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Multiplayer games over Vehicular Ad Hoc Networks: A new application

Ozan K. Tonguz, Mate Boban *

Carnegie Mellon University, ECE Dept., Pittsburgh, PA 15213-3890, United States

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ABSTRACT

In this paper we investigate the possibility of a new type of application, namely multiplayer games, in a Vehicular Ad Hoc Network (VANET) environment. First, we analyze the available empirical data on travel and traffic volume in the United States, and point out the most important challenges that have to be met in order to enable multiplayer games over VANET. We then propose a new paradigm of multiplayer games over VANET, one which utilizes the new, interactive and dynamic VANET environment, while adapting to its inherent constraints.

1. Introduction

Vehicular Ad Hoc Networks (VANETs) are aimed at providing support for safety, traffic management, and comfort applications by enabling vehicle-to-vehicle (V2V) communication or by connecting vehicles to nearby fixed infrastructure (V2I – vehicle-to-infrastructure). There are several initiatives at the national and international level that are working towards enabling Intelligent Transportation Systems (mainly safety and traffic control applications) by means of VANET (e.g., Vehicle Safety Communications Consortium in the US and PReVENT in Europe). Most of these initiatives account for only a certain degree of infrastructure support (e.g., Roadside Units, cameras, sensors, etc.) – ubiquitous infrastructure support would require very high cost to deploy, and perhaps even a higher cost to maintain in an operational condition. Hence, the need exists for V2V communication, where a network is constructed in an ad hoc fashion, and no infrastructure is necessary, except for the wireless network interfaces inside vehicles, which are likely to be a standard feature in vehicles in the near future. The ability to function without infrastructure and the fact that it comes practically free of charge for the end user is what distinguishes VANETs from other technologies, such as Cellular networks (3G and beyond) and WiMAX. This creates a very strong argument in using VANET for enabling not only active safety applications, but also in-vehicle comfort and entertainment applications.

In the context of multiplayer games, we can distinguish two different types of games: Internet multiplayer games and mobile multiplayer games. The vastly popular Internet multiplayer games are the predominant focus of industry, since the player base is significantly larger than that of mobile multiplayer games. Up to now, the main approach in the design of mobile multiplayer games has been to create games for small devices (e.g., cell phones, PDAs) that require players' movement in order to achieve the game objective (e.g., [1]). This approach did not lead to highly popular mobile multiplayer games.

As a significant departure from the aforementioned approaches, we envision that VANET multiplayer games will offer the players an opportunity to engage in a location-aware, mixed reality multiplayer game that takes advantage of inherent vehicular mobility; these are the features not available in Internet multiplayer games. Compared to mobile multiplayer games, VANET multiplayer games will not suffer from limited battery lifetime, and they will not be confined to small user-devices with relatively small computation power; since the players will be located in vehicles, they will have significantly higher computation power and battery life available, and it is easy to imagine that the devices on which VANET games will be played

* Corresponding author. Tel.: +1 412 482 2614.
E-mail addresses: tonguz@ece.cmu.edu (O.K. Tonguz), mboban@cmu.edu (M. Boban).

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could be much more elaborate than those currently used for mobile multiplayer games.

In the remainder of this paper, we analyze the challenges and opportunities for games over VANETs. More specifically, in Section 2 we first give a brief overview of Dedicated Short Range Communications (DSRC), the technology that is becoming the de facto standard for physical (PHY) and medium access control (MAC) layers of the proposed VANET communication stack. In Section 3, we provide incentive for enabling games over VANETs, and justify our motivation. In Section 4, we carefully analyze empirical data available for the US to characterize the most important constraints for games over VANET and we present simulation results based on the obtained data. Section 5 points out the new requirements that VANET environment necessitates in the game architecture and in the design of underlying protocols. Section 6 describes several novel characteristics games could posses in order to take advantage of the unique characteristics of such networks. Section 7 presents business entities potentially interested in VANET games business. Section 8 concludes the paper.

2. Overview of DSRC

The emerging technology for VANETs is DSRC, for which in 1999, FCC has allocated 75 MHz of spectrum between 5850 and 5925 MHz. The spectrum is intended for DSRC systems operating in the Intelligent Transportation System (ITS) radio service for V2V and V2I communications. The main goal is to enable public safety and traffic management applications. Commercial services are also envisioned (e.g., tolling, comfort, infotainment, among other), creating incentive for faster adoption of the technology. DSRC is based on IEEE 802.11 technology and is proceeding towards standardization under the standard IEEE 802.11p, whereas the entire communication stack is being standardized by the IEEE 1609 working group under the name Wireless Access in Vehicular Environments (WAVE). Fig. 1a shows the WAVE protocol stack [2]. WAVE Short Message Protocol (WSMP) is being developed for fast and efficient message exchange in VANETs. It will be used for safety, as well as for non-safety applications. Applications running over WSMP are able to directly control physical layer characteristics (e.g., channel number and transmitter power) on a per message basis. Applications that run over the standard TCP/IP protocol stack are also supported. Their operation is restricted to Service Channels (Fig. 1b), and the underlying physical layer characteristics are predefined, based on the application type. Safety and non-safety applications will be divided into a maximum of 8 levels of priority, with the safety applications having the highest level of priority. Furthermore, WAVE devices must monitor the Control Channel (CCH) for safety application advertisements during specific intervals known as control channel intervals. These intervals and management processes are specified to provide a mechanism that allows WAVE devices to operate on multiple channels while ensuring all WAVE devices are capable of receiving high-priority safety messages with high probability [3].

