This paper was presented as part of the Mini-Conference at IEEE INFOCOM 2011

PVA in VANETs: Stopped Cars Are Not Silent

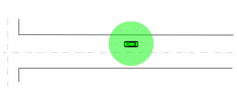
Nianbo Liu*†, Ming Liu*, Wei Lou†, Guihai Chen‡ and Jiannong Cao†
*School of Computer Science and Engineering,
University of Electronic Science and Technology of China, Chengdu, China
†Department of Computing, Hong Kong Polytechnic University, Hongkong, China
‡Department of Computer Science and Engineering, Shanghai Jiao Tong University, Shanghai, China

***Abstract*—In Vehicular Ad Hoc Networks (VANETs), the major communication challenge lies in very poor connectivity, which can be caused by sparse or unbalanced traffic. Deploying supporting infrastructure could relieve this problem, but it often requires a large amount of investment and elaborate design, especially at the city scale. In this paper, we propose the idea of Parked Vehicle Assistance (PVA), which allows parked vehicles to join VANETs as static nodes. With wireless device and rechargable battery, parked vehicles can easily communicate with one another and their moving counterparts. Owing to the extensive parking in cities, parked vehicles are natural roadside nodes characterized by large number, long-time staying, wide distribution, and specific location. So parked vehicles can serve as static backbone and service infrastructure to improve connectivity. We investigate network connectivity in PVA through theoretic analysis and realistic survey and simulations. The results prove that even a small proportion of PVA vehicles could overcome sparse or unbalanced traffic, and promote network connectivity greatly. Thus, PVA enhances VANETs from down to top, and paves the way for new hybrid networks with static and mobile nodes.**

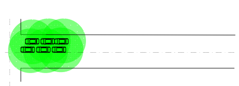
***Index Terms*—VANET, connectivity, parking, PVA.**

I. Introduction

As more and more vehicles are equipped with wireless devices, large scale vehicular networks are expected to be available in the near future. In VANETs, the major communication challenge lies in very poor connectivity, which can be caused by sparse or unbalanced traffic. As shown in Fig. 1, sparse traffic means one vehicle is very hard to find another, while unbalanced one describes the situations that vehicles are not evenly distributed in streets due to traffic light, jam, car-following driving or other reasons. Even if the average vehicle density is high, unbalanced traffic is inevitable and often leads to disconnection. Consequently, VANETs are regarded as extreme environments or challenged networks that are opportunistically connected.



(a) sparse traffic



(b) unbalanced traffic

Fig. 1. Poor connectivity in VANETs

Connectivity is crucial and significantly affects the underlying routing and the overall performance of applications. Many schemes are proposed to exploit the opportunistic connectivity, including the broadcast techniques and the delay-tolerant ones. Instead of these adaptable approaches, a more ambitious aim is presented: how to improve the connectivity? With better connectivity, transmission delay and possibility of lost messages, caused by long periods of partitioning, can be reduced. Correspondingly, vehicular applications could benefit from more reliable data delivery, and vehicle users could acquire more satisfying services, in less challenging environments.

Since Access Points (APs) can provide access service for nearby mobile nodes, integrating moving vehicles into the Internet through APs becomes a convenient choice. Recent efforts [1], [2], [3], [4] show that proper AP deployment techniques could dramatically improve connectivity. A viable alternative is to install some roadside units to relay packets. In [5], [6], [7], relay units for packet forwarding and their strategic placement are discussed. However, the wide deployment of infrastructure is very expensive. For example, Internet APs need costly installation of power and wired network connectivity - these costs can be as high as 5,000 US dollars per unit [8]. Relay nodes are cheaper, but more units are needed for the same performance. Furthermore, static roadside infrastructure is hardly adaptive to rapid-changing traffic. It seems all but impossible to build a single strategy that represents all aspects of optimal deployment, such as budget limits, street layout, traffic changes, transmission delay, and utilization. Generally, the introduction of supporting infrastructure does improve connectivity, but it often requires a large amount of investment and elaborate design, especially at the city scale.

In this paper, we propose the idea of PVA, which allows parked vehicles to join VANETs as static nodes. With wireless device and rechargable battery, parked vehicles can easily communicate with one another and their moving counterparts. Owing to the extensive parking in cities, parked vehicles are natural roadside nodes characterized by large number, long-time staying, wide distribution, and specific location. So parked vehicles can serve as static backbone and service infrastructure to improve connectivity. We investigate network connectivity in PVA through theoretic analysis and realistic survey and simulations. The results prove that even a small proportion of PVA vehicles could overcome sparse or unbalanced traffic, and promote network connectivity greatly. Thus, PVA enhances VANETs from down to top, and paves the way for new hybrid networks with static and mobile nodes.

