



Vehicular Ad-hoc Networks (VANETs): Architecture, Applications and Challenges

Manish Suroliya^{*}, V. S. Dhaka, Ramesh C. Poonia

School of Engineering & Technology, Jaipur
National University, Jaipur - India

Abstract— Vehicular ad hoc networks (VANETs) have been recently attracting an increasing attention from both research and industry communities due to low cost, flexibility, fault tolerance, high sensing fidelity, creating many new and exciting application areas for remote sensing. So, it has emerged as a promising tool for monitoring the physical world with wireless sensor that can sense, process and communicate. Their applications range from safety and crash avoidance to Internet access and multimedia. VANETs are emerging networks that provide the platform for information exchange between adjacent vehicles, roadside infrastructure elements, sensors, and pedestrian personal devices by using wireless ad hoc communications. This paper is focusing on the study of VANET features, architecture, challenges and its applications as it is an evolving field which offers scope for research.

Keywords— VANETs, DSRC, WLAN, VSC, WAVE

I. INTRODUCTION

One promising application of mobile ad hoc networks is the development of vehicular ad-hoc networks (VANET). A MANET is a network of self-formation, which can operate without the need for any centralized control. Each node in an ad hoc network acts as a data terminal and a router. Network nodes then use the wireless medium to communicate with other nodes in its radio range. A VANET is actually a subset of MANETs. The advantage of using ad hoc networks is that these networks can be deployed in areas where it is not possible to install the necessary infrastructure. Vehicular Ad-hoc Networks (VANETs) represent a rapidly growing, particularly difficult class of Mobile Ad-hoc Networks (MANET). VANETs are distributed communications networks, self-organizing built from vehicles traveling, and therefore are characterized by a very high speed and limited degrees of freedom in the movement patterns of nodes.

Vehicle-to-vehicle (V2V) communications is a crucial component of the intelligent transportation system (ITS) [1], which utilizes the Global Positioning System (GPS) and Dedicated Short-Range Communications (DSRC) or IEEE 802.11p radios [2] for vehicles to exchange information with each other in an ad hoc mode. One important V2V application is cooperative active safety that expands a driver's perception horizon and thus has the potential to enhance the roadway safety [3]. There can be numerous useful and interesting services on the road provided by VANETs [4], [5], [6], [7], [8], [9]. Vehicular ad hoc networks are also called Inter-vehicle Communications (IVC) or Vehicle-to-Vehicle (V2V) communications. ITS is the major application of VANETs. ITS includes a variety of applications such as cooperative traffic monitoring, control of traffic flows, blind crossing, prevention of collisions, nearby information services, and real-time detour routes computation. Another important application for VANETs is providing Internet connectivity to vehicular nodes while on the move, so the users can download music, send emails, or play back-seat passenger games.

II. RELATED WORK

VANET or IVC has drawn a significant research interests from both academia and industry. One of the earliest studies on IVC was started by JSK (Association of Electronic Technology for Automobile Traffic and Driving) of Japan in the early 1980s. Later, California PATH [10] and Chauffeur of EU [11] have also demonstrated the technique of coupling two or more vehicles together electronically to form a train.

Recently, the European project CarTALK 2000 [12] tries to investigate problems related to the safe and comfortable driving based on inter-vehicle communications. Following this trend, various new workshops were created to address research issues in this emerging area, such as ACM International Workshop on Vehicular Ad Hoc Networks from 2004 and International Workshop on Intelligent Transportation from 2003.

On the other hand, several major automobile manufacturers have already begun to invest inter-vehicle networks. Audi, BMW, DaimlerChrysler, Fiat, Renault and Volkswagen have united to create a non-profit organization called Car2Car Communication Consortium (C2CCC) [13] which is dedicated to the objective of further increasing road traffic safety and efficiency by means of inter-vehicle communications. IEEE also formed the new IEEE 802.11p task group which focuses on providing wireless access for the vehicular environment. A number of routing protocols [14], [15], [16], [17], [18] have been proposed to increase the likelihood of successfully delivering a message, which can be applied to VANETs.

