Exploiting Vehicular Communications for Reducing CO2 Emissions in Urban environments

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***Abstract*—In the overall effort of reducing CO2 emissions especially in large cities vehicular communications can play an important role. Intelligent transportation systems, which aim to use information and communication technology are considered to be a major factor in this effort. Eco-routing is already used to suggest most environmental-friendly routes in order to reduce overall mileage and CO2 emissions based on historical data. In this paper we propose a real time system based on Dedicated short-range communication (DSRC) capabilities in order to reroute vehicles to the most ecological route, avoiding congested roads and minimizing the overall travel time and C02 emissions.**

Keywords : CO2 reduction; VANET; Theory and Models for Optimization and Control; Communications and Protocols in ITS

I. Introduction - Motivation

Traffic congestion is a problem modern cities have to face; it costs time, fuel and, thus, money. Extending the road network is not suited to fight congestion due to spatial, financial and environmental constraints. Recent progress in the area of information and communication technology, however, promises to make todays transportation systems not only more efficient, but also safer, more reliable and more convenient. Vehicular Ad Hoc Networks (VANETs) are considered a central part of these Intelligent Transportation Systems (ITS). VANETs enable many actors in traffic (e.g., vehicles, traffic lights or road side units) to exchange information and to coordinate their driving behavior. As no or little underlying infrastructure is required and message exchange is carried out with low latency times, VANETs are an excellent tool to reduce congestion in the context of ITS.

Eco-routing is a mechanism used to suggest environmental-friendly routes in order to reduce overall mileage and CO2 emissions based on historical data. It is well known, however, that finding the optimal route is a complex and often daunting task, as re-routing decisions, whether due to accidents or traffic jams, may result in further jams and increased driving distance. A small fraction of additional traffic may lead to further road congestion, and therefore to additional microjams and even much longer, secondary jams [1]. In order to alleviate this effect, optimization problems (through the use of inter-vehicle communications) should be formulated and solved. These optimization problems could include a set of building blocks, or an area of a city [2].

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II. Fuel efficiency and CO2 reduction approaches

Applications of ICT(Information and Communication Technologies), such as cruise control, platooning, and traffic signal management, along with driver's behavior promotion and vehicle and infrastructure improvements can help to promote fuel consumption and CO2 emission reduction. Approaches that are based on inter vehicle communications can be divided in four major categories.

Cruise Control

A study of traffic flow improvement by utilizing vehicular communications for CACC has been done in [3]. The proposed CACC (Cooperative Adaptive Cruise Control) utilized communication technology as well as position systems to enhance the overall performance of the application by reducing an impact of a traffic shock wave on the flow of traffic since it enables anticipatory braking actions. This traffic shock wave is a major cause of traffic congestion. With the use of inter vehicle communications, upstream vehicles do not have to brake as severely when a down stream vehicle brakes. In [4], CACC was proposed with direct communication with the preceding vehicle only. Performance of CACC was also investigated in [5].

Platooning

Vehicle platooning is also one of the promising applications in order to provide fuel consumption and CO2 emission reduction. In [6], the authors focused on the platooning in automated highway systems (AHSs). Other platooning management methods have been proposed in [7].

Traffic Signal Management

TLVC (Traffic-light to-vehicle communication) is a novel idea investigated in a number of recent research papers. The authors in [8] proposed new eco-friendly routing protocols. In [9] a solution that uses intelligent traffic lights, mobile devices and wireless communication to reduce car emissions is presented.

IVC communications for Eco-routing

In [10] an event-driven architecture (EDA) is studied, as a mechanism for detecting traffic jams. The EDA can detect several types of traffic jams. CoTEC [11], is a novel cooperative and distributed V2V mechanism to efficiently detect traffic congestion. Innovative eco-routing methods based on V2V communications are proposed in [12].

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In this paper we propose a novel architecture for CO2 reduction, based on DSRC technology. The method combines all modes of communication - infrastructure to vehicle(I2V), vehicle to infrastructure (V2I) and infrastructure to infrastructure(I2I) - in order to perform eco-routing of vehicles that travel in an urban environment.

