VANET-enabled Eco-friendly Road Characteristics-aware Routing for Vehicular Traffic

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***Abstract*— The lack of significant breakthroughs in terms of alternative energy sources has caused both fuel consumption and gas emissions to constantly increase. In this context, improving fuel efficiency and reducing emissions in the transportation sector is vital, as vehicles are one of the important contributors to air pollution. This paper introduces EcoTrec, a novel eco-friendly routing algorithm for vehicular traffic which considers road characteristics such as surface conditions and gradients, as well as existing traffic conditions to improve the fuel savings of vehicles and reduce gas emissions. EcoTrec makes use of the Vehicular Ad-hoc NETworks (VANET) both for collecting data from distributed vehicles and to disseminate information in aid of the routing algorithm. The algorithm calculates the fuel efficiency of various routes and then directs the vehicle to a fuel efficient route, while also avoiding flash crowding. Simulation-based tests showed that by using EcoTrec, fuel emissions were significantly reduced, when compared with existing state-of-the-art vehicular routing algorithms.**

***Keywords*— ad-hoc networks; routing; vehicle communications; wireless LAN; road traffic**

I. INTRODUCTION

Greenhouse gases from vehicles are a major contributor to global warming. It was estimated in 2010 that 23% of global CO_2 emissions came from the transport sector and accounted for 30% of CO_2 emissions in OECD countries [1]. It is becoming imperative for governments to fulfill their commitments to reduce their gas emissions, in order to avoid exceeding the 2 degree Celsius threshold, which refers to the temperature rise the Earth could sustain, without experiencing very dangerous consequence [2]. Switching to using renewable energy is a solution, but it is still incredibly expensive. Clearly an approach is needed to reduce gas emissions, but, especially in this economic context, one which is not accompanied by a large cost.

One area which shows significant promise, in terms of reducing greenhouse gas emissions, as well as having a positive economic benefit, is Vehicular Ad hoc networks (VANETs)-based vehicular routing. By enabling vehicles to distribute real time information to one another, strategies can be used to reduce idle time and fuel consumption. Based on this information which could include traffic conditions on different roads, vehicles can then reroute to roads with less traffic, thus reducing fuel consumption. Traffic lights could also be enabled to communicate with vehicles via VANET. This would allow vehicles to be aware of when the traffic lights will change. This could reduce fuel consumption by eliminating unnecessary braking and acceleration. Vehicles could also turn off their engines if they knew that the traffic lights would remain red for an extended period of time. There are several parameters which contribute to fuel consumption. Some of these parameters vary depending on the characteristics of road sections, including the gradient and the surface condition of the road, for example. By placing sensors on board each vehicle equipped with vehicular communications, it is possible to record these parameter values and create a very efficient route recommender algorithm which would take them into account. The approach could also allow flag roads as having a certain hazards on them, such as ice or flooding, warning other vehicles in advance.

This paper proposes *EcoTrec, a novel eco-friendly routing algorithm for vehicular traffic which achieves fuel savings of vehicles and reduces gas emissions.* EcoTrec considers parameters related to weather, road surface and road gradient. These parameter values are gathered via the individual vehicles and then processed and aggregated. This information is disseminated to all the vehicles via VANET communications. The vehicles use the road and traffic parameters to calculate a quick, fuel efficient route to get to their destinations. The routes taken by the EcoTrec equipped vehicles gave an improvement of over 30% in terms of the number of vehicles which reached their destination and roughly 20% in terms of emissions, when compared with the original real life routes of vehicles collected and made available in [24].

The paper is structured as follows. Section II describes the related work. Section III describes the architecture and presents the EcoTrec algorithm. The simulation-based testing scenarios are described in Section IV. Section V presents the results and Section VI concludes the paper.

