Vehicular Ad Hoc Networks for Joint Traffic and Mobility Management

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Abstract—In the literature, the problems related to traffic and mobility management are typically addressed separately. However, the solutions to these problems—especially if based on vehicular ad hoc networks (VANETs)—are highly dependent, hence should be addressed jointly. Empirical studies demonstrate that improvements in traffic efficiency create latent travel demand. While lower tailpipe emissions and fuel consumption can be observed per single vehicle, global fuel consumption and emissions increase. It does not mean that improvements in traffic efficiency provide no benefits. Instead, they should be made in conjunction with mobility management initiatives, which allow global reductions in fuel consumption and emissions. In this article, we analyse examples of traffic and mobility management, where joint VANET-based solutions can be applied. Two mobility-related services are analysed—bus priority and real-time passenger information. As for traffic management, the focus is made on collaborative routing and green light speed advisory. We introduce a generic system architecture based on buses that can support traffic- and mobility-related applications relying on VANETs.

Keywords-Intelligent transport systems; vehicular ad hoc networks, traffic management, mobility management.

I. INTRODUCTION

Mobility management (also referred to as transportation demand management) aims at efficient use of transportation resources [1]. It prioritises more efficient modes (e.g. public transport), by taking into account value and costs of each trip. Objectives of mobility management are congestion reduction, energy saving, efficiency and equity. Consequently, mobility management gives consumers incentives and travel options that maximise overall benefits to society, leading to development of sustainable transport characterised by low impact on the environment. On the other hand, *traffic management* (or *optimisation*) deals with road network efficiency, i.e. it aims at maximisation of the throughput of vehicles. However, the claims that improvements in traffic efficiency will reduce global pipeline emissions and fuel consumption are not backed up by scientific evidence. Moreover, empirical evidence suggests *rebound effect* creating latent travel demand—the use of roads will increase due to reduced consumer costs [2]. While, per-kilometre cost/emissions will decrease, the total milage and emissions will increase. It does not mean that traffic management is wrong, but rather implies that global benefits

of efficiency gains are reduced by the rebound effect [2]. In this article we demonstrate that solutions to these problems—especially if based on vehicular ad hoc networks (VANETs)—are highly dependent, hence should be addressed jointly in order to allow sustainable transport development.

Currently, traffic and mobility management objectives are achieved by means of centralised Urban Traffic Management Systems (UTMS) [3]. Traffic is managed by Urban Traffic Control (UTC), responsible for traffic lights timings. Typically the goal of the timings is to minimise total vehicle delay [4]. UTC also implements strategies for bus priority at traffic lights. The methods for the implementation of these strategies evolved from bus inductive detectors, bacon-based detection to receivers based on the Global Positioning System (GPS) [3]. To reach its objectives UTMS is responsible for capturing, evaluation and dissemination of traffic-related information. The arrival of cellular communications technologies allowed to deploy Real Time Passenger Information (RTPI) services. Current traffic management solutions rely on conventional equipment such as traffic cameras, infrared sensors, ramp meters, Bus Message Signs (BMS), Variable Message Signs (VMS), and traffic lights. The information is first processed by UTC. Then it is typically provided to VMS and the navigation systems of vehicles. The main drawbacks of the conventional approaches are their centralisation, fixed and costly infrastructure, costly communication schemes and lack of dynamicity, i.e. traffic information update delay is typically in the range of 20 to 50 minutes [5]. In the near future, most of these drawbacks can be overcome by *cooperative traffic information systems* (CTISs), where traffic information is collected individually by vehicles and exchanged between themselves using *vehicular ad hoc networks* (VANETs) and/or cellular communication links [6]. Such systems can be integrated with UTMS. This will allow to eliminate the conflict between in-vehicle navigation guidance and UTMS-based guidance [3]. Two types of CTISs architectures are proposed in the literature—infrastructure-based (client-server or P2P) and infrastructureless relaying on vehicle-to-vehicle (V2V) communication only [6]. The client-server solutions can in theory cope with global traffic efficiency and are less dependent on the quality of data aggregation techniques.