III. VANET ARCHITECTURE

MANETs generally do not rely on fixed infrastructure for communication and distribution of information. VANETs follow the same principle and apply it to the highly dynamic environment of surface transportation. As shown in figure 1, the architecture of VANETs falls within three categories: pure cellular/WLAN, pure ad-hoc, and hybrid. VANETs may use fixed cellular gateways and WLAN access points at traffic intersections to connect to the Internet, gather traffic information or for routing purposes. The network architecture under this scenario is a pure cellular or WLAN structure as shown in figure 1(a). VANETs can combine both cellular network and WLAN to form the networks so that a WLAN is used where an access point is available and a 3G connection otherwise. Stationary or fixed gateways around the sides of roads could provide connectivity to mobile nodes (vehicles) but are eventually unfeasible considering the infrastructure costs involved. In such a scenario, all vehicles and roadside wireless devices can form a mobile ad hoc network (figure 1(b)) to perform vehicle-to-vehicle communications and achieve certain goals, such as blind crossing (a crossing without light control).

Fig. 1 Three possible netwo

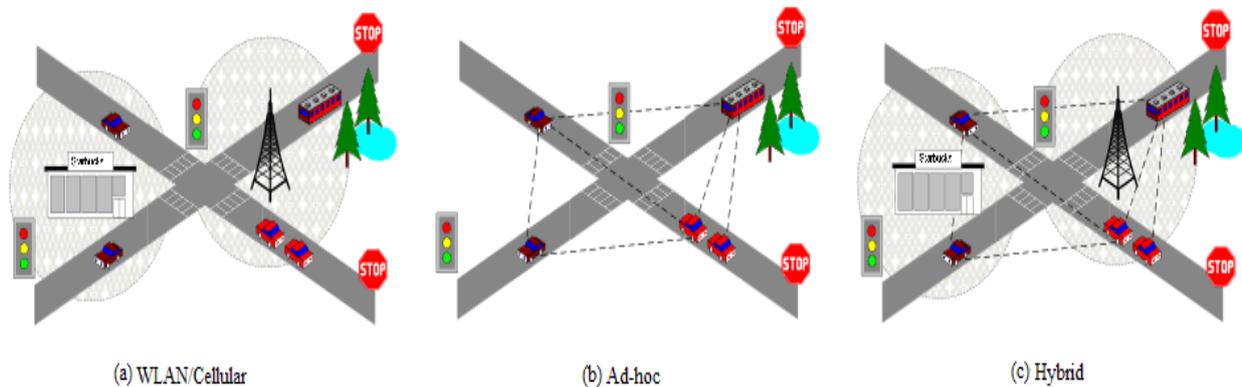


Fig.-Architecture for VANETs

rk

Hybrid architecture (figure 1(c)) of combining cellular, WLAN and ad hoc networks together has also been a possible solution for VANETs. Namboodiri [19] proposed such a hybrid architecture which uses some vehicles with both WLAN and cellular capabilities as the gateways and mobile network routers so that vehicles with only WLAN capability can communicate with them through multi-hop links to remain connected to the world

IV. SPECIAL FEATURES

Although VANET could be treated as a subgroup of Mobile Ad- hoc Networks (MANETs) and it is still necessary to consider VANETs as a distinct research field, especially in the light of security provisioning. The unique characteristics of VANET include features:

- a) **High Dynamic Topology:** The speed and choice of path defines the dynamic topology of VANET. If we assume two vehicles moving away from each other with a speed of 60 km/h (25 m/s) and if the transmission range is about 250m, then the link between these two vehicles will last for only 5 seconds (250m). This defines its highly dynamic topology.
- b) **Frequent Disconnected Network:** This feature necessitates that in about every 5 seconds or so, the nodes need another link with nearby vehicle to maintain seamless connectivity. But in case of such failure, particularly in case of low vehicle density zone, frequent disruption of network connectivity will occur. Such problems are at times addressed by road-side deployment of relay nodes.
- c) **Mobility Modelling and Prediction [20]:** The above features for connectivity therefore needed the knowledge of node positions and their movements which is as such very difficult to predict keeping in view the nature and pattern of movement of each vehicle. Nonetheless, a mobility model and node prediction based on study of predefined roadways model and vehicle speed is of paramount importance for effective network design.
- d) **Communication Environment:** The mobility model highly varies from highways to that of city environment. The node prediction design and routing algorithm also therefore need to adapt for these changes. Highway mobility model is essentially a one-dimensional model which is rather simple and easy to predict. But for city mobility model, street structure, variable node density, presence of buildings and trees behave as obstacles to even small distance communication make the model application very complex and difficult.
- e) **Unlimited Transmission Power:** The node (vehicle) itself can provide continuous power to computing and communication devices.
- f) **Hard Delay Constraints:** The safety aspect (such as accidents, brake event) of VANET application warrants on time delivery of message to relevant nodes. It simply cannot compromise with any hard data delay in this regard. Therefore, high data rates are not as important as an issue for VANET as overcoming the issues of hard delay constraints.
- g) **Interaction with onboard Sensors:** These sensors help in providing node location and their movement nature that are used for effective communication link and routing purposes.

- h) **Higher Computational Capability:** Indeed, operating vehicles can afford significant computing, communication and sensing capabilities.
- i) **Rapidly Changing Network Topology:** Due to high node mobility, the network topology in VANET tends to change frequently.
- j) **Potentially Unbounded Network Size:** VANETs could involve the vehicles in one city, several cities or even a country. Thus, it is necessary to make any protocols for VANET is scalable in order to be practical.
- k) **Anonymous Addressee:** Most applications in VANETs require identification of the vehicles in a certain region, instead of the specific vehicles. This may help protect node privacy in VANETs.
- l) **Time-Sensitive Data Exchange:** Most safety related applications require data packet transmission in a timely manner. Thus, any security schemes cannot harm the network performance of VANETs
- m) **Potential Support from Infrastructure:** Unlike common MANETs, VANETs can actually take advantage of infrastructure in the future. This property has to be considered to make any protocols and a scheme for VANET is better.
- n) **Abundant Resources:** VANET nodes have abundant energy and computation resources. This allows schemes involving usage of resource demanding techniques such as ECDSA, RSA etc.
- o) **Better Physical Protection:** VANET nodes are better protected than MANETs. Thus, Nodes are more difficult to compromise which is also good news for security provisioning in VANETs.
- p) **Partitioned Network:** Vehicular networks will be frequently partitioned. The dynamic nature of traffic may result in large inter vehicle gaps in sparsely populated scenarios and hence in several isolated clusters of nodes.

V. APPLICATIONS [21]

The main vehicular ad-hoc network applications can be broadly classified into three categories: a) road safety applications, b) traffic management applications, and c) comfort applications.

a) **Road-Safety Applications:**

The main goal of the safety applications [22] is to increase public safety and protect the loss of life. The main characteristic of these applications is that the safety data should be delivered to the intended receivers (vehicles approaching the dangerous area) within a bounded time. The Vehicles Safety Communication (VSC) project has defined 34 different safety applications to work under the DSRC technology. These applications were studied in depth to determine the potential benefit provided by them. In the following, we present some of the applications that, according to the VSC, provide the greatest benefit in terms of safety of life.

(i) **Cooperative Collision Avoidance (CCA):**

The main goal of this application is to prevent collisions. This type of safety applications will be triggered automatically when there is a possibility of collisions between vehicles. Vehicles, upon detecting a possible collision situation, send warning messages to alert the drivers approaching the collision area. The drivers can take the proper actions or the vehicle itself can stop or decrease the speed automatically. Another scenario where the CCA are of great importance is to avoid crashes during lane change. The CCA messages are disseminated to vehicles approaching the collision area. One of the proposed techniques to disseminate CCA messages on a highway was presented in [23].