The present work presents a new congestion avoidance routing protocol for VANETs. Several parameters are investigated in our scenarios in a Urban environment. The article makes the following contributions:

- A new IVC eco-routing method for Urban vehicular environments, the $ErouVe$, is described.
- I2V, I2I and V2I communications are combined in order to take appropriate routing decisions.
- $ErouVe$ exploits information gathered by road-side units (RSUs) from passing vehicles in order to solve a unique optimization problem for every vehicle.
- A performance evaluation of the proposed method against a baseline method($Shortest-Path$) is conducted, which attest the superiority of the new structure.

III. SYSTEM DESCRIPTION

We consider a network $G = (N, L)$, where N is the set of nodes (intersections - RSUs) and L is the set of links (road segments). Road segments that are adjacent to RSU n belong to the set $S(n)$. $M(l)$ is the subset of vehicles that have traversed road segment l the last s seconds. Each RSU calculates average values for each road segment l that is adjacent to its intersection and sends this information to adjacent RSUs. RSUs in order to exchange such information - mean travel duration, mean CO2 emissions - communicate with each other through beacon messages that are exchanged every s seconds.

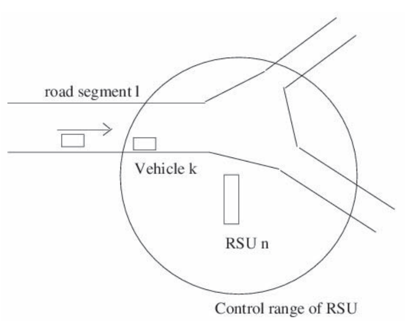

Fig. 1: Decentralized CO2 reduction system based on DSRC communications

A. Initialization phase

In the initialization phase each RSU n computes centrally the distance D_{nm} from every other RSU m using Dijkstra's algorithm, based on GPS data. No time cost or CO2 cost is initially calculated for the road segments. According to this data, each RSU is aware of its adjacent RSUs, and the road segments through which they are connected. In Table I the structure of information kept by a typical RSU n for I2I communication is illustrated. Column 3 represents the connecting road segment s between RSU n and the respective RSU in column 2.

A/A	*Adjacent RSU*	*Road segment*
1	RSU_k	S_n
2	RSU_l	S_o
3	RSU_m	S_p

TABLE I: Connection table of RSU n.

Each vehicle that enters the simulated area follows the shortest path to its destination ignoring time or ecological parameters.

B. Communication phase

For vehicle k (V2I):

As vehicle k, traveling on road segment l, enters in the control range (c.f. section V) of the intersection, RSU near the boundary of the control range impels this vehicle to:

- calculate total time traveled TT_{lk} and C02 emitted C_{lk} on the road segment l. Parameter C_{lk} is divided to the distance that vehicle k traveled along road segment l.
- send TT_{lk} and C_{lk} to RSU
- send destination d to RSU
- ask RSU to choose the next road segment to follow, sending an R_q message.

For RSU at intersection n (V2I):

Each RSU receives from approaching vehicles parameters TT_{lk}, C_{lk} and calculates average values for each road segment l that is adjacent to the intersection n, taking into account only values from the last s seconds in order to have updated information.

$$TT_l = \sum_{k \in M(l)} TT_{lk} \quad and \quad C_l = \sum_{k \in M(l)} C_{lk} \tag{1}$$

For RSU at intersection n (I2I):

Each RSU sends the accumulated values of mean travel time and mean CO2 / distance to adjacent RSU's every s seconds through the use of beacon messages.

For RSU at intersection n (I2V):

Each RSU, after solving the optimization problem(c.f. next section), sends routing instructions to vehicle via R_a message (route answer).

The main communication phases of the system are demonstrated in Figure 2.

IV. $ErouVe$ ALGORITHM

After introducing the basic communication architecture of our model, we present the Ecological Routing of Vehicles ($ErouVe$) applied in a traffic system. The proposed system, in order to eco-route vehicles, solves a decentralized optimization problem.