However, the question arises of how to deal with the huge number of updates and queries made to the system, which leads to scalability issues [7].

Research has already focused on the extension of traffic management with VANETs (see e.g. [6] for a survey). However, the proposed approaches focus on cooperative traffic information collection and dissemination, without addressing the question of how to coordinate routing of vehicles driven by self-regarding users. This is a significant issue, in particular for non-recurring congestion. On the other hand, the solutions related to mobility management that can be found in the literature are centralised and based on cellular communications technology. In this article, we analyse the fields related to traffic and mobility management, where VANET-based solutions can be applied to improve current methods. Two mobility-related services are analysed—bus priority and real-time traffic information. For traffic management, the focus is made on collaborative routing and and *green light speed advisory* (GLOSA). We describe a generic system architecture based on buses that can support traffic- and mobility-related applications relying on VANET technology. The architecture is currently developed in the MobiTraff project [8], which aims at integrating mobility and traffic management.

The paper is structured as follows. The next section discusses mobility management services. Section III focuses on traffic efficiency. Section IV introduces the bus-based architecture designed to provided mobility- and efficiency-related services using VANET communication. The final section summarises the main conclusion.

II. MOBILITY MANAGEMENT SERVICES

Sustainable urban mobility management is recognised by European Commission as one of the key ways to reach the EU objectives of combating climate change [9]. In this section, an overview of the current approaches of mobility management services is presented. Only services that are addressed in the MobiTraff project are described. Their main objective is to improve bus service quality. This includes (i) minimisation of traveling time of buses and harmonisation of their headways, (ii) minimisation of stop-and-go driving, and (iii) provision to passengers of hassle-free/cost-effective dynamic guidance throughout their trips. Finally, the concept of congestion pricing is introduced. It is an important mobility-management technique, aiming at reducing travel demand.

Bus priority (transit signal priority): Regularity is the main performance criterion for high-frequency bus services [4]. It is defined by time headway—time gap between the arrival times of a bus and the bus in front. Differential priority in urban environments provides higher level of priority to buses with headways much higher than scheduled. Recently, it has been shown in [4] that priority strategy for a bus should not only be based not the headway of the bus itself (classical approach) but should also consider the headway of the bus behind. Currently, the architecture for bus priority management is composed of the following centralised entities: Automatic Vehicle Location centre (AVL), responsible for monitoring of bus locations), UTC, and traffic signal controller [10]. These entities are linked by infrastructure-based communication systems to exchange information. The infrastructure-based priority management techniques differ in the location of the entity determining priority request, priority request method, and location of priority control [10]. The estimation of dwell time [11] (expected delay of buses at bus stops) is a significant component of priority request, allowing efficient prediction of link journey times for buses.

Real time passenger information: Modal shift towards public transport in the EU's Action Plan on Urban Mobility [9] acknowledges the role of role of providing consumers with better travel information. A trip has two phases, pre-trip and on-trip [12]. Conventional RTPI systems are based on a centralised AVL centre [10] and aim at providing real-time information. *Personalised navigation systems* (PNS) are the next-generation RTPI systems. They go one stop further by providing passengers (through their mobile devices) with on-trip personalised navigation cues [13]. The systems proposed in the literature assume the existence of a centralised back-office responsible for itinerary calculations. Communication with back-office is provided by cellular networks. Navitime [14] is a PNS deployed in Japan. It uses client-server architecture. Location awareness is based on GPS and cellular-based positioning. It requires Internet connection between the server and the client, hence is costly, especially to roamers. Computing tasks (computation of the best itineraries) are distributed among servers and mobile phone clients. ENOSIS system [15] integrates wireless and web-based communication technologies: its services are offered through the Internet, a voice portal, and information kiosks located in the city. The system involves several stakeholders. Recently introduced Navi [16] proposes to base location awareness of passenger on the electronic (RFID-based) ticketing system already developed in public transport. The system assumes near-field communication capability to be present in mobile phones. The web interface of the service is provided over the Internet of via kiosks. Trip computation is provided by back-office. The results of the computation are provided to travellers by means of the Short Message Service (SMS). The on-trip assistance is triggered by the validation of the electronic ticket. OneBusAway system [17] provides real-time departure information only about nearby stops (hence does not take into account the entire trip).