(ii) **Emergency Warning Messages (EWM):**

This type of applications is similar to the CCA. However, depending on the type of the emergency event, the EWMs either vanish once they are disseminated or may reside in the relevant area for longer period of time. For example, when vehicles detect an accident they start to send EWMs to warn vehicles that are close to the accident area. Another example is when vehicles sense a dangerous road conditions they send EWMs to other vehicles in a certain area, and these vehicles disseminate the EWMs to the new vehicles entering that area. Some of the proposed techniques are presented in [24].

(iii) **Cooperative Intersection Collision Avoidance (CICA):**

This type of applications will be used to avoid collisions at the intersections (signalized or non-signalized). Mainly, an RSU installed at the intersection periodically distributes the state of the intersection to the approaching vehicles. The distributed information includes:

Traffic Signal State that changes from red, green, yellow, and time remaining until the traffic switches to a new state.

State of the vehicles approaching the intersection that are within a relevant distance/time from the intersection

Intersection environmental conditions like weather, visibility, road surface at the intersection. Several of the works about the intersection collision avoidance can be found in [25] [26].

b) **Traffic managements Applications:**

This type of applications is used to facilitate traffic flow, thus reducing traffic congestion, fuel consumption, and travel time. This type of applications is less strict on real-time constraints. This means that if the messages are delayed, there is no real threat to life (no collision to occur), as opposed to the safety messages where a real threat to the life may occur if the messages are delayed. The information provided by these applications mainly describes the status of the traffic in a certain areas like intersection or road constructions. In this kind of applications, vehicles cooperate to generate messages. These messages are aggregated and sent, using inter-vehicle communications, in a multi-hop manner to other vehicles in other geographic areas. Some of the papers that discuss the aggregation and forwarding are [27].

c) **Comfort applications:**

The goal of this type of applications is to provide comfort and entertainments to the passengers. The advertisement applications have commercial purposes. The data of this type of applications should not consume the bandwidth on the count of the safety data. The priority should always be given to the safety data. Some of these applications are:

(i) **Electronic toll collection:**

Using this service, the drivers don't need to stop and make the payment; instead the payment is done electronically through the network.

(ii) **Entertainment Applications:**

Multimedia files (music, movies, news, e-books, and so on) can be uploaded to vehicles. These data can also be transferred from one vehicle to another. Information about local restaurants, hotels, malls, gas stations can be uploaded to the vehicles and can also be exchanged among vehicles using the inter-vehicular networks to facilitate travelling.

(iii) **Internet Access:**

Passengers can browse the internet and send/receive emails. Most of these applications will be downloaded from other networks (like internet). However, vehicles use the inter-vehicle networks to distribute these information to reduce the cost associated with the installation of the infrastructure along the roads.

(iv) **Group Communications:**

Many drivers may share some common interests when they are on the same road to the same direction, so they can use the VANET Group Communication functions. In the MAC layer, the Group Communications can use DSRC service channels except the control channel with the lowest priority comparing with the safety related applications and ETCs. In the network layer, it is used to support such application scenario in which multicast is the key technology. In the past, Internet multicast has not been successful due to its complexity because Internet multicast requires global deployment, which is virtually impossible. In a VANET, however, since all nodes are located in a relatively local area, implementing such group communication becomes possible. There are many Roadside Service Finders. For example, find restaurants, gas stations etc., in the nearby area along the road. A Roadside Services Database will be installed in the local area that connected to the corresponding RSUs (Road Side Units). In the MAC layer, the Roadside Services Finder application can use DSRC service channels except the control channel, with the lowest priority comparing with the safety related applications and ETCs. Each vehicle can issue a Service Finder Request message that can be routed to the nearest RSU and a Service Finder Response message that can be routed back to the vehicle. In short, the application layer requirements must be addressed in the MAC layer and network layer design. In the next section, we provide a network design framework to satisfy the above applications while providing sufficient security.

