. Finally, the third one consists of vehicles of 18 meters, which are capable of reaching a maximum speed of 90 km/h. This scenario can describe a network composed of passenger cars, buses and trucks. Note that the quantity of vehicles for each type is different during the simulation period. We considered a network composed of 50% of cars, 25% of buses and 25% of heavy trucks.

When the simulation reaches a stable state, an accident is induced on the highway and the involved vehicles produce a single data packet of 2048 bytes. Here, the data packet corresponds to an accident warning, which is being disseminated through multi-hop communication to notify the drivers who are approaching the place of the accident. We assessed two transport systems: in the first one, the vehicles do not receive information about the accident (traditional transport system) and in the second, the vehicles using our proposed solution can receive the accident warning and change their route before they get stuck in the congestion caused by the accident. We also evaluate different congestion times (1800, 3600, 5400 and 7200 seconds). In other words, they represent the duration through which the involved vehicles keep the highway blocked.

Therefore, the objective is to disseminate the accident warning in due time, delivering the warning to the largest number of vehicles which are approaching the place of the accident as possible. Apart from that, we have defined the bit rate to 18 Mbit/s in the MAC layer and have defined the transmission power to 0.98 mW, thus the communication range will be approximately 200 m under a two-ray ground propagation model [11]. Finally, for all presented results, each point in the curves represents the average of 33 replications with a confidence interval of 95%. Table 1 presents the configuration and parameters that were used to execute the simulations.

<table>
<thead>
<tr>
<th>Simulation parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmission power</td>
<td>0.98 mW</td>
</tr>
<tr>
<td>Transmission range</td>
<td>200 m</td>
</tr>
<tr>
<td>Bit rate</td>
<td>18 Mbit/s</td>
</tr>
<tr>
<td>Highway length</td>
<td>30 km</td>
</tr>
<tr>
<td>Number of runs</td>
<td>33</td>
</tr>
<tr>
<td>Confidence interval</td>
<td>95%</td>
</tr>
</tbody>
</table>

Simulation results presented in [13] show that DRIFT solves efficiently the broadcast storm problem in dense scenarios and maximizes the coverage in sparse scenarios. We use the following metrics to assess the performance evaluation of DRIFT:

- **Coverage**: relation between the number of vehicles within the area of interest when the warning dissemination is achieved and the number of vehicles that received the warning;
- **Cost**: quantity of transmissions achieved during the warning dissemination within the area of interest;
- **Delay**: necessary average time to achieve the warning dissemination within the area of interest;
- **Collisions**: average number of packets collided during the warning dissemination within the area of interest;
- **Duplicates**: the average number of replicated packets that each vehicle within the area of interest received;
- **Message propagation**: maximum distance average in meters in which the disseminate warning by the source vehicle was propagated within the area of interest.

In this work, the main goal is to decrease CO2 emission, average trip time and fuel consumption by avoiding congested roads. Thus, the following metrics have been used in the performance evaluation:
Figure 2: A warning dissemination example during an accident in the highway

Figure 3: Dom Pedro I Highway – scenario taken from OpenStreetMap and Google Images
• Trip time: the average time for vehicles going from point of origin to destination;
• CO2 emission: total of CO2 emissions during the journey of vehicles;
• Fuel consumption: total vehicles' fuel consumption for vehicles going from point of origin to destination.

4.2 Simulation Results
Table 2 shows that our proposal can reduce at least 50% of the trip time for the assessed scenarios. In particular, when we keep the vehicle insertion at a constant rate of 8000 vehicles/hour and vary the accident duration (Figure 4(a)), our proposal reduces about 30% on the average trip time. Moreover, when we keep the accident duration constant at 7200 s and vary the vehicle insertion rate, our proposal reduces more than 80% of the trip time.

Table 2: Decreased trip time with route change

<table>
<thead>
<tr>
<th>vehicles/hour</th>
<th>1800 s</th>
<th>3600 s</th>
<th>5400 s</th>
<th>7200 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>58.14%</td>
<td>75.19%</td>
<td>82.23%</td>
<td>86.33%</td>
</tr>
<tr>
<td>2000</td>
<td>57.25%</td>
<td>74.88%</td>
<td>82.22%</td>
<td>86.26%</td>
</tr>
<tr>
<td>4000</td>
<td>55.36%</td>
<td>74.24%</td>
<td>81.89%</td>
<td>86.04%</td>
</tr>
<tr>
<td>8000</td>
<td>50.98%</td>
<td>72.84%</td>
<td>81.21%</td>
<td>85.64%</td>
</tr>
</tbody>
</table>

Table 3 shows that our proposal can reduce the total of CO2 emission at least 20% for all assessed scenarios. For instance, when we keep the vehicle insertion at a constant rate of 8000 vehicles/hour and vary the accident duration (Figure 5(a)), the traffic information system reduces about 40% of the total CO2 emissions. Furthermore, when keeping the accident duration constant at 7200 s and varying the vehicle insertion rate, such reduction is more than 50%.