Congestion pricing: Congestion pricing allows surcharging users of private vehicles in periods of peak demand. The charges are related to the negative external costs (individual impact on the environment and congestion) they create, hence can easily be justified on equity grounds. Congestion pricing reduces traffic congestion—consumers have incentives to prioritise trips, that is, avoid marginal-value trips or to switch to other modes of transport. Cost-based fees (basis for congestion pricing) have high transaction costs [1]. However, the arrival of wireless communications technologies allows implementing charging schemes, according which consumers bear the costs they individually impose. Efficient congestion pricing assumes

that "Charges should reflect as closely as possible the marginal social cost of each trip in terms of the impacts on others" and "Charges should vary smoothly over time" [18].

III. Traffic management services

Dynamic changes in traffic lights schedules (e.g. due to priority at lights received by buses), or traffic incidents, change the optimal behaviour of vehicles (i.e. selection of the optimal speed and route). Vehicles should regularly re-evaluate and adapt their driving strategies using the available traffic information. Services described below have the following objectives (i) to optimise traffic flows in a distributed, infrastructureless way, (ii) to provide vehicles with a green light speed advisory system allowing them to adapt speeds to traffic lights and road conditions.

Collaborative routing in non-recurring congestion: Collection, storage and exchange of traffic information is only the first step in improving traffic efficiency. For instance, in case of sudden traffic breakdowns, informed drivers will most likely make the same routing decisions—typically select the route with the shortest traveling time—spawning new traffic congestion. This is referred to as *flash crowd effect* (FCE) or "similar advice" problem [19], [3]. Although, CTISs proposed in the literature provide vehicles with real-time traffic information, they do not consider how routing choices are made by the vehicles [6]. Hence, they do not address the FCE. One of the challenging issues in the FCE is the conflict between "user" and "system optimality" in individual route selection [3]. The question of optimality is related to the problem of prediction of traffic patterns, commonly addressed using network traffic equilibrium models [20] (similar to the Nash equilibrium in game theory). Wardrobe's first principle of equilibrium refers to "user optimality" according to which each vehicle selects its best route. Hence in "user equilibrium" (UE) flows all routes have an equal journey time [20]. The consequence of such a routing is that the average traveling time might be far from the optimal one [21]. It is the logic of the situation—absence of traffic regulation by some central authority and self-regarding users—that traps them in the inefficient outcome (*social dilemma* [22]). System (or social) optimum (SO) flows (described by Wardrobe's second principle) assume that vehicles choose routes in order to maximise the efficiency of the whole road system. However, due to self-regarding preferences of users, reaching system optimum—even if vehicles are provided with traffic information, in-vehicle navigation guidance, and methods for communication with other road users—is not feasible, unless additional measures like *variable congestion pricing* (VCP) [23] are applied. According to VCP charges are related to the negative external costs of individual vehicle, and depend on the actual traffic conditions [1]. Nevertheless, due to higher transaction fees comparing to lump-sum payments, deploying VCP is not efficient using current technologies [1]. The inefficiency of a system with self-regarded users (UE flows vs. SO flows) can be measured by the concept of Price of Anarchy [21].