II. RELATED WORKS

The aim of the research presented in this paper is to reduce gas emissions using a VANET-based routing algorithm for vehicular traffic, without greatly increasing travel time. In this context several papers will be discussed next. Four main areas of related works were identified. The first area of research focuses on various architectures for VANET-based systems. Torrent-Moreno et al. [3] proposed a layered architectural approach to deal with the complexity of VANETs. In the proposal there are two main layers: a communication layer and an application layer. The communication layer checks whether the message is relevant based on the time and area stamp, the application layer can analyse the data, modify it and decide whether to forward the message or not. The proposal uses dumb nodes which include solely communication layer components. The dumb nodes are used simply to forward every message which has the correct time and area stamps, in order to increase network connectivity. Fussler et al. [4] proposed a stack-based architecture to deal with VANETs. The authors stated that by using an un-layered approach an unacceptable level of complexity for interaction between modules is added, whereas a layered approach would be too restrictive, as information would have to pass through every layer. The stack-based approach uses a staircase configuration. The top layer is connected to all the bottom layers, which are piled on top of each other. This allows applications to bypass layers.

The second area of research centers on proposing novel navigation algorithms. These consist of algorithms for determining quicker and/or more fuel-efficient routes for the vehicles. Sommer et al. [5] showed that reducing the travel time by VANET-based routing can result in increased emissions. This can happen when the algorithm recommends the vehicle should take a long detour, when, in fact, waiting till the traffic jam eased would have been more fuel efficient. Collins et al [6] looked at considering the fuel cost per second used on each route; however with no data on the road conditions, the fuel cost is simply a function of speed and acceleration. Several other papers looked at ways in which VANETs could be used to support algorithms which reduce emissions [7–9]. Most of the research in these papers concentrated on communication with traffic lights. Optimizing light timing [8], [9] smoothes traffic flow which in turn reduces idle time. Knowledge of when traffic lights will change allows for smoother deceleration/acceleration of vehicles [7], and for turning off the engine of vehicles when waiting for the traffic light to turn green [9], helping reduce fuel consumption. Other papers concentrated on reducing journey time, which would also reduce emissions by reducing idle time spent [10]. However emissions are determined by a variety of factors such as acceleration, velocity, road surface, and wind speed and direction, not just idle time as assumed in some of these papers [10].

The third area of research focuses on the communication protocols and infrastructures. The most commonly used VANET communication protocol is the Dedicated Short Range Communication (DRSC) [11] or IEEE 802.11p [12]. DSRC and 802.11p are specially designed for two-way radio automotive communications. Several works take a different approach using cellular [13], satellite [14] or hybrid communications [15] [16]. A number of different algorithms for sending information between nodes were reviewed. VANETs can suffer from a low throughput due to lack of connectivity. Epidemic routing with store, carry and forward as proposed by Zhao et al. [17] can be used to make sure that messages manage to traverse the connectivity gaps. Epidemic routing is a flooding style algorithm. Messages are forwarded to all nodes which have not received them yet. This however results in large overhead which is not desirable. Teshima et al. [18] proposed using autonomous clustering to reduce the overhead caused by epidemic routing. The nodes group themselves into clusters with each cluster assigning a node to be the cluster head. Each cluster is regarded as a virtual node and epidemic routing is implemented. Nzouonta et al. [19] proposed the road-based vehicular traffic routing protocol. Using information from the messages distributed via the VANET, routes with a high probability of network connectivity are calculated. When packages need to be forwarded, they follow these routes. These routes are likely to be still connected and reduce the probability of a packet being dropped. The road-based protocol was simulated and outperformed existing protocols in terms of reduced delay.

The final area of research concentrated on user modeling. According to Johnson et al [20] there are two main types of user modeling. The first type is called static modeling. In static modeling the user is asked a number of questions and then is stereotyped as a certain type of user. The second type is called dynamic modeling. In dynamic modeling the user satisfaction is periodically determined and the stereotype of the user is constantly updated. Either of these approaches could be used by EcoTrec to add user personalization.