The remainder of this paper is structured as follows. In Section II, we explore urban parking behaviors and features. Section III analyzes PVA in theory, while Section IV evaluates PVA through realistic survey and simulations. Finally, Section

V summarizes the paper and outlines the perspectives.

II. From Parked Vehicles to PVA

A. Parking in Cities

At first, we build our research on a real world urban parking report [9], which provides the parking statistics of two surveys in a central area of Montreal city in Canada. It investigated the 61,000 daily parking events in an area of 5,500 square kilometers. According to the report, street parking, outside parking (mainly off-street parking on the ground), and interior parking (garages or underground parking lots) account for 69.2%, 27.1%, and 3.7% of total respectively, and the average duration of street parking lasts 6.64 hours. It generates many roadside vehicle nodes easy to communicate and enables them to support long-time communication. Figure 2 from [9] spatially describes the detailed parking distribution in Montreal at 22:00, which allows identifying the widespread parking locations along the streets. In the area, the total number of parked vehicles ranges from 26,990 to 34,170, which makes up substantive vehicle sources in all hours of one day.

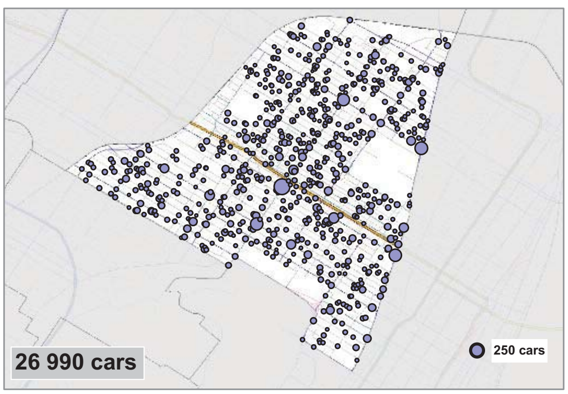


Fig. 2. Parking distribution in Montreal

Compared to their moving counterparts, parked vehicles show great advantages in communication. Traffic changes acutely and sometimes makes vehicles very sparse or unbalanced, whereas parked vehicles remain constant in large number all day. Moving vehicles have rapid-changing positions every second, but parked ones stay static for hours. Large ratio of street parking and widespread parking distribution make parked vehicles easy to be exploited in communication, where message delivery often follows road directions. Since parked vehicles are abundant, credible, and convenient node sources, PVA has a solid basis in urban areas.

B. Parking at Specific Locations

Individual parked vehicle nodes are far from stable roadside units, due to uncertain parking location and duration. But aggregated urban parking behaviors often show a high degree of temporal and spatial regularity. In order to balance supply and demand, city planners often enforce local restrictions and set up specific locations for parking on every block, such as on-street parking spaces and parking lots.

A survey [10] explores on-street parking in Ann Arbor, the US state of Michigan. The research team selected three sites of on-street parking meters in the city, and continuously monitored their usage during six mid-week days. As the shown in Table I, the selected sites (A/B) represent different downtown shopping areas, and the periods (Peak/Off-peak/Day) point out the survey time (Peak: 12:30-2:30pm and Off-peak: 8:30-10:30am). It carried out an all-day observation and some short ones within 2 hours. Although each parking is short and undulated, the utilization of the parking spaces is quite stable. Occupancy ratio, defined as occupied space-hour/available space-hour, averages 93.0% on Site A throughout one day, and nearly 100% around Site A and B during the peak. Even off-peak occupancy ratio averages almost 80%. For all practical purposes, the on-street parking spaces are used all of the time, for high parking demand. This result is not surprising, nevertheless it accords with the fact that about 30% of traffic is cruising for parking in downtowns of cities [11].

TABLE I
On-street Parking in Ann Arbor

Site and period	A, Day	A, Off-peak	A, Peak	B, Peak
Meters surveyed	61	33	34	35
Duration	21 h	2 h	2 h	2 h
Vehicles parked	476	84	94	94
Average stay	41.40 m	39.07 m	42.98 m	44.57 m
Standard deviation	27.17 m	25.09 m	28.43 m	29.96 m
Occupancy ratio	93.5%	79.0%	99.0%	100%

Similarly, another survey [12] provides the utilization of parking lots in Hattiesburg, the US state of Mississippi. It investigated eight parking lots of the city in November and December, 1996 and in March and April, 1997. The utilization and standard deviation of the parking lots demonstrate that these facilities often have considerable vehicle numbers (above 129 averagely) and small parking fluctuations (less than 13.7%). It proves that the possibility of being completely empty is very slim.