Cooperative traffic signal schedule advisory: a GLOSA system advises drivers with the optimal speed they should maintain when approaching signalised intersection [24]. Access to traffic light schedules was recognised by U.S. and European transport agencies [24], [25]. The integration of short range antennas into traffic lights is foreseen in the future. Until recently, only costly, infrastructure-based systems (roadside message sings wired to traffic lights) were proposed [25]. The authors propose SignalGuru—a cooperative approach for collection and dissemination of information about traffic lights schedule using smartphones mounted on car dashboards. The information is derived from the images captured by the phones cameras. System participants collectively derive timing of traffic lights. Infrastructureless exchange of the information between devices is performed using wireless ad hoc communication (IEEE 802.11g). In a GLOSA system tested in Berlin by Audi carmaker vehicles receive information about signal schedules from a central server using cellular networks [26]. In the future, schedule information will most likely be available via cooperative traffic information systems based on vehicular ad hoc networks (VANETs). In such systems traffic-related information is collected individually by vehicles and exchanged between themselves using wireless networks [6]. Two communication patterns in VANETs are suitable for a GLOSA system: *vehicle-to-vehicle* (V2V)—communication among nearby vehicles, and *vehicle-to-infrastructure* (V2I)—communication between vehicles and roadway infrastructure. Traffic lights equipped with wireless communications technology will be able to transmit Signal Phasing and Timing (SPaT) data to vehicles. Several works have already investigated the use of V2V and V2I communication for GLOSA (e.g. [27], [28], [29], [30], [31]).

IV. System architecture

The top-down overview of the problem and potential solutions tackled in the MobiTraff project are shown in Fig. 1. The services aiming at reaching mobility and traffic efficiency objectives given in the previous sections are highly dependant. For instance, dynamic prioritisation of public transportation (e.g. changes in traffic lights schedules) will modify traffic flows. This will have an influence on speed advisory and personalised navigation services. Therefore, it is a correlated optimisation process. Public transport receives prioritised treatment that optimises its performance. This implies that the optimal behaviour of vehicles and passengers might have changed. Thus they should re-calculate the driving strategies. The literature (e.g. [32]) acknowledged behavioural complexities of system users (drivers and bus passengers) as a factor that should influence traffic assignment methods. However, the availability of VANET-based information combined with an advisory system allows shifting from descriptive to prescriptive services.

A. Joint architecture for mobility and traffic objectives

Cooperative traffic and mobility management system: The services covering the defined objectives can rely on the
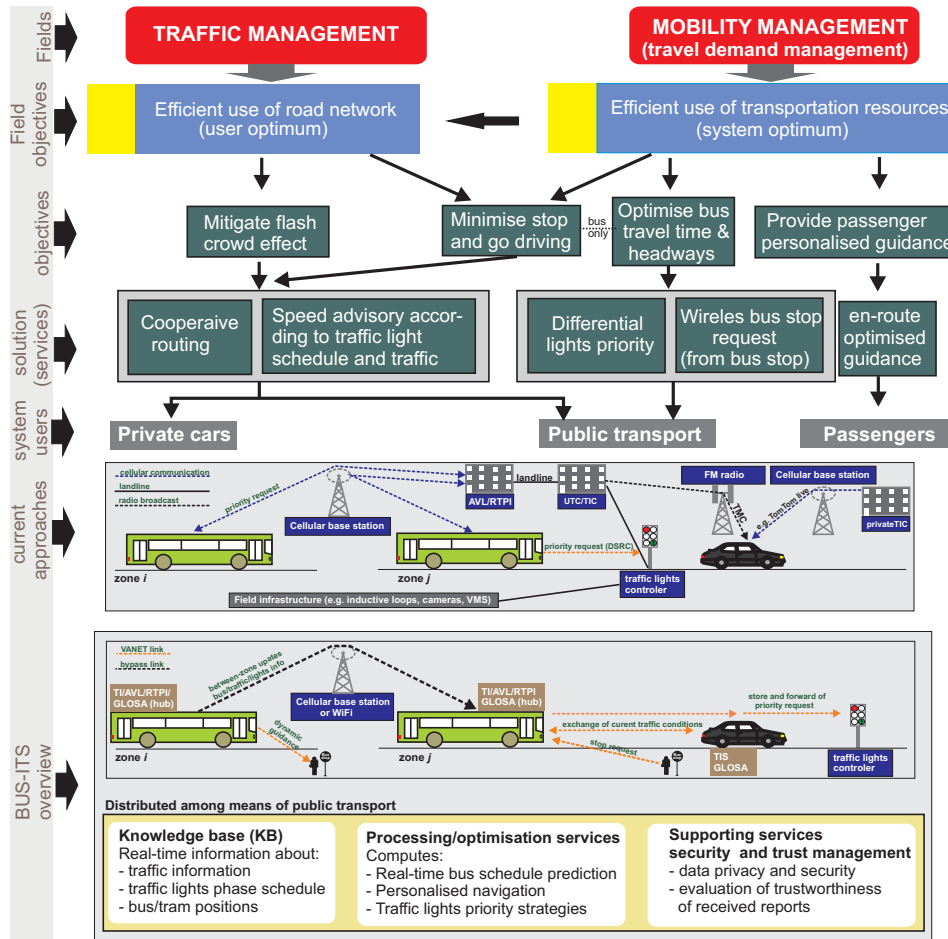
Fig. 1. Top-down architecture overview.