III. SYSTEM ARCHITECTURE AND ECOTREC ALGORITHM

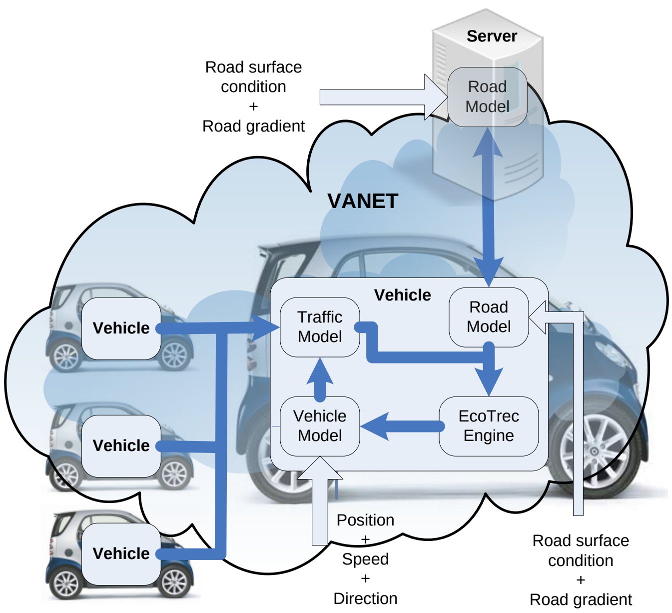

Figure 1 EcoTrec system architecture

A. *Architecture*

Figure 1 illustrates the EcoTrec system architecture. Each vehicle has various sensors such as: GPS receiver, tilt sensor and accelerometer, which gather information about the position, angle, acceleration of the vehicle and road surface condition and gradient.

This information is fed into the *Vehicle Model* which models the individual vehicle behavior in terms of direction, speed and position. The EcoTrec Engine controls regular sending of messages containing the ID, speed and position of the vehicle to the other vehicles. Upon receiving these messages, each vehicle aggregates the information it receives with existing data and builds a Traffic Model. The messages are sent to the other vehicles using the IEEE 802.11p. Endemic routing was used to make sure vehicles receive the messages. The number of hops is up bounded by MaxHopCount in order to localize message exchange, not to load the VANET and avail from high throughput (which decreases with the number of hops).

The Road Model considers road surface condition and road gradient. This information is stored on a server, but it is updated by data received from the vehicles. The Vehicle Model, Traffic Model and Road Model data on each vehicle is fed to the EcoTrec Engine which deploys the EcoTrec algorithm which computes the recommended route for the vehicle. The EcoTrec algorithm is described in the next section.

B. EcoTrec Algorithm Description

The EcoTrec algorithm takes into account two main factors: the road conditions, reflected in the road condition rating (R) and traffic condition, reflected in the traffic condition rating (T). The multiplicative utility function presented in equation (1) relates the two parameters to determine the value associated with a road segment. It uses a weight W_T which helps tune the contribution of the traffic conditions on the overall utility function. The rationale behind using a multiplicative utility function was that a very good road would be useless to the driver if there was a serious traffic jam on it, due to an accident or road works.

$$U = R/(T^{W_T}) \quad (1)$$

Making use of this novel utility function, the vehicles are then routed according to the Dijkstra lowest edge weight algorithm [21]. Each time a vehicle receives new information from VANET messages, the vehicle re-computes the utility function updating the optimum route.

Each vehicle regularly sends and forwards messages concerning the road they are travelling on. For an inter-message transmission interval of one second, EcoTrec uses approximately 300 bps for control message exchange, accounting for less than 0.01% of the IEEE 802.11p's actual bandwidth of roughly 3 Mbps [22]. This overhead is maintained very low by employing a mechanism which decreases MaxHopCount logarithmically with the increase in number of vehicles.

The road condition rating R is calculated according to equation (2) and is derived from the Handbook Emission Factors for Road Transport (HBEFA) formula [19]. R is normalized by making use of a value for the most emission intensive route (R_{max}).

$$R = A \cdot RR \cdot v + B \cdot RR \cdot v^2 + C \cdot v^3 + m \cdot g \cdot RG + m \cdot a \cdot v \quad (2)$$

In equation (2), RR is road roughness-dependent coefficient which accounts for the increase in emissions due to the surface conditions; RG- road gradient, g- gravitational acceleration, v –velocity, m- vehicle mass, a- acceleration, A, B – rolling resistances for the vehicle and C- air resistance for the vehicle.