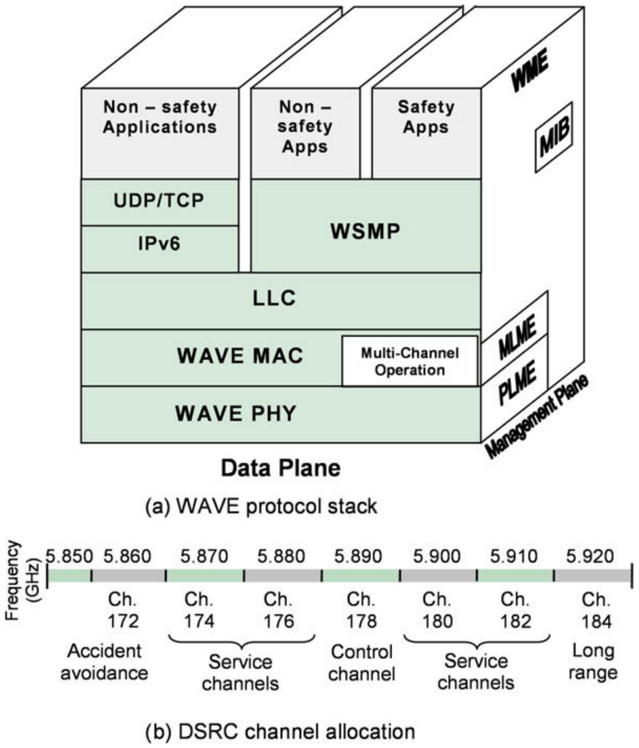


Fig. 1. WAVE protocol stack and DSRC channel allocation.

On the Logical Link Control (LLC) WAVE Networking Service is going to support the connectionless unacknowledged (Type 1) operation of the LLC as specified in IEEE standard 802.2. On the management plane, MAC Layer Management Entity (MLME) and Physical Layer Management Entity (PLME) are in charge of MAC and PHY layers, respectively. Management Information Base (MIB) stores data for local channel assignments and other parameters. DSRC channel assignments are shown in Fig. 1b.

The US Department of Transportation (DOT), along with the car manufacturers and academia, is investing substantial time and effort into developing the technology and applications that will run over the WAVE protocol stack, in order to increase active safety, reduce fuel consumption, and create more pleasant travel experience.

3. Motivation

3.1. On travel

According to Department of Transportation, Bureau of Transportation Statistics [4], 87% of all trips in the US are personal vehicle trips. In a personal vehicle, Americans travel 4.5 trillion personal miles per year; even if we average this number with an optimistically high average speed of 60 miles per hour (although the overall average speed in the US is not available, [5] showed that US nation level average commute speed is 32 miles per hour, indicating that 60 miles per hour is probably higher than the overall average speed), we get 75 billion person-hours spent in vehicle, which amounts to more than 250 h/year in vehicle for every person in the US.

Furthermore, it is important to note that 82% of all trips are not related to commute (see Fig. 2a), and on these trips,

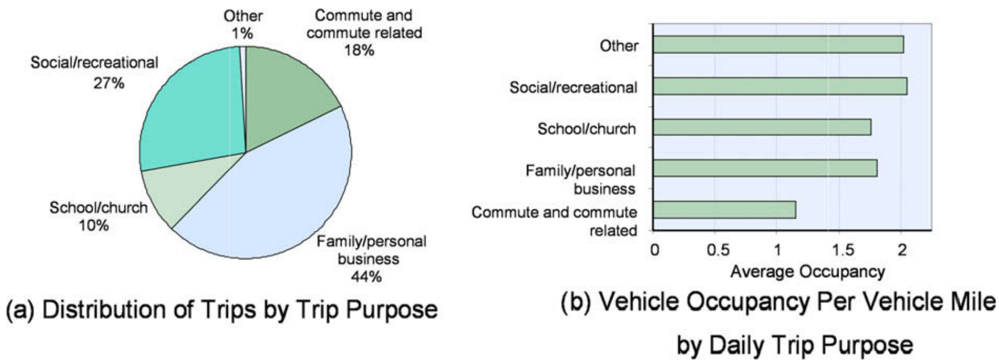


Fig. 2. Distribution of trips by purpose and average vehicle occupancy by trip purpose.

the average number of occupants (persons in vehicle) is roughly 1.9 (see Fig. 2b) [4]. This information is interesting because it indicates that in trips not related to commute there is, on average, another person in each vehicle besides the driver. We assume that trips not related to commute will account for the biggest portion of target audience for games in vehicle. We base this assumption on two facts that can be observed from the data in Fig. 2: (1) the average vehicle occupancy in commute-related trips (1.15 persons per vehicle) is significantly lower compared to the ones not related to commute (1.9 persons per vehicle); (2) the demographics and the purpose of trips not related to commute are obviously more "comfort-oriented".

3.2. On games market

According to [6], in 2007 in the US only, computer and video game software sales amounted to $ 9.5 billion, with 65% of American households playing computer or video games. The same study showed that 49% of game players played games online one or more hours per week. Furthermore, in October 2008 Reuters reported an 18% increase in videogames hardware and software sale compared to October 2007 [7].

3.3. Existing in-vehicle entertainment

Traditional entertainment systems in the vehicle comprise of an AM/FM radio receiver with optional CD/DVD player, hard drive, and recently ports enabling the interconnection with popular portable media players. In the past few years, new in-car communications and entertainment systems emerged, enabling interconnection of various multimedia components in vehicles (e.g., AM/FM radios, TVs, CD/DVD players, navigation systems, cell phones and media players). Notable examples include Media Oriented Systems Transport – MOST (http://www.mostcooperation.com) and FlexRay (http://www.flexray.com), both of which account for the increased interplay between different multimedia devices and the additional network capacity incurred. However, majority of currently available entertainment applications pertain to multimedia reproduction, wherein the passengers are passive consumers, rather than active participants, which is the case with games. Furthermore, it has to be noted that the games market was already a large industry even before the emergence of Internet and multiplayer gaming, whereas currently the in-vehicle game market is practically nonexistent. However, due to the fact that the entertainment opportunities in a vehicle are quite limited compared to virtually countless entertainment activities at home (where online multiplayer games are played) and due to the aforementioned lack of engaging in-vehicle applications, there seems to exist an opportunity for VANET games to compete with the current in-vehicle entertainment applications.