cooperative traffic and mobility management system (hereafter referred to as BUS-ITS). It extends the emerging concept of CTIS with new types of information and services. In particular, BUS-ITS is responsible for collection, storage, and dissemination of information regarding traffic conditions, public transport and SPaT data (see Fig. 1). Each bus stores the information in its knowledge base (KB). In addition, buses provide traffic- and mobility-related services. A city is divided into zones, while zones into road segments. The main actor of the system—public buses are used as "information ferries" serving a role of an information hub. Since the buses belong to the same authority, they are used to guarantee security and privacy of provided services. The second actor—all remaining vehicles (belonging to different authorities) are used as traffic sensors and message relayers. The third actor—passengers in pre- and on-trip phases—communicates with the system to obtain personalised navigation services and to register bus stop demand. The fourth actor is traffic lights. All actors are assumed to be equipped with wireless communication capabilities. Within each zone traffic information is collected and exchanged between all vehicles using V2V communication. Between segments, the information is exchanged only between

buses using long-range communication links.

B. Methods for mobility management objectives:

Personalised navigation: We focus here on the on-trip phase of travel. The problem of the estimation of the location of a passenger acknowledged in [16] can be provided by wireless communication between the passenger (on-board of a bus) and the bus, i.e. the bus can serve as personalised location sensor. In contrary to personal navigation approaches found in literature (e.g. [16]) the infrastructure-based communication (cellular communication) can be replaced by direct wireless communication between the bus and the passenger. Dynamic itinerary calculation/re-calculation can be performed locally by the bus that the passenger is traveling on (on-bus phase). In the "at bus stop phases" the itinerary calculation can be performed by the device of the traveller using real-time schedule of the buses received from the closest bus. Publish-subscribe messaging pattern can be used.

Improvement of bus service quality via differential priority: The objective of the improvement of bus service quality can be reached by providing buses with differential

priority at traffic lights. This not only allows to minimise traveling time in general, but also enables to optimise lights in order to harmonise headways between buses. In addition, buses traveling in bus-only lanes can benefit from a GLOSA system (described later). Buses can perform evaluation of the requirements using V2V communication with support (in limited cases) of infrastructure-based communication (bypass links). Priority requirement determination can be located in buses. The priority request method uses decentralised communications with virtual detectors—the bus communicates to traffic lights (via wireless link) its priority requirements. Prediction of time of the arrival at traffic lights is a significant challenge that has to be addressed in order to be able to efficiently manage differential priority requests. The prediction not only should take into account traffic conditions, but also dwell time.

C. Methods for traffic management objectives

Cooperative route selection

Specific methods for cooperative routing selection depend on whether the aim is to satisfy "user optimality" of "system optimality" principles. The first case is game theoretic problem. It the MobiTraff project it is addressed using BUS-ITS-based cooperative guidance. The second case is an optimisation problem. Reaching system optimality is much harder to accomplish. The combination of BUS-ITS-based cooperative guidance extended with variable congestion pricing mechanisms can be used to achieve the objectives. BUS-ITS can manage evaluation and dissemination of congestion pricing information. VANETs can be used a tool for variable congestion pricing according to the principles introduced by Vickrey [18]. In particular, the integration of congestion pricing mechanism with traffic information within BUS-ITS allows charging users according to marginal costs they impose. By measuring the Price of Anarchy [21] one can estimate the social inefficiency of the user optimal solution.