DAHNI (Driver Ad Hoc Networking Infrastructure): DAHNI provides numerous possibilities to revolutionize the automotive and transportation industry of the future. For example, data captured by DAHNI, when properly aggregated, can be fed into the traffic monitoring and flow control system for real-time traffic management. Alternatively, such information can be archived for off-line analysis to understand traffic bottlenecks and devise techniques to alleviate traffic congestion. **Dedicated Short-Range Communications (DSRC) [28]:** DSRC system has emerged in North America, where 75 MHz of spectrum was approved by the U.S. FCC (Federal Communication Commission) in 2003 for such type of communication that mainly targets vehicular networks. On the other hand, the Car-to-Car Communication Consortium[4] (C2C-CC) has been initiated in Europe by car manufacturers and automotive OEMs (original equipment manufacturers), with the main objective of increasing road traffic safety and efficiency by means of inter vehicle communication. IEEE is also advancing within the IEEE 1609 family of standards for wireless access in vehicular environments (WAVE).

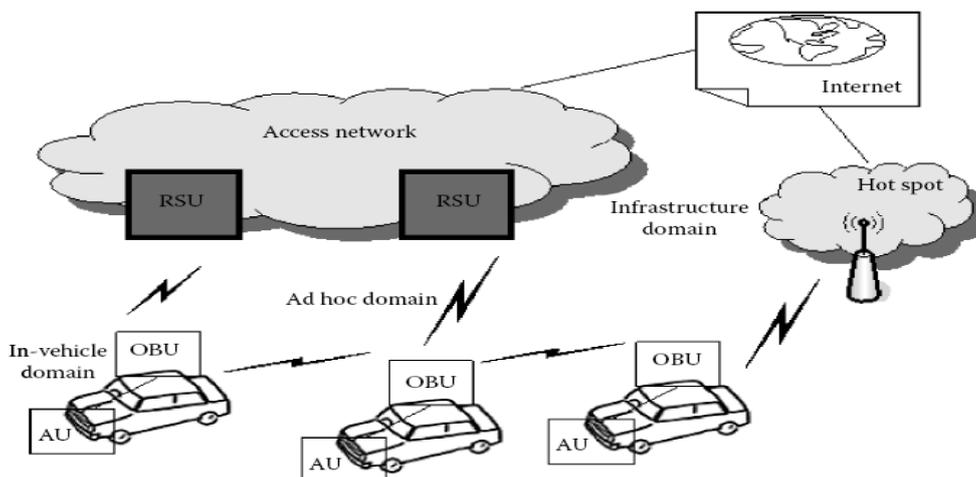


Fig. 2 C2C-CC reference architecture [29]

VI. CHALLENGES

We outline some of the VANET research challenges that still need to be addressed to enable the ubiquitous deployment and widespread adoption of scalable, reliable robust and secure VANETs architectures, protocols, technologies and services.

a) **Mobility**

The basic idea from Ad Hoc Networks is that each node in the network is mobile, and can move from one place to another within the coverage area, but still the mobility is limited, in Vehicular Ad Hoc Networks nodes moving in high mobility, vehicles make connection through their way with another vehicles that maybe never faced before, and this connection lasts for only few seconds as each vehicle goes in its direction, and these two vehicles may never meet again. So securing mobility challenge is hard problem [30], [31].

b) **Volatility**

The connectivity among nodes can be highly ephemeral, and maybe will not happen again, Vehicles traveling through coverage area and making connection with other vehicles, these connections will be lost as each car has a high mobility, and maybe will travel in opposite direction [32]. Vehicular networks lack the relatively long life context, so personal contact of users device to a hot spot will require long life password, and this will be impractical for securing VC.

c) **Network Scalability**

The scale of this network in the world approximately exceeding the 750 million nodes [33], and this number is growing, another problem arises when we must know that there is no global authority govern the standards for this network [34] for example: the standards for DSRC in North America is different from the DSRC standards in Europe, the standards for the GM Vehicles is different from the BMW one.

d) **Bootstrap**

At this moment only few number of cars will have the equipment required for the DSRC radios, so if we make a communication we have to assume that there is a limited number of cars that will receive the communication, in the future we must concentrate on getting the number higher, to get a financial benefit that will encourage the commercial firms to invest in this technology.