Consequently, we can assume such frequently occupied on-street parking spaces and parking lots have some "fixed" vehicles, as stable roadside units in communication, for the positions and occupancy ratios can be marked and maintained in an electric map.

III. Network Connectivity Analysis

Since PVA involves practical parking distribution in urban streets, we examine several static characteristics as node density, inter-vehicle distance, and one-dimensional connectivity, to analyze network connectivity in PVA at different levels of granularity.

Node Density: The density of vehicles provides a reasonably picture of potential connectivity in a specific region. Specifically, suppose vehicle number N and road length L respectively represent the total vehicle number and the sum of the length of each street in the region. And traffic function $f(t)$ indicates the traffic changing by time of day. The penetration ratio r_{pen} defines the percentage of vehicles with wireless device, out of all vehicles. Thus, $r_{pen}f(t)N$ denotes the available vehicle nodes for communication. In this region, the density of moving vehicles ρ_{mv} is given by:

$$\rho_{mv} = \frac{r_{pen}f(t)N}{L} \tag{1}$$

In PVA, parked vehicles within the region become a part of the network. Here we divide traffic into two categories: local traffic and transit traffic (that does not originate or terminate in the area, and cannot bring any valid parked vehicles). Suppose local traffic ratio r_{loc} indicates the percentage of local traffic, out of all traffic. Thus, $r_{loc}(1-f(t))N$ reflects the changing of local parked vehicles by time of day. The PVA ratio r_{pva} defines the percentage of parked vehicles willing and able to provide assistance. So the density of parked vehicles ρ_{pv} is equivalent to:

$$\rho_{pv} = \frac{r_{pen}r_{loc}r_{pva}(1-f(t))N}{L} \tag{2}$$

Formally, the node density in presence of PVA can be stated as follows:

$$\rho_{mv} + \rho_{pv} = (f(t) + r_{loc}r_{pva}(1-f(t)))\frac{r_{pen}N}{L} \tag{3}$$

where $f(t)+r_{loc}r_{pva}(1-f(t))$ represents vehicle node distribution by time. Since a typical vehicle is parked 23 hours one day [13], the moving vehicles occupies 1/24, or 4.17% of total vehicles on average. Based on real daily traffic variation [14], the equivalent traffic volume distribution of average is shown as $f(t)$ in Fig. 3. The parking distribution $1-f(t)$ is nearly 100%, which reflects the fact that parked vehicles dominate whole vehicle nodes in most time of a day. Of cause, not all of them are able and willing to support PVA. But even a small proportion of PVA vehicles will bring great effect: 10% and 30% PVA could promotes node density 3.3 times and 7.9 times respectively, if there's no transit traffic. In particular, PVA eliminates the traditional low-density time during night.

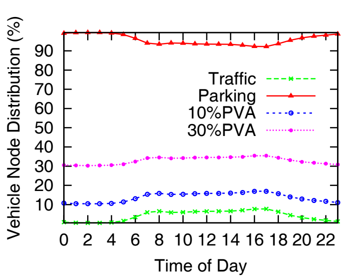
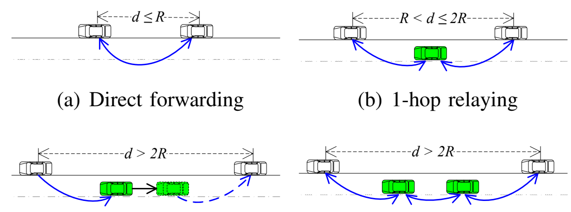


Fig. 3. Vehicle node distribution by time of day

Inter-vehicle Distance: Since forwarding packets can be stored at parked vehicles, inter-vehicle distance between them decide whether and how they relay data accurately. Figure 4 depicts data transmission between two parked vehicles, according to different inter-vehicle distance:

Let R denotes the radio range and d denotes inter-vehicle distance. If $d \le R$ as Fig. 4(a), one vehicle can directly