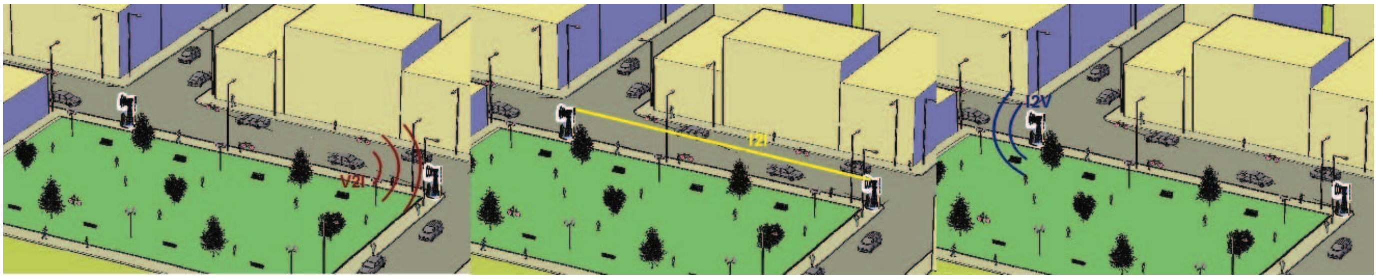

Fig. 2: Application example of $ErouVe$ System: A. Vehicle approaching intersection sends a beacon message to RSU (V2I) B. I2I communication for information exchange C. Vehicle receives routing instructions (I2V).

After receiving the route request message - R_q message - from a vehicle k, RSU solves an optimization problem in order to guide the vehicle to a more green route through the road network.

Next road segment selection algorithm

For each segment l' adjacent to the current road, that the vehicle k is currently on, assign a local weight $w_{l'k}(t)$ according to $TT_{l'}$, $C_{l'}$ and whether or not it helps the vehicle k reach its destination

$$w_{l'k}(t) = (w_1 * TT_{l'}) + (w_2 * C_{l'}) + (w_3 * A_{l'}) \quad (2)$$

, where parameter A indicates if the road segment l' is closer to the destination d of vehicle k or not according to equations 3, 4.

$$A_{l'} = 1/(D_{ld(k)} - D_{l'd(k)}), \quad D_{ld(k)} > D_{l'd(k)} \quad (3)$$

$$A_{l'} = D_{ld(k)} - D_{l'd(k)}, \quad D_{ld(k)} \leq D_{l'd(k)} \quad (4)$$

Then, define the road segment l'' with the minimum weight:

$$w_{l''k} = \min_{l' \epsilon S(n)} w_{l'k}(t)$$

s.t.

$$A_{l''} < D_{th}$$

Parameters w_1,w_2,w_3 are used in order to focus to one of the different optimization parts, e.g. time, distance or CO2 emissions. In the default system settings, all optimization parts have the same significance. If w_1 and w_3 take very low values (e.g 0.001 or 0) then only CO2 (ml/m) is used as a routing parameter, which could lead cars to follow green but maybe too long routes. This would have a direct effect in the system's performance since total CO2 emissions would not decrease and moreover cars would have to travel more time in order to reach their destinations. The opposite happens if only time is used in order to select the next road to travel. Cars in this scenario would follow the fastest road (in terms of mean velocity) neglecting how far from their destination this road would lead them and how much CO2 they would emit when traveling on it. All three parameters are crucial in order to keep cars on logical paths and minimize CO2 emissions and need to be combined when calculating weights of roads.

After solving the optimization problem, RSU sends routing instructions to each vehicle with a Ra message. Routing instructions are given to vehicles at each intersection in order to achieve traffic load balance, total CO2 and travel time reduction. The algorithm runs in an autonomous way at each intersection.

V. Simulation

We use the simulator Veins [1]. Veins is an open source framework for running vehicular network simulations. It is based on two well-established simulators: OMNeT++, an event-based network simulator, and SUMO, a road traffic simulator [13]. In order to calculate CO2 emissions we use the EMIT model integrated in Veins. EMIT is a simple statistical model for instantaneous emissions and fuel consumption for light-duty composite vehicles based on speed and acceleration. For our experimentation we use the 'Category 9' -e.g Dodge Spirit 1994 - vehicle [14] implemented in VEINS. The competitor is the $Shortest - Path$ routing algorithm, where each vehicle follows the path with the least total distance to the destination. In our simulation, we consider various road traffic and network data parameters.

The simulation environment (Figure 3) is a one direction road about 2km long with two available paths. The upper part is longer (upper part: 275 meters, lower part: 190 meters), while the lower part is shorter. Both parts have the same capacity in cars (2 lanes). These parts merge at junction 2, where the upper part can occupy two lanes of the next 3 lane road segment and the lower part can occupy only one lane. This setup is used in order to demonstrate a typical city scenario, when one lane can be temporarily blocked due to a stopped car or an accident. Similar situations, where traffic is accumulated in the last part of a road segment, arise when a road intersects with another with higher priority or when a traffic light exists. Any of the above cases combined with medium traffic, make a road segment that seems to be the best choice (the lower road segment in our simulated scenario) incapable to accommodate all the vehicles and major traffic congestion instances occur. Updated information of the road conditions, which are collected by the incoming cars can effectively - in most cases - alleviate traffic congestion incidents.