Numbers on time spent in vehicle, vehicle occupancy, and games market provide a very lucrative and significant incentive for investigating the possibility of games in the VANET environment.[1]

4. The challenge and opportunity

Enabling games over VANET will require innovative approaches to designing the game and the underlying architecture, in order to cope with the following specific VANET characteristics, that also provide new opportunities:

1. Very high, but predictable mobility that creates dynamic, rapidly changing topology with varying QoS, which in turn implies the need for fast and efficient protocols; on the other hand, it also provides for a potentially dynamic gameplay with a lot of interactivity between players.
2. Constrained movement due to static roadway geometry that can be utilized for location-aware gameplay.
3. Large-scale but often partitioned network, which implies potentially large number of players, but with intermittent connectivity.
4. Two distinct environments: highway and urban.
5. Feedback information from on-board sensors (e.g., GPS).
6. No significant constraints related to the capacities of the user devices (in terms of space, computation, and power), as opposed to other wireless networks (e.g., sensor and cellular).

[1] The reason we analyze the case for games in the US is that the data on vehicular traffic, travel, and games market is most systematically maintained and readily available for the US market. In addition to US, it would be interesting to investigate the potential for VANET games in Europe, Japan, etc.

Table 1
Interstate traffic volume distribution.

Traffic volume (veh/h)	Percentage
>2000	59.55
>1000	77.94
>500	90.11
⩽500	9.89

These unique characteristics of VANETs point implicitly to the most important challenge that has to be faced in order to enable games over VANETs: the end-to-end connectivity and the connection duration.

4.1. Real-world connectivity

Although researchers often assume end-to-end connectivity in VANET, Cheng and Robertazzi showed in [8] that the probability of end-to-end connectivity in infrastructureless wireless networks, such as VANETs, decreases with distance, as a function of node density and transmission range of nodes. More specific results on the connectivity of VANETs in highway scenarios were reported recently (based on both empirical data and a detailed analysis) by Wisitpongphan et al. [9].

In order to determine the probability of a fully connected network in the real world, we analyzed the traffic data collected from five longest east–west and four out of five longest north–south interstates [10,11],[2] in order to shed light on the traffic volume, which directly affects connectivity. The results obtained are as follows: the average traffic volume on the analyzed interstates was 3964 veh/h and on approximately 78% of the sections, the traffic volume exceeded 1000 veh/h. Table 1 shows traffic volume distribution in more detail. Traffic volume is highly dependent on the time of day and on the day of the week. Intuitively, one would expect higher volume during a specific time of the day (e.g., morning and afternoon rush hour). Based on the nation level trip distribution by the time of the day [5], Fig. 3 shows the equivalent traffic volume distribution on a weekday and on weekend for two values of average traffic volume (namely, 1000 veh/h and 2000 veh/h). Traffic distribution by the time of day confirms intuition: traffic volume during the day is significantly higher, with peaks during rush hour on weekdays. From the connectivity aspect, it is clear that, even on roads with relatively low traffic volumes (fewer than 1000 veh/h), one could expect significantly better connectivity during daytime, because the traffic volume doubles compared to the baseline traffic volume. This information is interesting for enabling games in VANET, since it is reasonable to expect that majority of passengers will want to play games during daytime (this is especially the case with younger passengers).

[2] We analyzed the AADT (Annual Average Daily Traffic – the total volume of vehicle traffic in both directions of a highway for a year divided by 365 days). The data was collected from interstates I-10, I-40, I-70, I-80, I-90 (east–west interstates), and I-5, I-15, I-75, I-95 (north–south); the data for all sections was available for I-5, I-15, I-80, I-90, and I-95, whereas for interstates I-10, I-40, I-70, and I-75, the data was partially available. The data for I-35, the second longest north–south interstate, was not available.

4.2. Connection duration, end-to-end delay, jitter

Multiplayer games are real-time applications that require a certain level of QoS in order to be playable. The most important QoS metrics for games are [12]: end-to-end delay, jitter, and packet loss. The required data rates for most games are quite modest when compared to the DSRC data rates (from 6 Mb/s to 54 Mb/s), with majority of games generating under 100 Kb/s per player [13,14].

However, due to the fact that VANET is an infrastructureless network whose capacity limitations are governed by the rules described in [15], to determine the potential network load of the games in VANET environment, we provide the following calculation. To set up a worst-case scenario with regards to network load, let us assume that a game generates 100 Kb/s per player over the lowest DSRC data rate (6 Mb/s) with 25 players in a game session.[3] Based on the fundamental wireless network capacity formula provided in [15], the throughput $\lambda(n)$ obtainable by each node n capable of transmitting W bits per second is $\lambda(n) = \Theta\left(W/\sqrt{n * log(n)}\right)$. Using the above values ($n = 25$, $W = 6$ Mb/s), the formula gives the achievable per-node throughput of 1 Mb/s, which is an order of magnitude more than required by the game.

Different games tolerate different levels of end-to-end delay, ranging from 100 ms for fast-paced sports and action games, up to a few seconds for role playing and turn-based strategy games. The same is true for jitter and packet loss. To cope with these constraints, game designers can compensate by prediction of the game state, scheduling of the game data and reducing the velocity of the game objects. This results in robust games that are able to tolerate higher delay, jitter, and packet loss. Nevertheless, shifting the games from a well structured network such as the Internet to VANETs, an infrastructureless environment with unreliable transmission medium, will undoubtedly pose a great challenge in meeting the QoS requirements. Additionally, in order to have a meaningful interaction between the players in a game, the connection between them should last a certain amount of time. To that end, authors in [16,17] reported the feasibility studies of existing Internet multiplayer games in VANETs. Both of the studies used AODV (Ad hoc On-Demand Distance Vector) for routing in VANET. It was shown in [18,19] and several other studies that AODV performs suboptimally in the dynamic VANET environment. As opposed to AODV, in this paper we use a routing solution developed in [20] that does not incur additional loss or overhead, thus enabling the analysis of achievable game performance over infrastructureless, DSRC-enabled VANETs.