The traffic condition rating defined in equation (3) is obtained by gathering information on the speeds of the vehicles on a stretch of road. The traffic condition rating is obtained by normalizing the average speed of the vehicles by considering the maximum speed on that road. This information is then distributed to other vehicles via the VANET.

$$T = \frac{AS}{MS} \quad (3)$$

In equation (3), AS =Average Speed and MS =Maximum Speed of vehicles on a road segment.

IV. Simulation and Scenarios Description

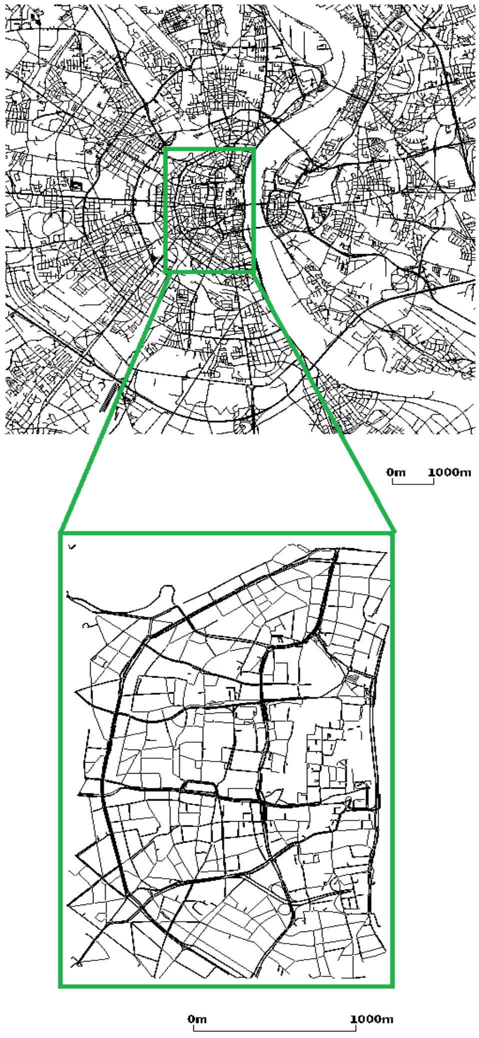

Figure 2 Inset map of an area of Köln used for simulations (data for the maps was obtained from TAPASCologne [23])

A. Simulation-based Models

The EcoTrec algorithm was modeled and tested on the iTETRIS [24] simulator. iTETRIS consists of the network simulator (NS-3) [25] and the traffic simulator Sumo [26]. Sumo was extended to include data about the road conditions and gradient. For emission calculation the additional acceleration required to overcome gravity on a slope was added to the vehicles' acceleration to determine the fuel used on that route.

The proposed EcoTrec routing algorithm was compared against three alternative approaches: the routing algorithm described in Sommer et al [5], Dijkstra shortest path algorithm, commonly used by GPS road guidance systems, according to Dong et al [27] and against the real-life routes taken by the vehicles, as recorded from in the TAPASCologne dataset [23]. The TAPASCologne project aims to reproduce "*with the highest level of realism possible, car traffic in the greater urban area of the city of Cologne*". This was taken as it includes the routes the cars took if they had no rerouting information.

To simulate the Dijkstra routing algorithm a travel time function from Sumo was used. To implement the Sommer algorithm, in which the vehicles avoid roads with heavy traffic, the edge weight of the blocked routes was multiplied by 1000, so the vehicles avoid these routes. To implement the EcoTrec algorithm the edge weight was calculated according to equation (1) using the information on that route. If no traffic data was available for the route or the most recent traffic data was too old (over 20 seconds), the route was assumed to be free of traffic leaving a T value of 1. In this paper W_T from equation (1) was set to 2 and MaxHopCount was set to 10.

B. Simulation Scenarios

The map used for the testing scenario in this paper is taken from the TAPASCologne project [23]. The map was cut in order to reduce the simulation time and the area considered in the simulations is represented in Figure 2. The new map is 2000 m x 3000 m and is at the location latitude 50.924043 and longitude 6.93643.The gradients for the roads in the map were obtained using Google Earth [28].