Green light optimal speed advisory

Each vehicle independently uses a GLOSA system. Two inputs from CTIS regarding the segments that a vehicle plans to travel on are used: current traffic information, and a schedule of traffic lights. Using such data, the system can perform optimisation process, which results in speed advisory per segments (hereinafter referred to as the advisory strategy). GLOSA systems can be either single or multi-segment. In the former speed advisory is calculated for the segment preceding the nearest signals. In the latter, a vehicle calculates a set of speed advisories (one speed per each segment) before entering the segment with the first signals on the vehicle's route. The GLOSA system developed in the MobiTraff project is multi-segment. Such a system has to deal with the following problem: when a large number of segments is considered—the search space is far too big to be searched exhaustively in reasonable time. Therefore, if our work [33] a genetic algorithm is used as an optimisation tool. In [34] we demonstrated that as long as traffic conditions allow drivers to select a wide range of speeds, the multi-segment GLOSA results in much better performance in terms of fuel consumption when compared with the single-segment approach.

If significant changes in traffic occur during the execution of the advisory strategy, the system should re-evaluate the strategy. In addition, specific advisory methods for a bus travelling on a bus-only lane can be designed, as in such a case the interfering traffic has different properties comparing to roads used by all vehicle types. In addition, travel time prediction for a bus, not only depends on the traffic itself, but also on the behaviour of the bus at stops.

D. Realistic simulation of the system:

Due to costs large scale VANET-based systems are evaluated using simulation, which captures two fundamental elements: *vehicular mobility* and *network communication*. Bidirectional coupling between network and traffic simulators is required as soon as the objective is to evaluate the influence of VANET-based applications on the road traffic [35], [36]. The quality (degree of realism) of underlying vehicular mobility models is crucial [37]. Vehicular traces (typically used as a basis for realistic mobility models) can in general be classified as either *real-world* or *artificial* [35]. Real-world traces are typically obtained from GPS-based tracking of road transportation (e.g. taxi, busses). However, they only exist for very few cases. Hence, methods for generating realistic artificial traces are required. An attempt to generate traces using real-world traffic information and traffic simulation is proposed in [38]—a model called *VehILux* is based on *traffic volume counts* corresponding to the area covered by the map. A traffic volume count is a count of traffic along a particular road. It provides precise information about the number of vehicles and their type. The advantage of VehILux is that it can generate realistic mobility for any area, for which traffic count data exists. However, the model does not address the question of how the values of its parameters should be set. Hence, in [37] a method for automatic discovery of these values for any area, where traffic count exists. In particular, the values corresponding to the mobility of Luxembourg are discovered.

V. Conclusion

Traffic efficiency initiatives have often been motivated with pipeline emission and gas consumption reductions. This is true at the micro (per-vehicle) level. However, due to the rebound effect, global emission and gas consumption are questionable. This can be achieved via mobility management initiatives. In this article we argue that mobility- and traffic -related services should be jointly addressed using cost-effective vehicle-to-vehicle communications technology. The following services related to mobility and traffic management were discussed: personalised navigation, differential priority, green light speed advisory and cooperative route selection. A generic system architecture developed in the MobiTraff project was introduced.

References

[1] (2010) Tdm encyclopedia, victoria transport policy institute. [Online]. Available: http://www.vtpi.org/tdm/tdm12.htm

[2] "Rebound effects, TDM encyclopedia, Victoria Transport Policy Institute, [online] $http : //www.vtpi.org/tdm/tdm64.htm$," 2010. [Online]. Available: http://www.vtpi.org/tdm/tdm64.htm

[3] N. Hounsell, B. Shrestha, J. Piao, and M. McDonald, "Review of urban traffic management and the impacts of new vehicle technologies," *Intelligent Transport Systems*, vol. 3, no. 4, pp. 419–428, 2009.