[3] The number of concurrent players in a game session for a vast majority of multiplayer games is under 25 players, with the most frequent number of players being between 2 and 10; even if the game is a massive multiplayer game, rarely does the number of actively interacting players within a game session surpass 25.

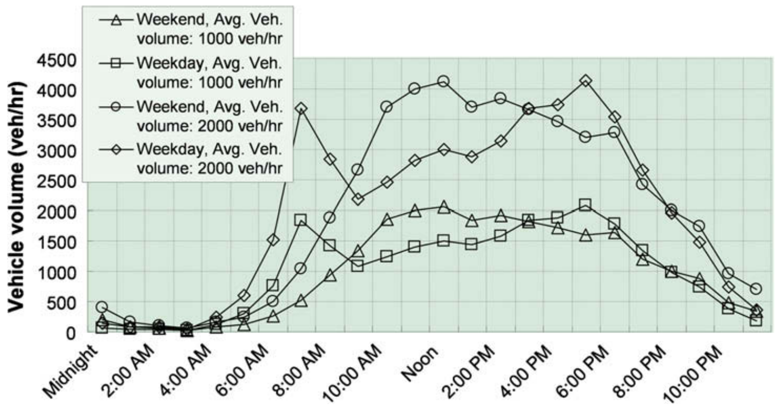


Fig. 3. Distribution of traffic by time of day.

Table 2
Simulation parameters.

Parameter	Value
Number of senders	2 (sending messages to each other)
Number of messages	20/s
Message size	Normally distributed Mean = 100*B*; std. dev. = 15*B*
TTL (max. # of hops allowed)	20
Vehicle densities	5, 10, 20 veh/km
Speeds of vehicles	Normally distributed Mean = 100 km/h Std. dev. = 20% of mean
Simulation duration	600 s
Signal propagation model	Two-ray
Effective transmission range	550 m
Transmission rate	6 Mb/s

4.3. Simulation environment

Based on the traffic data presented in the previous subsections, and using the framework developed in [20], we performed simulations in order to characterize the connection duration, end-to-end delay, and jitter for games in highway environment. We conducted simulations using the Jist/SWANS simulator with the STRAW mobility model. JiST (Java in Simulation Time) is a discrete event simulation environment, and SWANS (Scalable Wireless Ad Hoc Network Simulator) is a publicly available Java-based scalable wireless network simulator [21]. STRAW (STreet RAndom Waypoint) [22] is a vehicular mobility model, built on top of the JiST/SWANS platform, that constrains the node movement to real US streets based on the US Census Bureau's TIGER data [23]. STRAW implements the car-following model [24] with lane changing, intersection control, and supports flows of vehicles (groups of vehicles with the same starting and destination point).

We implemented the DSRC PHY and MAC layers based on the ASTM standard [25], and we used connectionless unacknowledged (Type 1) operation of the LLC as specified in the IEEE standard 802.2. Atop the DSRC, we implement the routing scheme described in [20], which does not incur additional loss and delay due to routing and in turn enables us to analyze the performance that any game can achieve over DSRC-enabled VANETs. Detailed simulation parameters are presented in Table 2. The transmission range of 550 m was based on the recent field testing of DSRC equipment reported in [26], while [27] indicated that the signal propagation on highways can be adequately modeled with a two-ray path loss model. All of the nodes in the simulations were equipped with DSRC radios, and DSRC parameters were set up based on [25,26].

Vehicle densities were selected based on the traffic data presented earlier in this section, whereas the mapping between vehicle flow and vehicle density was determined assuming free flow phase of the traffic, which yields a linear relationship between vehicle flow and density given by $F = D * v$, where F is vehicle flow (in vehicles per hour), D is vehicle density (in vehicles per kilometer) and v is the average speed (in kilometers per hour) [28]. Therefore, vehicle densities of 5, 10, and 20 veh/km are equivalent to flows of 500, 1000, and 2000 veh/h, respectively, given that the average speed is 100 km/h. We ran the simulations on a segment of I-80 in Elko County, NV, presented in Fig. 4a, with equivalent simulation visualization in Fig. 4b (vehicle icons are not drawn to scale). The roadway portion we used was approximately 43.5 km long, with 2 lanes per direction.

Since we were interested in modeling the message exchange scenario for a game, we opted to base the message size and frequency on the network traffic pattern measurements of a First Person Shooter game Counter-Strike conducted in [12]. The simulation time for all scenarios was 600 s, with an additional warm-up time of 200 s during which no packets were sent, in order to have a more realistic initial vehicle distribution.

In this paper, we focus on the case for VANET games in the *highway environment* because the statistical data on traffic volume and travel is systematically maintained and available, whereas such data for urban environments is not available.

4.4. Simulation results

Fig. 5 shows connection duration for different vehicle densities when observed nodes move in the opposite and same direction. Clearly, higher vehicle densities significantly increase the connection duration for the opposite