(a) Direct forwarding (b) 1-hop relaying

(c) Store-carry-forward (d) Multi-hop relaying

Fig. 4. Transmission between two parked vehicles

transmit packets to another vehicle within mutual radio range. In this case, the connection is reliable. In Fig. 4(b), $R < d \le 2R$, there's no direct connection, but any passing vehicle can relay packets between two vehicles. With an average speed v, a moving vehicle brings a temporary connection lasting $(2R-d)/v$. If traffic is dense enough to maintain $\rho_{mv}(2R-d) \ge 1$, or $\rho_{mv} \ge 1/(2R-d)$, the link between two parked vehicles can be regarded as reliable connection. However, when $d > 2R$, possible connection becomes very transient, and sometimes only supports one-way transmission. If traffic is sparse, a moving vehicle can carry packets and forward them to next parked vehicle as Fig. 4(c), with a delay of d/v. In dense traffic environments, multiple moving vehicles can form transient connection to relay packets as Fig. 4(d). In fact, *store-carry-forward* in Fig. 4(c) and multi-hop relaying in Fig. 4(d) often concur in data transmission, which lead to opportunistic delivery and uncertain transmission delay. It remains poor connectivity, if vehicles are parked far from each other. So short inter-vehicle distance, less than twice of the radio range, brings good connectivity.

One-dimensional Connectivity: Since packet forwarding in urban areas is limited by street map, one-dimensional connectivity along a single street becomes very important. Here we discuss this metric by giving a simple example of on-street parking. In a 1000m street, there are 200 roadside parking spaces with a length of 5m. The radio range is 250m. We assume a sender S and a receiver D located at the ends of the street. If vehicles are parked without overlapping onto randomly chosen parking spaces, and each space is equally attractive to vehicle drivers, how many vehicles are enough to form reliable connection between S and D?

Obviously, at leat 3 vehicles could achieve stable connection. Since every fifty spaces is equal to the radio range, the max value of sequential empty spaces is 50. Otherwise, disconnection happens. We can conclude that the link SD is always connected if vehicles are above 150, because there's no 51 empty spaces at all. Similarly, vehicles can be parked along two sides of a street, where available parking spaces are doubled to 400. If we omit the width of the road, the radio range remains unchanged. In two-side parking, 3 vehicles are possible to form stable connection, and 300 vehicles or more avoid disconnection for ever. To a given vehicle number ranging from 1 to 300, we run simulations to check the connection probability with different disconnection gaps, and find the following results.

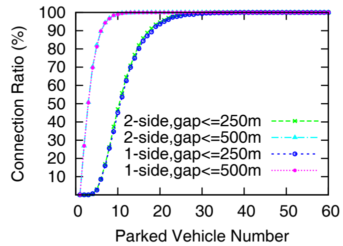


Fig. 5. One-dimensional connectivity along a street

In Fig. 5, one-side and two-side parking have proximal connection probabilities by every vehicle number. When PVA vehicles exceed 29, nearly 100% connection ratio is achieved. If we consider the inferior case in Fig. 4(b), where the gap is no more than 500m, nearly 100% connectivity is observed with a vehicle number above 11. It means there are stable links in urban streets once roadside vehicles participating PVA arrive at 29 veh/km (vehicle per kilometer). Although per street density of parked vehicles affects connectivity, the PVA ratio decides the effectiveness of this metric finally. In saturated two-side parking, a PVA ratio of 7.25% is enough to form reliable link as Fig. 4(a), and that of 2.25% is enough to implement 1-hop relaying as Fig. 4(b). It shows a much lower requirement of cooperative users in PVA than that in current Internet P2P systems. Thus, a very low participation rate of PVA, even 10%, will bring good connectivity in dense-parking streets. In another word, PVA can tolerate a high percentage of free-riders.