Two vehicle traces, one of 900 vehicles and the other of 1100 vehicles, were obtained from the TAPASCologne website [23]. The vehicles were considered light passenger vehicles with engines between 1.4 and 2 liters in the Sumo simulations. The two vehicle traces consider the situation in the German city of Koln from 6am to 6:15am and 6:15am to 6:30am, respectively.

V. TESTING RESULTS

Table 1 Percentage of vehicles which have reached their destination

	900 vehicles 6:00-6:15 (%)	Gain from baseline (%)	1100 vehicles 6:15-6:30(%)	Gain from baseline (%)
EcoTrec	65	36	60	30
Sommer	52	10	53	14
Dijkstra	54	16	52	12
TAPASCologne	47	0	46	0

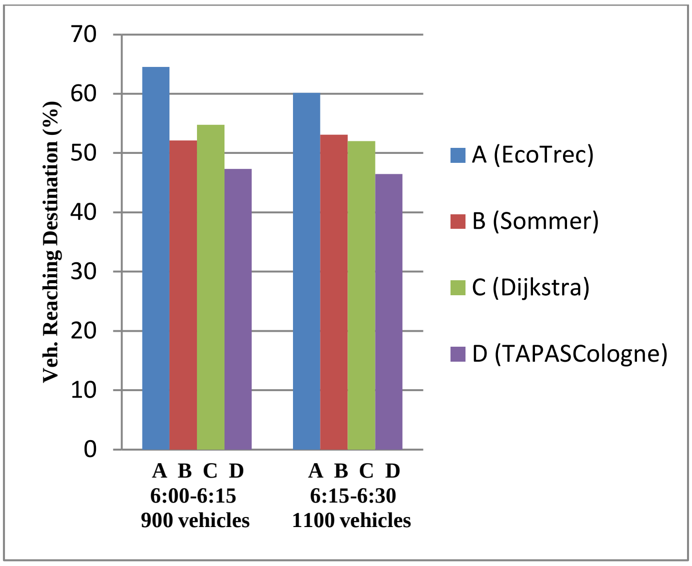

Figure 3 Percentage of vehicles which reached their destination between 6:00-6:15 and 6:15-6:30 for different routing mechanisms

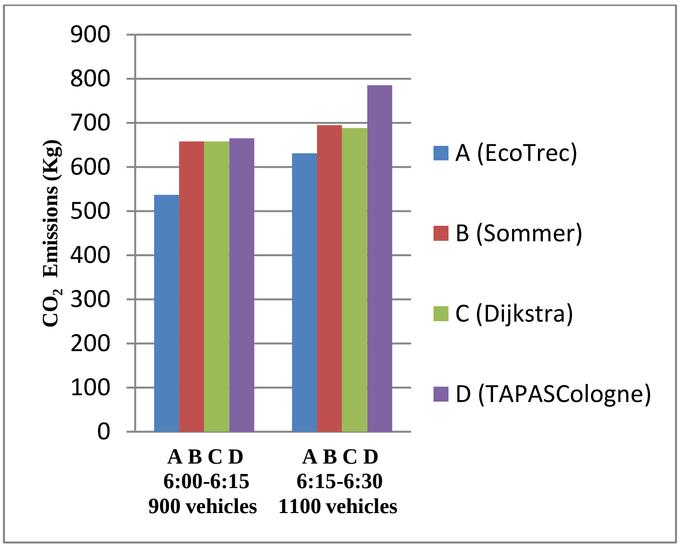

Figure 4 CO_2 emissions generated by the vehicles between 6:00-6:15 and 6:15-6:30 for different routing solutions

Table 2 Total Emissions in Kg

	900 vehicles 6:00-6:15 CO_2 emissions (Kg)	Gain from baseline (%)	1100 vehicles 6:15-6:30 CO_2 emissions (Kg)	Gain from baseline (%)
EcoTrec	536	19	631	20
Sommer	658	1	694	12
Dijkstra	658	1	688	12
TAPASCologne	664	0	785	0

Figure 3 shows the percentage of vehicles which have reached their destination within the allotted time. For both vehicle traces the EcoTrec algorithm resulted in the highest number of vehicles reaching their destination. EcoTrec outperformed the baseline, TAPASCologne, by 36% and 30% in the 900 and the 1100 vehicle traces, respectively. It also outperformed the next most energy efficient solution, Sommer by roughly 24% and 13% in the 900 and 1100 vehicle traces, respectively. EcoTrec outperforms the other schemes because it considers the speed of the vehicles on each road in order to judge how long it will take to traverse the road infrastructure.