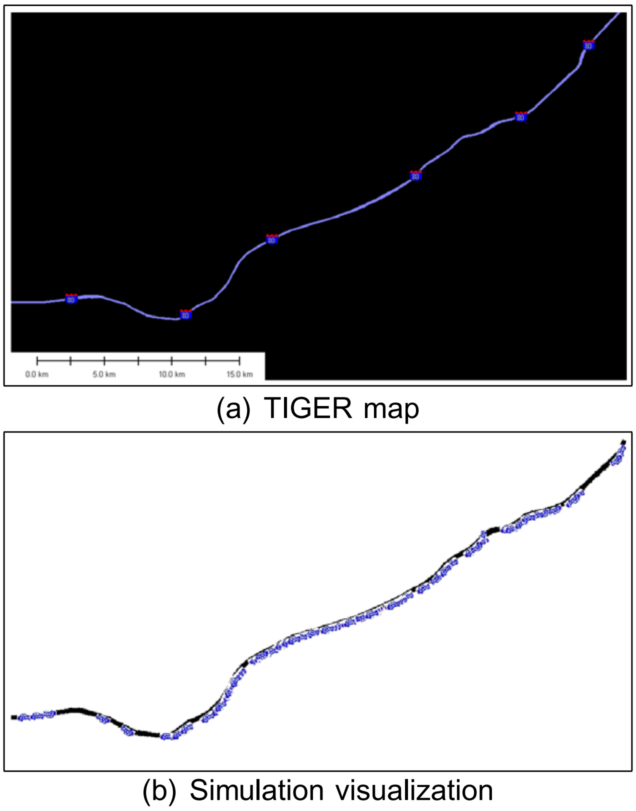


Fig. 4. TIGER map screenshot of the I-80 interstate in Elko County, Nevada, over which the simulation has been conducted, along with the accompanying simulation visualization.

direction scenario, with median duration increased by four times for 20 veh/km compared to 5 veh/km (Fig. 5a). Vehicle density does not have such a significant impact when nodes move in the same direction. In the same direction scenario, median values of connection duration for the three densities are between 170 and 200 s, implying that a meaningful communication between players can be achieved.

The large difference in the connection duration between the same and opposite direction highway scenarios suggests the following:

- It will be useful for the underlying game protocols to distinguish between opposite and same direction traffic and, given enough information is available, to predict potential connection duration.
- Games will have to be able to interpret and make use of same direction, longer player interaction and opposite direction, shorter player interaction, based on the predicted connection duration.
- Multihop communication is necessary in order to provide longer connection duration.

Furthermore, as shown in Fig. 6, the underlying DSRC protocols have the potential to provide satisfactory levels of QoS for the majority of games, since even the games that have the most stringent delay and jitter requirements can cope with delay of 40 ms and jitter which is largely confined to 10 ms [29].

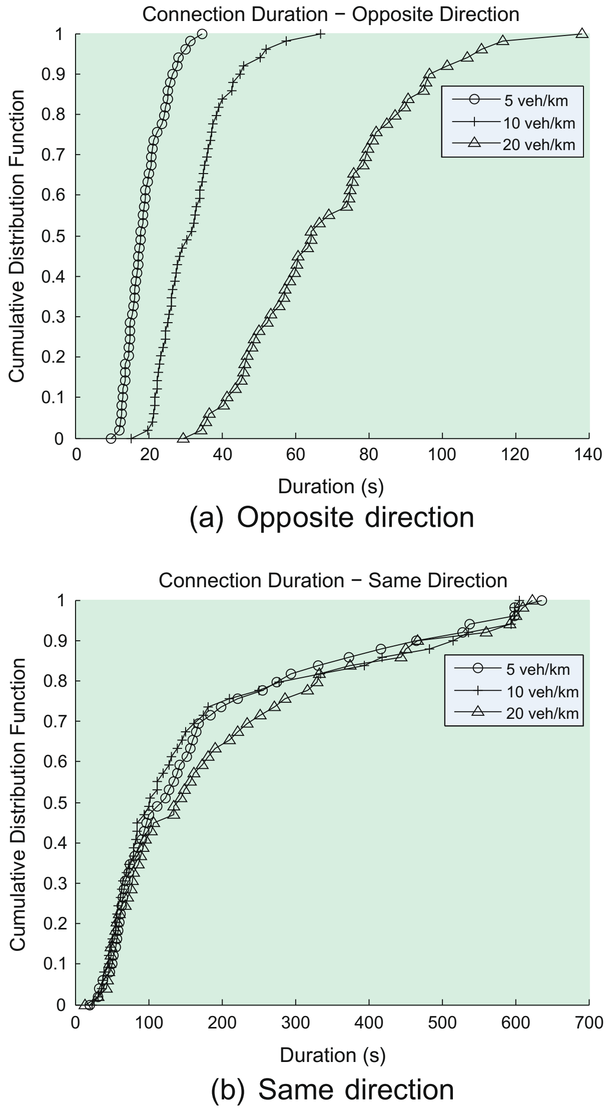


Fig. 5. Connection duration.

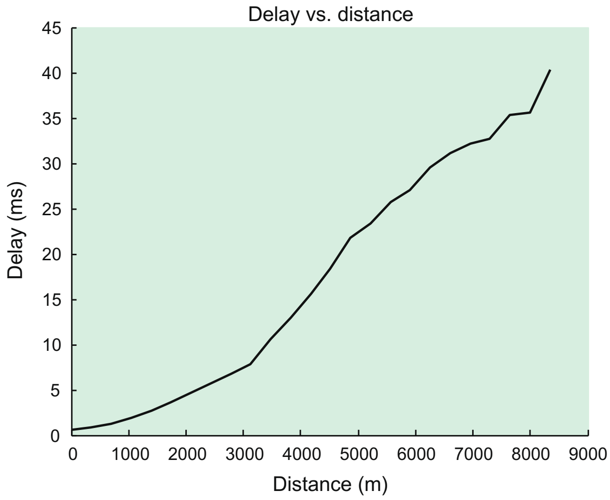
5. VANET gaming vs. Internet gaming

In the previous section we analyzed empirical data in order to better understand the implicit, real world restrictions that apply to games in VANETs. Based on those results, in this section we focus on the requirements that VANET environment implies on game design and on the underlying protocols.