VII. FUTURE WORK

It's basically a network of cars that are in constant communication. Each car knows where it is, where it's going and basically any other quantity that it can measure. Not only has every car been made "self aware", it can also communicate with any other car on the road. Just take a minute to think of all the possibilities. The first one that comes to mind is road safety. If all cars know where all other cars are, cars headed for an imminent crash can warn their respective drivers and even apply autonomous control to avoid accidents. Not only drivers can be informed about delays to their destination, but traffic lights can be connected to the communication network to most efficiently route traffic in real time. This creates a system where the road network always serves the current needs of the users on the network.

VIII. CONCLUSIONS

VANET is a promising wireless communication technology for improving highway safety and information services. In this paper, we explore the features and architecture that design an oriented network framework. We also study several applications and wide analysis for the current challenges. VANET applications range from safety and crash avoidance to Internet access and multimedia. Although many problems are not yet solved, the general feeling is that vehicles could benefit from spontaneous wireless communications in a near future, making VANETs a reality. We believe that our study can provide a guideline for more practical work in VANET.

REFERENCES:

- [1] R. Sengupta, "Cooperative Collision Warning Systems: Concept Definition and Experimental Implementation", *J. Intelligent Transportation Sys.*, Vol. 11, no. 3, 2007.
- [2] *Wireless Access in Vehicular Environments (WAVE) in Standard 802.11*, Specific Requirements: IEEE 802.11p/D2.01, Mar. 2007.
- [3] F. Bai, "Towards Characterizing and Classifying Communication-based Automotive Applications from a Wireless Networking Perspective," *Proc. 1st IEEE Wksp. Automotive Networking and App.*, Dec. 2006.
- [4] D. Reichardt, M. Miglietta, L. Moretti, P. Morsink, and W. Schulz. *CarTALK 2000*, "Safe and Comfortable Driving Based upon Inter-Vehicle-Communication", *IEEE Intelligent Vehicle Symposium*, 2002
- [5] X. Yang, J. Liu, F. Zhao, and N. Vaidya, "A Vehicle-to-Vehicle Communication Protocol for Cooperative Collision Warning MobicQuitous", 2004.
- [6] Q. Xu, T. Mark, J. Ko, and R. Sengupta, "Vehicle-to-Vehicle Safety Messaging in DSRC", *ACM Workshop VANET*, 2004.
- [7] J. Luo and J.-P. Hubaux, "A Survey of Research in Inter-Vehicle Communications Securing Current and Future Automotive IT Applications", pp. 111-122, Springer-Verlag, 2005.
- [8] J. Ott and D. Kutscher, "A Disconnection-Tolerant Transport for Drive-thru Internet Environments", In *Proc. INFOCOM'05*, Mar. 2005.
- [9] J. Burgess, B. Gallagher, D. Jensen, and B. N. Levine, "MaxProp: Routing for Vehicle-Based Disruption-Tolerant Networks", In *Proc. INFOCOM'06*, April 2006.