All nodes are equipped with GPS receivers and On Board Units (OBU). Location information of all vehicles/nodes, needed for the routing algorithm is collected with the help of GPS receivers. The communication paths are available via the ad-hoc network and the RSUs, which are scattered in every junction in the simulation environment. The communication range of both vehicles and RSUs is set to 300 meters. Every RSU has three important ranges, when communicating with any approaching vehicle:

- *The communication range*: This is the communication range that can be achieved between RSUs and vehicles according to the setup of the system. For our simulations the communication range is set to 300 meters.
- *The handshake range*: this is the range after which the approaching vehicle enters the area of the RSU. At this point the vehicle stores the position of the RSU, using the information of the packets the RSU sends. In our simulation the handshake range is set to 100 meters.
- *The control Range*: The control range is the distance where the vehicle receives the message of the RSU with the rerouting instructions. This range is the closest to the RSU but is set to a medium value in order to give time to the vehicles to perform rerouting, if necessary. In our simulation the control range is set to 50 meters.

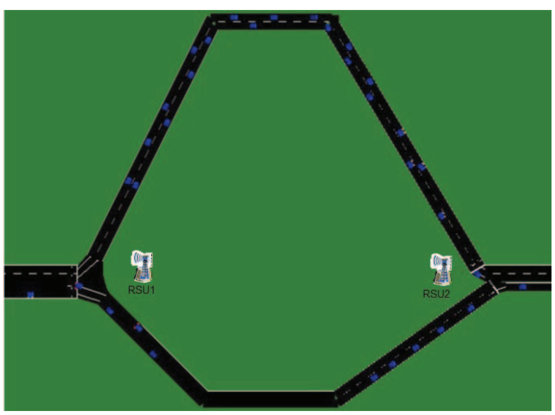

Fig. 3: Simulation environment

A. Evaluation criteria

To demonstrate the benefits of the $ErouVe$ system, a number of variables need to be analyzed. In this section, we want to analyze the environmental impact of $ErouVe$, comparing the individual and aggregated CO2 emissions of vehicles that travel towards the same destination with and without the $ErouVe$ system. Since vehicles have to take one of the two available paths, when approaching the first junction, the main difference in their travel would be the upper or the lower part of the road between junctions (called **area of interest** from now on), while the rest of their trip would be the same as far as distance is concerned. For that reason the individual performance of each vehicle in these two road segments (upper and lower) is evaluated in this section. Mean aggregated values of the system's performance parameters, e.g. time and CO2, are also compared for both the area of interest and for the complete route of the vehicles.

Parameters w_i are set to their default values for this simple simulation scenario. Performance evaluation of the system according to the values of these parameters is an open issue for investigation and it is out of the scope of this article. Optimal values for these parameters for any topology, is a matter of discussion. Parameter s has a direct impact on the performance of $ErouVe$, since it affects the accuracy of the aggregated values. Values from 30 seconds to 3 minutes were used in order to capture this impact. Finally two scenarios were investigated with 45 and 90 vehicles representing a medium and a high dense situation in an urban environment.

Independent parameter	*Range of values*	*Default value*
$Number\ of\ Vehicles$	45, 90	45
$Velocity\ (Km\backslash h)$	40	40
$Communication\ Range\ (m)$	300	300
$Parameter\ s(sec)$	30, 200	30
$Parameters\ w_1, w_2, w_3$	1	1

TABLE II: Simulation parameters.

For this analysis, the definition of each variable whether for individual vehicle analysis or aggregated calculations is given as follows:

- Route (area of interest) CO2 emissions per vehicle k (individual; in grams): cumulative sum of an individual vehicle CO2 emissions.
- Route (area of interest) Travel time per vehicle (individual; in seconds).
- Average CO2 emissions per vehicle / distance traveled (individual; in grams/m).
- Average velocity per vehicle (aggregated; in meters/second).