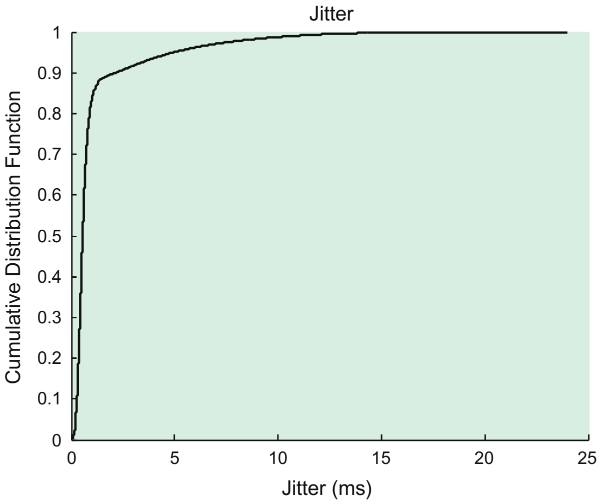
5.1. Client–Server model is not a solution for infrastructureless VANETs

Multiplayer games in Internet are predominantly based on the Client–Server (C/S) model, because of its inherent characteristics:

- *Simplicity of design and implementation.* From a network programming perspective, C/S model is very well studied and optimized. *N* unicast connections are used to connect *N* clients to a single server or, if necessary, multiple servers connected in a cluster either by LANs, or by forming computing grids.



(a) Delay vs. Distance



(b) Jitter

Fig. 6. Delay and jitter.

- *Hosting the game world*. Hosting the game on a centralized server allows the players to share the same virtual game world.
- *Business aspect*. The server is responsible for account management and player authentication in C/S model. Also, it is much easier to control cheating and unauthorized access to the game if there is a single point to control.

Using C/S model for VANET gaming is not viable because of the following:

- *Single point of failure*. One of the nodes (vehicles) should act as an ad hoc server for the session. If this node becomes disconnected, the entire game session is lost for all the other players. This calls for a distributed game model that is resilent to dropout of any single node.
- *The data traffic in C/S is unevenly distributed*. As noted in [12], the server traffic is significantly higher than the client traffic, because all clients communicate directly with it. In VANETs, this could easily create a bottleneck at the node that was selected to act as an ad hoc server, thus affecting the throughput.

These facts inevitably call for a distributed, peer-to-peer (P2P) model, in which all nodes (vehicles) simulate the game state of interest. Benefits of the distributed model are:

- *No single point of failure*. If every node is simulating the game session in which it is involved, single point of failure does not exist, since the outage of any single node does not cause the overall game session to terminate. The rest of the nodes will simply acknowledge that the player has left the game session, and continue playing.
- *Support for fast changing game sessions and dynamic physical environment*. Using a distributed model, players can continue interacting with other players in the game even when they get partitioned from some of the players. Because there is no single point of failure, one could envision a situation where a game session with four or more players gets partitioned in two and players in newly created partitions simply continue to play under two different game sessions.

The findings regarding unsuitability of C/S model for VANET games are in line with the study presented in [16]. In the Internet, the main problems of P2P gaming are scalability and security [30]. In VANET, even though the total number of players could be very large, the players will be divided geographically into smaller partitions. This implies that each player only has to replicate the game state of a specific partition, which is likely to comprise a small number of players. Therefore, the practical limitations on the number of players that are incurred by VANET environment alleviate the issue of scalability. Security issues in P2P games in VANETs are not different from the well studied security problems that P2P games face in the Internet: this is why we will not discuss it further in this paper.

Because of these facts, we claim that the decentralized approach of P2P model, capable of sustaining a highly dynamic network, is necessary in order to support games over VANETs, by creating an overlay network on top of VANETs physical network. Therefore, multiplayer games in VANET will have a very different underlying architecture when compared to online multiplayer games.

5.2. Provisioning for games in VANETs

With respect to empirical and simulation results obtained in previous sections, in this subsection we point out the most important characteristics the underlying VANET protocols need to have in order to support games. Since DSRC is the standardized VANET technology on physical and link layers, here we only discuss the desirable characteristics of higher layer protocols.

5.2.1. Network layer

Simulation results in previous section confirm that, in order to support longer connection duration, a multihop routing protocol is preferred. Furthermore, games would benefit greatly from a QoS-aware, position-based routing protocol that forms routes based on predicted connection duration and link characteristics. For instance, the GPS information and the received signal strength could be used to provision for better link stability, lower delay, and longer connection duration.

The use of WSMP (WAVE Short Message Protocol) for games, instead of IP, could be an interesting option, especially because single WAVE Short Message (WSM) can be delivered to multiple destinations, and WSMP leaves it to the application to differentiate between messages [2]. Also, the purpose of the WSMP is to provide rapid and reliable datagram delivery with minimum overhead (the WSMP header is only 11 Bytes long).

5.2.2. Transport layer

Depending on the type of transmission needed, games in the Internet use TCP and/or UDP; when reliable transmission is necessary (e.g., instant messages within the game), TCP is preferred. When fast transmission of data is necessary (e.g., player coordinates in a fast-paced game), UDP is most often used. However, numerous studies have shown that connection oriented transport protocols, such as TCP, perform poorly in wireless ad hoc networks, especially when the nodes are mobile [31]. High mobility in VANETs induces varying QoS, thus creating a significantly different environment that requires transport protocols to be aware of the underlying network conditions. Besides physical characteristics of the network, VANET transport protocols have to account for the fact that WAVE Networking Service shall support the connectionless unacknowledged (Type 1) operation of the LLC. Therefore, segment acknowledgments would be one of the useful features for VANET transport protocols. Also, successive segments in VANETs can arrive over different intermediate nodes, thus making it possible for segments to arrive out of order; segment reordering via the use of sequence numbers could be used to alleviate this problem.

5.2.3. Application layer

Besides the mechanisms used by games in the Internet to compensate for high delay, jitter, and packet loss, games in VANETs will have to acknowledge specific properties of VANET environment.

5.2.3.1. Connection duration awareness. Given that the connection between players is intermittent, games should be able to "seize the moment", taking into account the scarcity of the connection and enabling the interaction between players, even in the case where connection duration is of the order of seconds. Based on the simulation results obtained, at least three types of interaction between players should be recognized by VANET games:

1. Shorter communication with the player in the vehicle traveling in the opposite direction.
2. Longer communication with the player in the vehicle traveling in the same direction.
3. Determinably long, but potentially intermittent communication. This scenario could occur when passengers in different vehicles are sharing the same short term (e.g., both of the vehicles exit the highway on the next exit) or long term destination (e.g., both vehicles are going to New York). A game can obtain the destination information from GPS. A similar scenario can be envisioned in the case of platooning, where multiple vehicles are coordinated along a highway.