[4] N. Hounsell and B. Shrestha, "A new approach for co-operative a new approach for co-operative bus priority at traffic signals," *IEEE Transactions on Intelligent Transportation Systems*, vol. 13, no. 1, pp. 6–14, 2012.

[5] L. Wischof, L. Ebner, and H. Rohling, "Information dissemination in self-organizing intervehicle networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 6, no. 1, pp. 90–101, 2005.

[6] M. Seredynski and P. Bouvry, "A survey of vehicular-based cooperative traffic information systems," in *Proc. 14th International IEEE Conference on Intelligent Transportation Systems (ITSC)*. IEEE, 2011, pp. 163–168.

[7] C. Lochert, J. Rybicki, B. Scheuermann, and M. Mauve, "Scalable data dissemination for inter-vehicle-communication: Aggregation versus peer-to-peer," *Information Technology*, vol. 50, no. 4, pp. 237–242, 2008.

[8] MOBITRAFF—Cooperative Way to Mobility and Traffic Efficiency, FNR/NCBR. [Online]. Available: $http : //www.fnr.lu/en/Research-Programmes/Research-Programmes/Projects/Cooperative-Way-to-Mobility-and-Traffic-Efficiency-MOBITRAFF$

[9] (2009) Action plan on urban mobility [com(2009) 490].

[10] N. Hounsell and B. Shrestha, "AVL based bus priority at traffic signals: A review and case study of architectures," *European Journal of Transport and Infrastructure Research*, vol. 5, no. 1, pp. 13–29, 2005.

[11] N. Hounsell, B. Shrestha, and A. Wong, "Datamanagement and applications in aworld-leadingbusfleet," *Transportation Research Part C: Emerging Technologies*, vol. 22, pp. 76—87, 2012.

[12] B. Caulfield and M. O'Mahony, "An examination of the public transport information requirements of users," *IEEE Transactions on Intelligent Transportation Systems*, vol. 8, no. 1, pp. 21–30, 2007.

[13] K. Rehrl, S. Bruntsch, and H.-J. Mentz, "Assisting multimodal travelers: Design and prototypical implementation of a personal travel companion," *IEEE Transactions on Intelligent Transportation Systems*, vol. 8, no. 1, pp. 31–42, 2007.

[14] M. Arikaa, S. Konomi, and K. Ohnishi, "Navitime: Supporting pedestrian navitime," *IEEE Pervasive Computing*, vol. 6, no. 3, pp. 21–29, 2007.

[15] K. G. Zografos, K. N. Androutsopoulos, and V. Spitadakis, "Design and assessment of an online passenger information system for integrated multimodal trip planning," *IEEE Transactions on Intelligent Transportation Systems*, vol. 10, no. 2, pp. 311–323, 2009.

[16] A. Aguiar, F. Nunes, M. Silva, P. Silva, and D. Elias, "Leveraging electronic ticketing to provide personalized navigation in a public transport network," *IEEE Transactions on Intelligent Transportation Systems*, vol. 13, no. 1, pp. 213–220, 2012.

[17] B. Ferris, K. Watkins, and A. Borning, "Location-aware tools for improving public transit usability," *IEEE Pervasive Computing*, vol. 9, no. 1, pp. 13—19, 2010.

[18] W. Vickrey, "Principles of efficient congestion pricing," 1992. [Online]. Available: http://www.vtpi.org/vickrey.htm

[19] A. Casteigts, A. Nayak, and I. Stojmenovic, "Communication protocols for vehicular ad hoc networks," *Wireless Communications and Mobile Computing*, vol. 11, no. 5, pp. 567–582, 2011.

[20] M. Florian, "Untangling traffic congestion - application of network equilibrium models in transportation planning," *OR/MS Today - Operations Research/ManagementScience*, vol. 26, no. 2, pp. 52–57, 1999.

[21] T. Roughgarden, "Intrinsic robustness of the price of anarchy," in *Proc. 41st annual ACM symposium on theory of computing*. ACM, 2009, pp. 513—522.