B. Individual Vehicle Results

CO2 emissions per vehicle

In Figure 4, CO2 emissions (ml) of each vehicle are demonstrated. $ErouVe$ outperforms $Shortest-Path$ almost for every vehicle, though vehicles have to take longer paths. This is due to the fact that at the exit of the lower part of the map, vehicles can occupy only one lane at the next road segment, leading to road congestion and thus increasing CO2 emissions and travel time of each vehicle in the specific road segment. $ErouVe$ alleviates such traffic congestions by rerouting vehicles to the upper road segment -and thus splitting traffic- when traffic grows at the lower shortest segment. Decrease of more than 50 % in individual CO2 emissions of vehicles during traveling the area of interest are observed.

Travel time per vehicle

Similar to CO2 emissions, travel time is also better when cars are rerouted by the least congested, yet longer, road (see

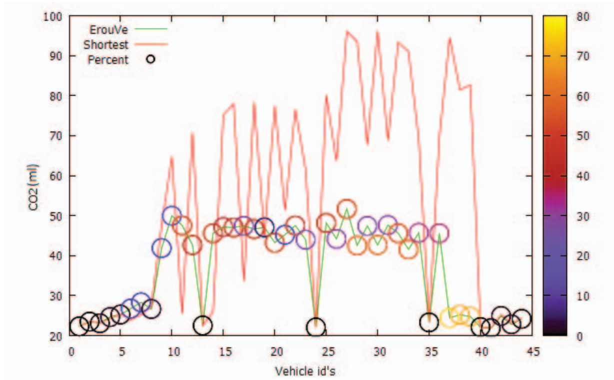

Fig. 4: CO2 emissions per vehicle

Figure 5). The deviation in time is smoothened when vehicles are smartly rerouted and and thus the travel time of most vehicles is reduced. With the use of the $ErouVe$ system, travel times vary from 10 to 20 seconds (for the area of interest), while when vehicles follow the $Shortest-Path$, in terms of distance, the time that a vehicle needs to cross this segment of the road can be up to 70 seconds.

Although $ErouVe$ manages to keep travel time of all vehicles relatively low, some vehicles that use the $ErouVe$ system take longer times to pass the area of interest. This is due to the fact that although traffic jam exists in the lower part of the road, some vehicles manage to pass through it in a rather short time due to the lane they happen to occupy.

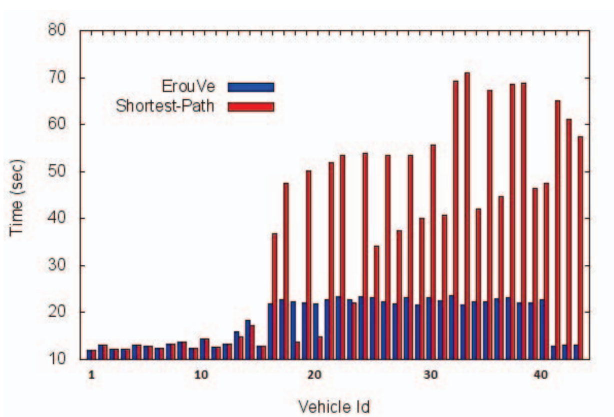

Fig. 5: Travel time per vehicle

Parameter s

Updated information of traffic conditions play a significant role in the performance of $ErouVe$. In Figure 6 we see that when parameter s is relatively long (3 minutes), accumulated values for CO2 (CC_l) and time (TT_l) do not represent realistic data of the road conditions, rendering $ErouVe$ inefficient. The performance of our method is then degraded and the benefits are lost. A relatively low value that keeps data up to date is an important factor for the optimal performance of the method.

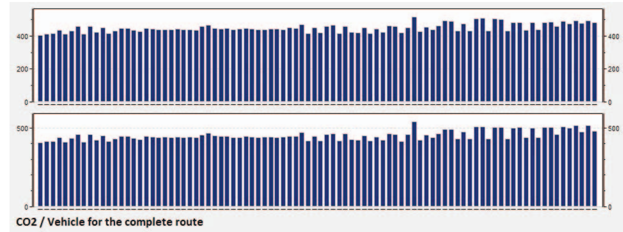

Fig. 6: Parameter s affects CO2 emissions :
Upper diagram s=30 sec, Lower diagram s =170 sec.