Table 3: Total of CO2 reduction

<table>
<thead>
<tr>
<th>vehicles/hour</th>
<th>1800 s</th>
<th>3600 s</th>
<th>5400 s</th>
<th>7200 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>25.38%</td>
<td>39.36%</td>
<td>48.87%</td>
<td>55.84%</td>
</tr>
<tr>
<td>2000</td>
<td>25.09%</td>
<td>39.21%</td>
<td>48.81%</td>
<td>55.82%</td>
</tr>
<tr>
<td>4000</td>
<td>24.04%</td>
<td>38.52%</td>
<td>48.35%</td>
<td>55.48%</td>
</tr>
<tr>
<td>8000</td>
<td>21.46%</td>
<td>36.79%</td>
<td>47.39%</td>
<td>54.77%</td>
</tr>
</tbody>
</table>

Table 4 shows that our proposal can reduce the fuel consumption at least 15% for all assessed scenarios. In particular, when keeping a constant vehicle insertion rate and varying the accident duration, the reduction is about 27%. Furthermore, fuel saving is directly proportional to the amount of vehicles. Hence, the greater the traffic is, the greater the savings are. For instance, when keeping the accident duration constant at 7200 s and varying the vehicle insertion rate, our system can induce a fuel economy in more than 40%.

Table 4: Reduction of fuel consumption

<table>
<thead>
<tr>
<th>vehicles/hour</th>
<th>1800 s</th>
<th>3600 s</th>
<th>5400 s</th>
<th>7200 s</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>17.67%</td>
<td>27.42%</td>
<td>35.06%</td>
<td>41.28%</td>
</tr>
<tr>
<td>2000</td>
<td>17.49%</td>
<td>27.30%</td>
<td>35.01%</td>
<td>41.25%</td>
</tr>
<tr>
<td>4000</td>
<td>16.65%</td>
<td>26.65%</td>
<td>34.50%</td>
<td>40.84%</td>
</tr>
<tr>
<td>8000</td>
<td>14.55%</td>
<td>24.99%</td>
<td>33.56%</td>
<td>40.08%</td>
</tr>
</tbody>
</table>

These results show that the traffic congestion does not affect the trip time, CO2 emission and fuel consumption for our proposal, mostly because the alternative routes used by vehicles lead to a smooth traffic condition. Therefore, it decreases idling time, unnecessary stops, and alternating accelerations and braking actions. Moreover, our system is not susceptible to the accident duration, which is not the case for the traditional approach. As we can see in Figures 4(a), 5(a) and 6(a), the results for our proposal remain constant, while for the traditional transport system, results get worse as the accident duration increases.

Another crucial factor for both systems is the traffic flow, since increasing the traffic means that more vehicles are emitting CO2 and consuming fuel. However, for our proposed approach, the rate at which emissions and consumption increase is much lower when compared with the traditional system, as can be seen in Figures 5(b) and 6(b).

5. CONCLUSION AND FUTURE WORK
Traffic congestion has several negative impacts for society as discussed above. In this work, we proposed an intelligent traffic information system based on inter-vehicle communication, where vehicles can avoid congested roads and reduce the trip time, fuel consumption and CO2 emissions. To this end, we used a data dissemination algorithm called DRIFT that, when an accident occurs, the involved vehicles start to disseminate warning messages to notify the drivers, so they can take alternative routes and avoid the accident area.

We used a realistic scenario taken from the OpenStreetMap, by considering 30 km of an important highway in the State of São Paulo, Brazil. In the simulation, we induce an accident in the middle of the highway to start traffic congestion. Then, we performed two types of simulation. The first one considered a traditional transportation system, while the other one deployed our proposed intelligent transportation system. Both simulations were executed with different congestion times and different types of vehicles (cars, trucks and buses) to ensure a near to real scenario.

The results showed a reduction in trip time, CO2 emission and fuel consumption. For the trip time, we decreased approximately 86% for the fuel consumption, the savings were up to 40%, and for the CO2 emission, we decreased approximately 55% for different traffic flows. All these results also show that the more the traffic increases, the more the fuel is saved and less CO2 is emitted when using our proposal.

As future work, we intend to analyze the performance of our proposed solution in more realistic scenarios by using traces of real environments.

6. ACKNOWLEDGMENTS
We would like to thank FAEPX, CAPES and FAPESP for the financial support.

7. REFERENCES
[2] R. Bauza, J. Gozalvez, and J. Sanchez-Soriano. Road traffic congestion detection through cooperative...
Figure 4: Trip time

Figure 5: CO2 total emissions

Figure 6: Fuel consumption