IV. Performance Evaluation

A. Survey and Simulations

We firstly performed a six weeks' survey on an urban area of Chengdu, a city in China. Since choosing target area is crucial in performance evaluation, we prefer ordinary urban region with typical parking distribution to downtown areas where the parking is above average. As shown in Fig. 6, we extract a real street map with the range of 1600m×1400m, which contains 9 intersections and 14 bidirectional roads totaled up to 7,860 meters. Each intersection is marked by a number from 0 to 9. During the survey, we investigated the traffic and roadside parking statistics at 16:00, 18:00 and 22:00 of every Tuesday, Thursday, and Saturday. We counted the vehicles parked along each street within 5 meters, and skipped those parked in middle of obstacles or too far from the roads. To on-street parking lots, only fringed vehicles along road direction were calculated. We found three kinds of streets with different parking limits. The first kind permits free parking at roadside, as R_{04}, R_{15}, and R_{26}, which results in a very high node density as 308 veh/km in average. The second one, as R_{37} and R_{79}, lacks public parking spaces. These streets have a very low vehicle density as 21 veh/km, which comes from some reserved parking spaces and illegal parking. The rest streets belong to the third one, where has a moderate vehicle density as 95 veh/km. During the survey, we also calculated daily traffic by counting the passing vehicles within fifteen minutes at random positions, and found traffic fluctuating from 300 veh/h to 2200 veh/h at different time of one day. If the road width is 20m, the corresponding moving vehicles within the area ranges from 60 to 400, , with the average speed ranges of 40km/h to 80km/h.

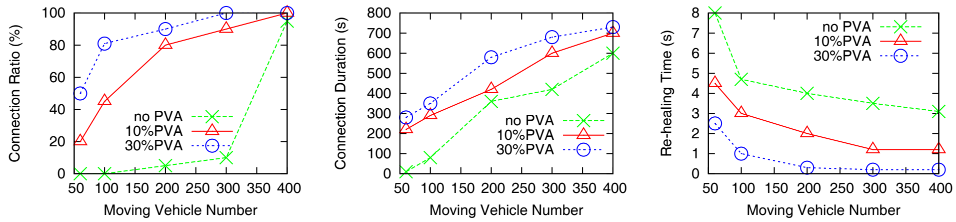
Fig. 6. Road topology in survey and simulations

We use the open source software, VanetMobiSim-1.1 [15], to generate realistic urban mobility traces, for the generated traffic file can be directly utilized by NS-2.33. To produce sparse traffic and traffic changing, we deploy different vehicle numbers, i.e. 60, 100, 200, 300, and 400, to the map. Since unbalanced traffic can be caused by traffic light, we use different vehicle light settings, i.e. 0, 60, 90, 120, and 150 seconds, to simulate unbalanced vehicle distributions in various degrees. The radio range is set at 250m, and the MAC protocol is 2Mbps 802.11. In the simulation, parked vehicle nodes are located on random positions of each street, following the densities collected in survey. They are placed at the beginning of simulation and keep static till the end. The intersections in the map cover a 20m×20m segment without parking. Since free-riding is inevitable, a PVA ratio of 10% and 30% is deployed.

B. Simulation Results

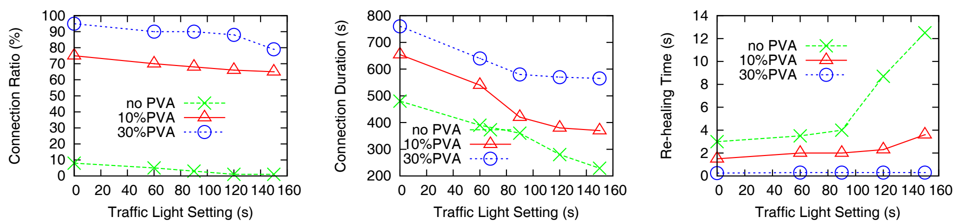
We mainly evaluate PVA on point-to-point connectivity, connection duration, and re-healing time in simulation. As a static metric, point-to-point connectivity reflects the reachability between two random positions at a specific time, and decides whether two nodes can communicate with each other without any delay. Connection duration indicates the connection duration between two nodes, which shows how frequently the path between two vehicles becomes unavailable. As a dynamic feature of connectivity, this metric reflects the stability of connection by time. Re-healing time denotes the period during which two vehicles are disconnected. It indicates how long the vehicles, once disconnected, need to wait before a new connection established.

Figure 7 describes network connectivity over traffic density with 90s traffic light setting, in which PVA shows obvious improving of all metrics, especially in sparse traffic. Figure 8 provides network connectivity over traffic light with a moving vehicle number as 200, in which PVA plays positive effect



(a) point-to-point connectivity (b) connection duration (c) re-healing time

Fig. 7. Network connectivity over traffic density



(a) point-to-point connectivity (b) connection duration (c) re-healing time

Fig. 8. Network connectivity over traffic light

with the increase of unbalanced degree of traffic. Thus, PVA effectively overcomes sparse or unbalanced traffic, and greatly promotes network connectivity in urban VANETs.