C. Aggregated Results

The density of the cars play a significant role in congestion management methods. Tables III and IV show aggregated performance values for different number of vehicles. We see that for different vehicle densities, $ErouVe$ outperforms $Shortest-Path$ for every investigated parameter of the system's performance e.g. CO2, CO2/m, time. When all vehicles follow the same shorter path the capacity of the road cannot satisfy the instantaneous flow. This is a typical bottleneck effect where the section of a route with a small carrying capacity produces major congestion problems. With the use of $ErouVe$ bottlenecks can be bypassed at a very short time and vehicles can be rerouted to more efficient paths in terms of CO2 and time.

Method	*CO2 (ml)*	*CO2 / Distance (ml/m)*	*Velocity*
	scenario 1 : 45 vehicles		
$Shortest-Path$	53.1	0.366	4.03
$ErouVe$	36.4	0.185	10.07
	scenario 2 : 90 vehicles		
$Shortest-Path$	49.6	0.342	4.48
$ErouVe$	39.2	0.228	8.79

TABLE III: Mean performance values for the area of interest

As seen in Table IV when comparing $Shortest-Path$ and $ErouVe$ with the default system parameters, $ErouVe$ achieves a decrement in CO2 emissions (ml/m) between 4% and 6%, while the additional distance that each vehicle has to travel is at most 45 meters(2.20 % longer that the shortest one).

Method	*CO2 (ml)*	*CO2 / D (ml/m)*	*Distance(m)*
	scenario 1 : 45 vehicles		
$Shortest-Path$	450	0.221	2043
$ErouVe$	436	0.208	2088
$\%Difference$	3.11	5.86	2.20
	scenario 2 : 90 vehicles		
$Shortest-Path$	481	0.235	2047
$ErouVe$	467	0.225	2076
$\%Difference$	2.90	4.21	1.41

TABLE IV: Average performance results of the complete routes

Comparison of Tables III and IV shows that the improvements, when measured on the entire vehicle paths are significant but not so impressive as when the area of interest is investigated in isolation. This happens for two reasons. First the alternative paths that constitute the area of interest are only 190 and 275 meters long, which are rather small segments compared to the whole trip that each vehicle has to travel ($\sim$ 2km). Another reason may be the fact that rerouting of vehicles happens in an individual way leading to major lane changing of vehicles when approaching first junction. A cooperative lane changing system or a local mechanism for rerouting combining V2V and I2V communications would eliminate this effect leading to further improvement of the system's performance.

Traffic management

Splitting traffic efficiently has a major impact on car emissions and on the time that a vehicle needs in order to reach its target. In Figure 7 we present how $ErouVe$ splits vehicle's flow in the two available paths for different number of simulated vehicles.

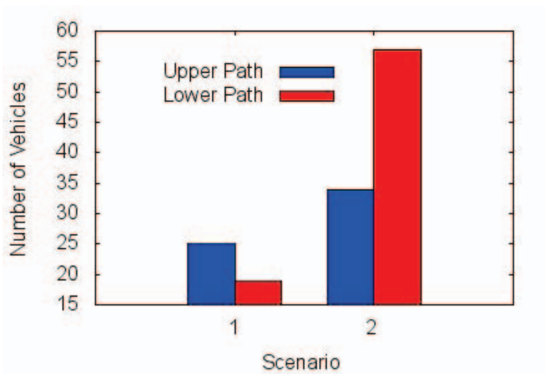

Fig. 7: $ErouVe$ manages traffic efficiently

In Figure 8 CO2 emissions of vehicles, according to the path they follow and the method they use for routing, is represented. When all vehicles follow the $Shortest - Path$ the deviation of values is larger. Using the proposed routing mechanism $ErouVe$, vehicles that take the longer path emit more CO2 but this increase is limited due to the fact that the method ensures that both paths are not over occupied.

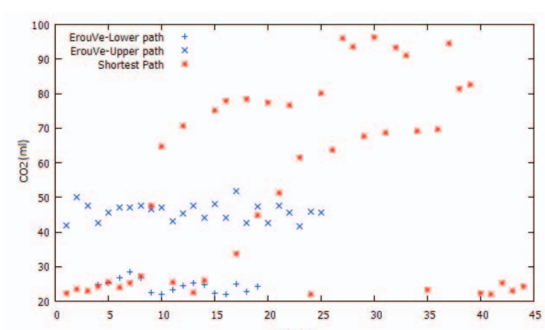

Fig. 8: $ErouVe$ manages CO2 efficiently

VI. Conclusions

In this paper we presented a novel routing optimization method based on DSRC communications. The method exploits data transmitted from vehicles, in order to guide them in selecting the greener road segment to follow at each intersection. Based on the communication between RSUs and vehicles, the local routing problem is expanded from a single road segment to the whole area of investigation that covers all the surrounding road segments, helping reducing CO2 emissions and total travel time, while keeping additional traveled distance low.