Fig. 7a shows typical highway connection scenarios. Based on the available information (speed, direction, destination), game should be able to predict connection duration, and base players' interaction on that prediction.

5.2.3.2. Fast switching between players and sessions. Given the dynamic nature of VANETs, a game should be able to tolerate frequent player movement between different game sessions that could occur either because of player's preference or because of physical disconnection between players. Based on the physical network described in Fig. 7a, Fig. 7b illustrates different scenarios where the game engine and the underlying protocols should provision for:

- fast and efficient game session change (e.g., when player F decides to interact with D instead of E),
- seamlessly supporting both unicast and multicast/broadcast (e.g., if a player G joins the game session between E and F, unicast communication should be changed to many-to-many multicast or broadcast).

Using a distributed model where each node (vehicle) replicates the game session in which it is involved ensures that consistency will not be affected by other nodes entering and exiting the game session.

5.2.3.3. Disconnection tolerance. In Internet multiplayer games, players generally do not accept network-based interruptions of gameplay and are inclined to changing game servers in case of frequent game outages. The simulation results presented previously indicate that in VANETs the network interruptions have to be accounted for due to very high mobility that enables players to interact only for a certain amount of time. For this reason we believe that any VANET game, whose underlying architecture and the story behind the gameplay would not be modified to account for the network-based interruptions, would risk being abandoned by the players due to the frustration with unsatisfying gaming experience. However, using the mechanisms described above (namely, *connection duration awareness* and *fast switching between players and sessions*), gameplay can be designed in a way that can assure that network-based interuptions are accounted for and incorporated in the gameplay. In a multiplayer game, a player is allowed three kinds of actions [30]: position change, player–object interaction, and player–player interaction. When players are in the communication range of each other, they interact in the game. However, when there are no other players available, a

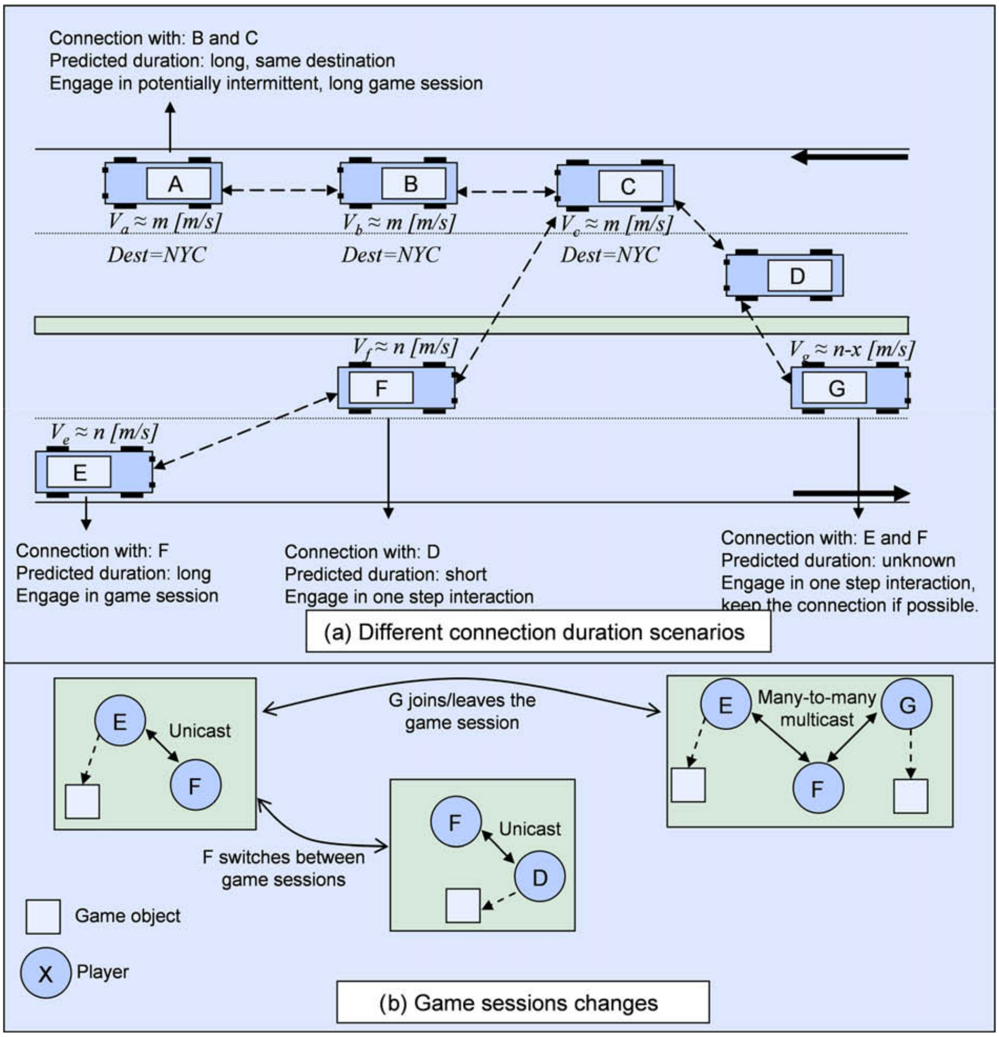


Fig. 7. Different connection duration scenarios and dynamics of player interactions.

player should be able to play by fulfilling other goals in the game (e.g., interacting with objects in the game and moving through the game world). Furthermore, the game has to be able to seamlessly incorporate newly reachable players in the game, without disturbing player's activity in the game.