V. Conclusion and Perspective

Motivated by poor connectivity of VANETs and substantial costs of supporting infrastructure, we propose PVA to make the best of urban parked vehicles for communication. The basic idea of PVA is simple: if we can use mobile devices no matter whether we are walking or stay static, why not let parked vehicles join vehicular communications as moving ones?

In the paper, we introduce parked vehicles as static nodes to support VANETs. We investigate urban parking, evaluate PVA through theoretical analysis and simulations, and find that a small proportion of PVA vehicles could promote network connectivity greatly. Founded on realistic parking behaviors, PVA discovers neglected resources, enhances VANETs from down to top, and promotes vehicular researches in depth and scope. Since some implementation issues have not been carefully considered, we list them as future work:

1) Resource sharing for parked vehicles.
2) Incentive mechanisms to encourage PVA.
3) Typical parking models in urban areas.
4) Clustering strategies of parked vehicle units.
5) Self-adaptive routing on PVA environments.
6) Data safety and privacy protection for parked vehicles.
7) New services and applications in PVA.

Acknowledgment

This research is supported in part by the China NSF grant (60703114, 60903158, 60721002, 60825205, 61073152), and the Hong Kong RGC GRF grant (PolyU 5236/06E, PolyU 5243/08E, PolyU 5253/09E, PolyU 5102/08E). Ming Liu is the corresponding author (csmliu@uestc.edu.cn).

References

[1] Z. Zheng, P. Sinha, and S. Kumar, “Alpha Coverage: Bounding the Interconnection Gap for Vehicular Internet Access,” in *Proc. of IEEE INFOCOM Mini-Conference*, 2009.
[2] Z. Zheng, Z. Lu, P. Sinha, and S. Kumar, “Maximizing the Contact Opportunity for Vehicular Internet Access,” in *Proc. of IEEE INFOCOM*, 2010.
[3] B. Dorronsoro, P. Ruiz, G. Danoy, P. Bouvry, and L. Tardón, “Towards connectivity improvement in VANETs using bypass links,” in *Proceedings of the Eleventh conference on Congress on Evolutionary Computation*, 2009, pp. 2201–2208.
[4] S. Yousefi, E. Altmaiv, R. El-Azouzi, and M. Fathy, “Connectivity in vehicular ad hoc networks in presence wireless mobile base-stations,” in *Proc. of ITST’07*, 2007, pp. 1–6.
[5] Y. Ding, C. Wang, and L. Xiao, “A static-node assisted adaptive routing protocol in vehicular networks,” in *Proc. of ACM VANET 2007*. ACM New York, NY, USA, 2007, pp. 59–68.
[6] C. Lochert, B. Scheuermann, M. Caliskan, and M. Mauve, “The feasibility of information dissemination in vehicular ad-hoc networks,” in *Proc. of WONS’07*, 2007, pp. 92–99.
[7] R. Lu, X. Lin, and X. Shen, “Spring: A social-based privacy-preserving packet forwarding protocol for vehicular delay tolerant networks,” *Engine*, 2009.
[8] JUPITERRESEARCH, “Municipal Wireless: Partner to Spread Risks and Costs While Maximizing Benefit Opportunities,” Jupitermedia Corporation, Tech. Rep., 2005.
[9] C. Morency and M. Trépanier, “Characterizing Parking Spaces Using Travel Survey Data,” *CIRRELT*, 2006.
[10] A. Adiv and W. Wang, “On-street parking meter behavior,” *Transportation Quarterly*, vol. 41, pp. 281–307, 1987.
[11] D. Shoup, “Cruising for parking,” *Transport Policy*, vol. 13, no. 6, pp. 479–486, 2006.
[12] B. Albanese and G. Matlack, “Utilization of parking lots in Hattiesburg, Mississippi, USA, and impacts on local streams,” *Environmental management*, vol. 24, no. 2, pp. 265–271, 1999.
[13] T. Litman, “Parking management: strategies, evaluation and planning,” *Victoria Transport Policy Institute*, vol. 25, 2006.
[14] “Road Statistics 2008: Traffic, Speeds and Congestion,” 2008. [Online]. Available: http://www.dft.gov.uk/pgr/statistics/datatablespublications/roadstraffic/speedscongestion/roadstatstsc/roadstats08tsc
[15] J. Härri, F. Filali, C. Bonnet, and M. Fiore, “VanetMobiSim: generating realistic mobility patterns for VANETs,” in *Proc. of VANET’06*. ACM New York, NY, USA, 2006, pp. 96–97.