In the future, information from RSUs that are n hops away from the current junction is going to be exploited, in order to give longer term routing instructions to vehicles. Optimal values for the various parameters of the system is another open issue. Additional constraints such as deadlines or limits on fuel consumption would make the model more realistic reflecting drivers' needs. Finally routing information itself is going to be embedded in the optimization problem of each vehicle giving the method a glance in the near future.

References

[1] C. Sommer, R. German, and F. Dressler, "Bidirectionally coupled network and road traffic simulation for improved ivc analysis," *IEEE Transactions on Mobile Computing*, vol. 10, no. 1, pp. 3–15, 2011.

[2] Q. Song and X. Wang, "Efficient routing on large road networks using hierarchical communities," *Intelligent Transportation Systems, IEEE Transactions on*, vol. 12, no. 1, pp. 132–140, 2011.

[3] D. de Bruin, J. Kroon, R. van Klaveren, and M. Nelisse, "Design and test of a cooperative adaptive cruise control system," in *Intelligent Vehicles Symposium, 2004 IEEE*, 2004, pp. 392–396.

[4] R. Naus, G.J.L.and Vugts, M. M. v. d. Ploeg, J. and, and M. Steinbuch, "Towards on-the-road implementation of cooperative adaptive cruise control," in *Proceedings of the 16th World Congress and exhibition on Intelligent Transport Systems and Services (ITS-16)*, 2009.

[5] C. Desjardins and B. Chaib-draa, "Cooperative adaptive cruise control: A reinforcement learning approach," *Intelligent Transportation Systems, IEEE Transactions on*, 2011.

[6] M. J. Woo, J. W. Choi, and H. S. Han, "Carrier phase gps/millimeter-wave radar for vehicle platooning," in *Industrial Electronics, 2001. Proceedings. ISIE 2001. IEEE International Symposium on*, 2001.

[7] M. Segata, F. Dressler, R. Lo Cigno, and M. Gerla, "A simulation tool for automated platooning in mixed highway scenarios," *ACM SIGMOBILE Mobile Computing and Communications Review*, 2012.

[8] M. Alsabaan, K. Naik, T. Khalifa, and A. Nayak, "Vehicular networks for reduction of fuel consumption and co2 emission," in *Industrial Informatics (INDIN), 2010 8th IEEE International Conference on*, 2010.

[9] C. Dobre, A. Szekeres, F. Pop, V. Cristea, and F. Xhafa, "Intelligent traffic lights to reduce vehicle emissions," in *26th EUROPEAN CONFERENCE ON MODELLING AND SIMULATION*, 2012.

[10] F. Terroso-Saenz, M. Valdes-Vela, C. Sotomayor-Martinez, R. Toledo-Moreo, and A. Gomez-Skarmeta, "A cooperative approach to traffic congestion detection with complex event processing and vanet," *Intelligent Transportation Systems, IEEE Transactions on*, 2012.

[11] R. Bauza, J. Gozalvez, and J. Sanchez-Soriano, "Road traffic congestion detection through cooperative vehicle-to-vehicle communications," in *Local Computer Networks (LCN), 2010 IEEE 35th Conference on*, 2010.

[12] R. Zhang, Z. Li, C. Feng, and S. Jiang, "Traffic routing guidance algorithm based on backpressure with a trade-off between user satisfaction and traffic load," in *Vehicular Technology Conference (VTC Fall), 2012 IEEE*, 2012.

[13] J. Epstein and D. W. Peterson, "An experimental study of wave propagation at $850MC$," *Proceedings of the IRE*, vol. 41, no. 5, 1953.

[14] A. Cappiello, I. Chabini, E. K. Nam, A. Lue, and M. A. Zeid, "A statistical model of vehicle emissions and fuel consumption," *IEEE 5th International Conference on Intelligent Transportation Systems.*