Figure 4 shows the total amount of CO_2 produced during the simulation. For both vehicle traces the EcoTrec algorithm resulted in the least amount of emissions produced by the vehicles. EcoTrec outperformed the baseline, TAPASCologne, by 36% and 30% in the 900 and 1100 vehicle traces, respectively. It also outperformed Sommer solution by roughly 18% and 9% in the two scenarios considered. A t-test was performed and confirmed that there is a significant statistical difference between these results with 99% confidence interval. EcoTrec results are better than those of the other schemes because it considers the amount of emissions which will be released into the atmosphere on each road in order to judge taking which route will determine the least emissions, while at the same time reducing idle time by avoiding very slow roads.

VI. CONCLUSIONS AND FUTURE WORK

This paper presented EcoTrec, a novel VANET-based eco-friendly routing algorithm for vehicular traffic which considers road characteristics such as surface conditions and gradients, as well as existing traffic conditions to improve the fuel savings of vehicles and reduce gas emissions. Test results show that the algorithm outperforms existing state of the art vehicular routing algorithms in terms of gas emissions, while maintaining very good travel times. Future work will focus on the optimization of the weights used in the algorithm and include more extensive testing.

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REFERENCES

[1] International Transport Forum, *Reducing Transport Greenhouse gas Emissions Trends & Data*. 2010. Available Online at www.internationaltransportforum.org

[2] M. Meinshausen, N. Meinshausen, W. Hare, S. C. Raper, K. Frieler, R. Knutti, D. J. Frame, and M. R. Allen, "Greenhouse-gas emission targets for limiting global warming to 2 C," *Nature*, vol. 458, no. 7242, pp. 1158–1162, 2009.

[3] M. Torrent-Moreno, A. Festag, and H. Hartenstein, "System design for information dissemination in VANETs," *the 3rd International Workshop on Intelligent Transportation (WIT),* March 2006, Hamburg, Germany, pp. 27-33.

[4] H. Füssler, M. Torrent-Moreno, M. Transier, A. Festag, and H. Hartenstein, "Thoughts on a protocol architecture for vehicular ad-hoc networks," *the 2nd International Workshop on Intelligent Transportation (WIT)*, Hamburg, Germany, March 2005, pp. 41-45

[5] C. Sommer, R. Krul, R. German, and F. Dressler, "Emissions vs. travel time: simulative evaluation of the environmental impact of ITS," in *IEEE Vehicular Technology Conference (VTC-Spring)*, Taipei, Taiwan, 2010, pp. 1–5.

[6] K. Collins and G. M. Muntean, "A vehicle route management solution enabled by Wireless Vehicular Networks," in *IEEE INFOCOM Workshops, Phoenix, Arizona, USA 2008*, pp. 1–6.

[7] J. D. Vreeswijk, M. K. M. Mahmod, and B. van Arem, "Energy efficient traffic management and control-the eCoMove approach and expected benefits," in *IEEE International Conference on Intelligent Transportation Systems (ITSC)*, Madeira, Portugal 2010, pp. 955–961.

[8] M. Alsabaan, K. Naik, T. Khalifa, and A. Nayak, "Vehicular networks for reduction of fuel consumption and CO2 emission," in *IEEE International Conference on Industrial Informatics (INDIN)*, Osaka Japan, 2010, pp. 671–676.

[9] L. W. Chen, P. Sharma, and Y. C. Tseng, "Eco-Sign: a load-based traffic light control system for environmental protection with vehicular communications," in *Proceedings of the ACM SIGCOMM conference*, Toronto, Canada, 2011, pp. 438–439.