- [10] J.K. Hedrick, M. Tomizuka, and P. Varaiya, "Control issues in automated highway systems", IEEE Control Systems Magazine, vol. 14, no. 6, pp. 21–32, Dec 1994.
- [11] O. Gehring and H. Fritz, "Practical results of a longitudinal control concept for truck platooning with vehicle to vehicle communication", in Proceedings of the 1st IEEE Conference on Intelligent Transportation System (ITSC'97), pp. 117–122, Oct. 1997.
- [12] D. Reichardt, M. Miglietta, L. Moretti, P. Morsink, and W. Schulz, "Cartalk 2000— safe and comfortable driving based upon inter-vehicle communication", in Proceedings of the IEEE Intelligent Vehicle Symposium (IV02), 2002.
- [13] "Car-to-car communication consortium," <http://www.car-to-car.org>.
- [14] E. Jones, L. Li, and P. Ward, "Practical Routing in Delay-Tolerant Networks", In Proc.ACM Chants Workshop, Aug. 2005.
- [15] S. Jain, K. Fall, and R. Patra, "Routing in a Delay Tolerant Network", In Proc.SIGCOMM'04, pp. 145-158, 2004.
- [16] A. Vahdat and D. Becker, *Epidemic routing for partially connected ad hoc networks Technical Report CS-200006*, Duke University, April 2000.
- [17] B. Burns, O. Brock, and B. N. Levine. MV, "Routing and Capacity Building in Disruption Tolerant Networks", In Proc. INFOCOM'05, March 2005.
- [18] T. Spyropoulos, K. Psounis, and C. S. Raghavendra, "Spray and Wait: An Efficient Routing Scheme for Intermittently Connected Mobile Networks", In Proc. WDTN'05, Aug. 2005.
- [19] V. Namboodiri, M. Agarwal, and L. Gao, "A study on the feasibility of mobile gateways for vehicular ad-hoc networks", in Proceedings of the First International Workshop on Vehicular Ad Hoc Networks, pp. 66–75, 2004.
- [20] A.K. Saha and D.B. Johnson, "Modeling Mobility for Vehicular Ad Hoc Networks", Department of Computer Science, Rice University, Houston, USA.
- [21] Y. Qian and N. Moayeri, "Design Secure and Application-Oriented VANET", National Institute of Standards and Technology.
- [22] Z. Li, Z. Wang and C. Chigan, "Security of Vehicular Ad Hoc Networks for Intelligent Transportation Systems in Wireless Technologies", Nova Science Publishers, 2009.
- [23] S. Biswas, R. Tatchkou, F.Dion , "Vehicle-to-Vehicle Wireless Communication Protocols for Enhancing Highway Traffic Safety", IEEE Communications Magazine, January, 2006.
- [24] Q. Yu, "Abiding Geocast for Warming Message Dissemination in Vehicular Ad Hoc Networks", IEEE Communications Workshops, 2007.
- [25] L. Tong, S. Geirhofer, B. Sadler, "Cognitive Frequency Hopping Based on Interference Prediction: Theory and Experimental Results", ACM SIGMOBILE Mobile Computing and Communications Review 13 (2): 49-61, 2009.
- [26] A. Benmimoun, J. Chen, "Communication-based intersection assistance", Intelligent Vehicles Symposium, 2005
- [27] M Kahl, M. Sichitiu, "Inter-Vehicle Communication Systems: A Survey", IEEE communications surveys & tutorials 10(2), 2008.
- [28] *Dedicated Short Range Communications (DSRC)*, <http://www.learmstrong.com/DSRC/DSRCHomeset.htm> September 2005.
- [29] *Car-to-Car Communication Consortium*, <http://www.car-to-car.org>., February 2012.
- [30] B. Parno and A. Perrig, "Challenges in Securing Vehicular Networks", Proc. of HotNets-IV, 2005.
- [31] F. Karnadi, Z. Mo, "Rapid Generation of Realistic Mobility Models for VANET ", proc. IEEE Wireless Communications and Networking Conference, 2007.
- [32] M. Raya, P Papadimitratos, JP Hubaux, "Securing Vehicular Communications", IEEE Wireless Communications, Vol 13, October 2006.
- [33] M. Raya, D Jungels, P Papadimitratos, I. Aad, JP Hubaux,"Certificate Revocation in Vehicular Networks " , Laboratory for computer Communications and Applications (LCA) School of Computer and Communication Sciences ,EPFL, Switzerland, 2006 .
- [34] Aad. JP Hubaux, EW Knightly, "Impact of Denial of Service Attacks on Ad Hoc Networks", Networking, IEEE/ACM Transactions on Volume 16, August, 2008.