[22] P. Kollock, "Social dilemmas: The anatomy of cooperation," *Annual Review of Sociology*, vol. 24, pp. 183–214, 1998.

[23] H.Yang, "Evaluating the benefits of a combined route guidance and road pricing system in a traffic network with recurrent congestion," *Transportation*, vol. 26, no. 3, pp. 299–322, 1999.

[24] (2007) Car 2 car communication consortium manifest communication consortium manifest.

[25] E. Koukoumidis, L. Peh, and M. R. Martonosi, "SignalGuru: leveraging mobile phones for collaborative traffic signal schedule advisory," in *Proc. 9th international conference on mobile systems, applications, and services (MobiSys)*, 2011.

[26] "[online] $http : //news.drive.com.au/drive/motor-news/the-car-that-can-beat-traffic-lights-20130618-2of6n.html$." [Online]. Available: $http : //news.drive.com.au/drive/motor-news/the-car-that-can-beat-traffic-lights-20130618-2of6n.html$

[27] T. Tielert, M. Killat, H. Hartenstein, R. Luz, S. Hausberger, and T. Benz, "The impact of traffic-light-to-vehicle communication on fuel consumption and emissions," in *Proc. Internet of Things (IOT)*, 2010.

[28] K. Katsaros, R. Kernchen, M. Dianati, and D. Rieck, "Performance study of a green light optimized speed advisory (GLOSA) application using an integrated cooperative ITS simulation platform," in *Proc. 7th International Wireless Communications and Mobile Computing Conference (IWCMC)*, 2011, pp. 918–923.

[29] K. Katsaros, R. Kernchen, M. Dianati, D. Rieck, and C. Zinoviou, "Application of vehicular communications for improving the efficiency of traffic in urban areas," *Wireless Communications and Mobile Computing*, vol. 12, no. 11, pp. 1657–1667, 2011.

[30] A. Wegener, H. Hellbruck, C. Wewetzer, and A. Lubke, "VANET simulation environment with feedback loop and its application to traffic light assistance," in *Proc. IEEE GLOBECOM Workshops*, 2008, pp. 1–7.

[31] D. Krajzewicz, L. Bieker, and J. Erdmann, "Preparing simulative evaluation of the GLOSA application," in *Proc. 19th ITS World Congress*, 2012.

[32] Y. Liua, J. Bunkera, and L. Ferreira, "Transit users' routechoice modelling in transit assignment: A review," *Transport Reviews: A Transnational Transdisciplinary Journal*, vol. 30, no. 6, pp. 753–769, 2010.

[33] M. Seredynski, W. Mazurczyk, and D. Khadraoui, "Multi-segment green light optimal speed advisory," in *Proc. IEEE 27th International Parallel and Distributed Processing Symposium Workshops & PhD Forum*. IEEE, 2013.

[34] M. Seredynski, B. Dorronsoro, and D. Khadraoui, "Comparison of green light optimal speed advisory approaches," in *Proc. 16th International IEEE Conference on Intelligent Transportation Systems (ITSC)*, 2013.

[35] C. Sommer and F. Dressler, "Progressing toward realistic mobility models in VANET simulations," *IEEE Communications Magazine*, vol. 46, no. 11, pp. 132–137, 2008.

[36] A. Grzybek, M. Seredynski, G. Danoy, and P. Bouvry, "Aspects and trends in realistic VANET simulations," in *Proc. IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 2012)*, 2012.

[37] M. Seredynski, G. Danoy, M. Tabatabaei, P. Bouvry, and Y. Pigné, "Generation of realistic mobility for VANETs using genetic algorithms," in *Proc. of the IEEE Congress on Evolutionary Computation*, 2012.

[38] Y. Pigné, G. Danoy, and P. Bouvry, "A vehicular mobility model based on real traffic counting data," in *Proc. 3rd International Workshop on Communication Technologies for Vehicles (Nets4Cars 2011)*, vol. 6596. Springer, LNCS, 2011, pp. 131–142.