[10] G. V. Lioudakis, C. A. Papagianni, D. I. Kaklamani, I. S. Venieris, and A. H. Salden, "An Intelligent Traffic Management System for the Eco-Optimization of Urban Traffic Flows," in *IEEE International Conference on, Communications Workshops (ICC), Cape Town, South Africa,* 2010, pp. 1–5.

[11] Q. Xu, R. Segupta, D. Jiang, and D. Chrysler, "Design and analysis of highway safety communication protocol in 5.9 ghz dedicated short range communication spectrum," in *IEEE Vehicular Technology Conference. VTC Spring*, Jeju, Korea, ,2003, vol. 4, pp. 2451–2455.

[12] S. Eichler, "Performance evaluation of the *IEEE* 802.11 p WAVE communication standard," in *IEEE Vehicular Technology Conference. VTC Fall*, 2007, Baltimore, USA, pp. 2199–2203.

[13] J. Santa, A. F. Gómez-Skarmeta, and M. Sánchez-Artigas, "Architecture and evaluation of a unified V2V and V2I communication system based on cellular networks," *Computer Communications*, vol. 31, no. 12, pp. 2850–2861, 2008.

[14] B. Aslam, P. Wang, and C. C. Zou, "Pervasive Internet Access by Vehicles through Satellite Receive-only Terminals," in *International Conference on Computer Communications and Networks, ICCCN* Zurich, Switzerland,*2009*, pp. 1–6.

[15] F. Chiang and J. I. Agbinya, "Bio-Inspired Topology Convergence Algorithms in Resource-Constrained VANETs.",The Australian Telecommunications Networks and Applications Conference, Christchurch, New Zealand, 2007, pp. 1-6

[16] W. Du, M. Zhengxin, Y. Bai, C. Shen, B. Chen, and Y. Zhou, "Integrated Wireless Networking Architecture for Maritime Communications," *ACIS International Conference on Software Engineering Artificial Intelligence Networking & Parallel/Distributed Computing (SNPD),* London, UK, 2010, pp. 134–138.

[17] J. Zhao and G. Cao, "VADD: Vehicle-assisted data delivery in vehicular ad hoc networks," *International Conference on Computer Communications (INFOCOM),* Arlington, USA, 2006, pp. 1–12.

[18] S. Teshima, T. Ohta, E. Kohno, and Y. Kakuda, "A data transfer scheme using autonomous clustering in VANETs environment," in *International Symposium on Autonomous Decentralized Systems (ISADS),* Kobe, Japan, 2011 , pp. 477–482.

[19] J. Nzouonta, N. Rajgure, G. Wang, and C. Borcea, "VANET routing on city roads using real-time vehicular traffic information," *IEEE Transactions on Vehicular Technology,* vol. 58, no. 7, pp. 3609–3626, 2009.

[20] J. Hothi and W. Hall, "An evaluation of adapted hypermedia techniques using static user modelling," in *Proceedings of the second Workshop on Adaptive Hypertext and Hypermedia*, 1998, Pittsburgh, USA, pp. 45–50.

[21] M. Barbehenn, "A note on the complexity of Dijkstra's algorithm for graphs with weighted vertices," *IEEE Transactions on Computers,* vol. 47, no. 2, p. 263, 1998.

[22] W. Cho, S. I. Kim, H. kyun Choi, H. S. Oh, and D. Y. Kwak, "Performance evaluation of V2V/V2I communications: the effect of midamble insertion," *1st Int. Conf. on Wireless Communication, Vehicular Technology, Information Theory and Aerospace & Electronic Systems Technology, VITAE 2009.*, pp. 793–797.

[23] *TAPASCologne*. http://kolntrace.project.citi-lab.fr/.

[24] *iTETRIS*. Available Online at ict-itetris.eu.

[25] *NS3*. Available Online at www.nsnam.org.

[26] *Sumo*. Available Online at sumo.sourceforge.net .

[27] W. Dong, "An overview of in-vehicle route guidance system," *Australasian Transport Research Forum,* Adelaide, Australia, Sep. 2011.

[28] *Google Earth*. .Available Online at http://earth.google.com .