6. VANET multiplayer games – a new paradigm

While playing certain types of "classic" Internet games over VANETs (ones that do not require overly long game sessions) could be possible, dynamic and interactive nature of VANET environment creates new opportunities for games which are not available in any other environment. Following are some of the characteristics we believe VANET games could possess.

6.1. Location awareness

Using information from positioning system (e.g., GPS), the game will be able to incorporate physical world in the game state, thus creating a mixed reality experience by utilizing the inherent dynamical properties of driving to enrich the game, and using the road surroundings to enhance user experience. Furthermore, knowing that all players in a game session are located in a certain geographical area enables new types of interaction between players (e.g., based on the physical distance between players). Brunnberg in [32] created a simple location-aware, mixed reality multiplayer game named The Road Rager, that presented some of the interesting possibilities for multiplayer games in VANET.

6.2. Mixed reality potential

Exploiting real world properties in a mobile mixed reality application is usually constrained by the power, storage, and processing limitations. Given the fact that vehicles do not suffer from these limitations, VANET games could be the first commercial mobile applications to implement mixed reality, by linking virtual game world with real world objects. Another practical aspect that limits the implementation of mixed reality applications is the size and weight of the equipment used to merge physical and virtual world. This obstacle does not exist in VANETs either, because equipment can be built in the vehicle, thus allowing for a more pleasurable experience, without the burden of equipment.

6.3. Player-based game content creation

Since virtually the entire road infrastructure can be observed as a game world for VANET games, creating location-based objects for such a vast game world will be time consuming. However, observing recent trends in user-based content creation and distribution, it seems natural to assume that players could be the contributors to the game, by creating game objects for specific physical locations of their interest. Objects could then be obtained from other players during V2V communication, or via Internet – either using in-vehicle Internet access [33], at home [34], or during the V2I communication, whichever is available.

6.4. New type of game world

In an Internet multiplayer game (e.g., World of Warcraft, often abbreviated as WoW), the game world consists of immutable landscape information representing the virtual terrain where all objects interact (in case of WoW, several planets), characters controlled by players (in WoW, avatars from 10 different races), mutable and immutable objects (e.g., tools, weapons, food), mutable landscape information (e.g., trees that can be cut down), and non-player characters (NPCs) that are controlled by automated algorithms [30] (in WoW, there are three types of NPCs: friendly, hostile and neutral). Information on interaction between all of these objects is stored in the server, in order to ensure game consistency and persistent world. Persistent world is maintained on the server continuously and users connect to it in order to participate in the game. In VANETs, assuming there is no ubiquitous Internet connectivity, this kind of persistent world is not going to be available. Players will be partitioned into geographically bound game sessions where overall game consistency cannot be assured. However, players in VANETs are likely to display locality of interest (due to limited connectivity), and form self-organizing groups based on their location in real (as opposed to virtual) world. Also, since personal vehicles are becoming multimedia environments with large storage and processing capabilities, players will be able to store parts of the geographically bound game world data (immutable landscape information, objects and non-player characters) locally on their devices in vehicles, as part of the client software. On the other hand, game state synchronization data and player interactions could be exchanged in a V2V manner, so the up-to-date game state is available to all of the other players they encounter on the road. Player's character and current game state information (e.g., the remaining power, items that character possesses, player's interactions with nearby non-mutable objects) are only relevant to those players directly communicating with the player, thus consistency only has to be achieved on a game session level. Therefore, the game world in VANET games will be distributed over the nodes with the consistency achieved between players communicating directly in a game session.

6.5. Utilizing the existence of Internet connectivity

It is natural to expect that Internet access will be present in majority of vehicles in the relatively near future, either through dedicated infrastructure via Internet connected roadside units (RSUs) [35], or through existing networks (e.g, cellular or WiMax), which already offer commercial solutions for in-vehicle Internet access [36]. In the case of Internet availability, VANET games could be enhanced by maintaining a persistent world on Internet servers, as well as interconnecting players at distant geographical locations, thus significantly increasing the number of reachable players. Furthermore, many of the immanent VANET QoS restrictions would be alleviated. At the same time, even with the full penetration of in-vehicle Internet access, the intrinsic VANET characteristics discussed in this paper (e.g., location awareness, direct physical interaction due to proximity, and mixed reality) are going to be the distinguishing features of VANET games, creating a much more dynamic and interactive gaming environment compared to that available for Internet games.

6.6. Simple VANET multiplayer game example

In this subsection, we will provide a simple example of a VANET game that can be envisioned to possess the characteristics mentioned above. Assume there is a player in the car A that is traveling on an interstate. He has a head-mounted display that uses coordinates provided by the on-board GPS system in order to link the real world with the artifacts in the virtual game world. Car A passes by a small forest which triggers the game engine to unveil the non-player character (NPC) which gives the player his quest in the game (Fig. 8a). Player's quest is to discover where a certain treasure is hidden. The player in the car A is joined by another player in the car B that is traveling in the same direction (Fig. 8b). The underlying protocols and game engine use GPS and speedometer data to determine that the cars A and B are traveling at approximately the same speed and the players are offered an option to engage in a longer interaction. At the same time, the game engine runs a game session synchronization in the background. The players exchange voice and chat data, discuss the findings that they have obtained so far, and work together in order to solve a problem of mutual interest. After he gets disconnected from the player in the car B, the player in the car A passes by an old building which triggers the game engine to display several user-created objects around that building (Fig. 8c). The player in the car A obtains an artifact that could be of use to him in the game. Next, the player in the car A approaches another player in the car C that is traveling in the opposite direction (Fig. 8d). The game engine acknowledges that the players can engage in a short interaction and offers players an option to perform one step game artifact exchange, while at the same time synchronizing the game state in the background. Players exchange artifacts and get disconnected. Finally, the player in the car A notices a treasure chest hidden in the castle next to the road and uses the keys he obtained earlier to open it and extract treasure (Fig. 8e). Because he successfully completed the mission, the player is awarded a certain amount

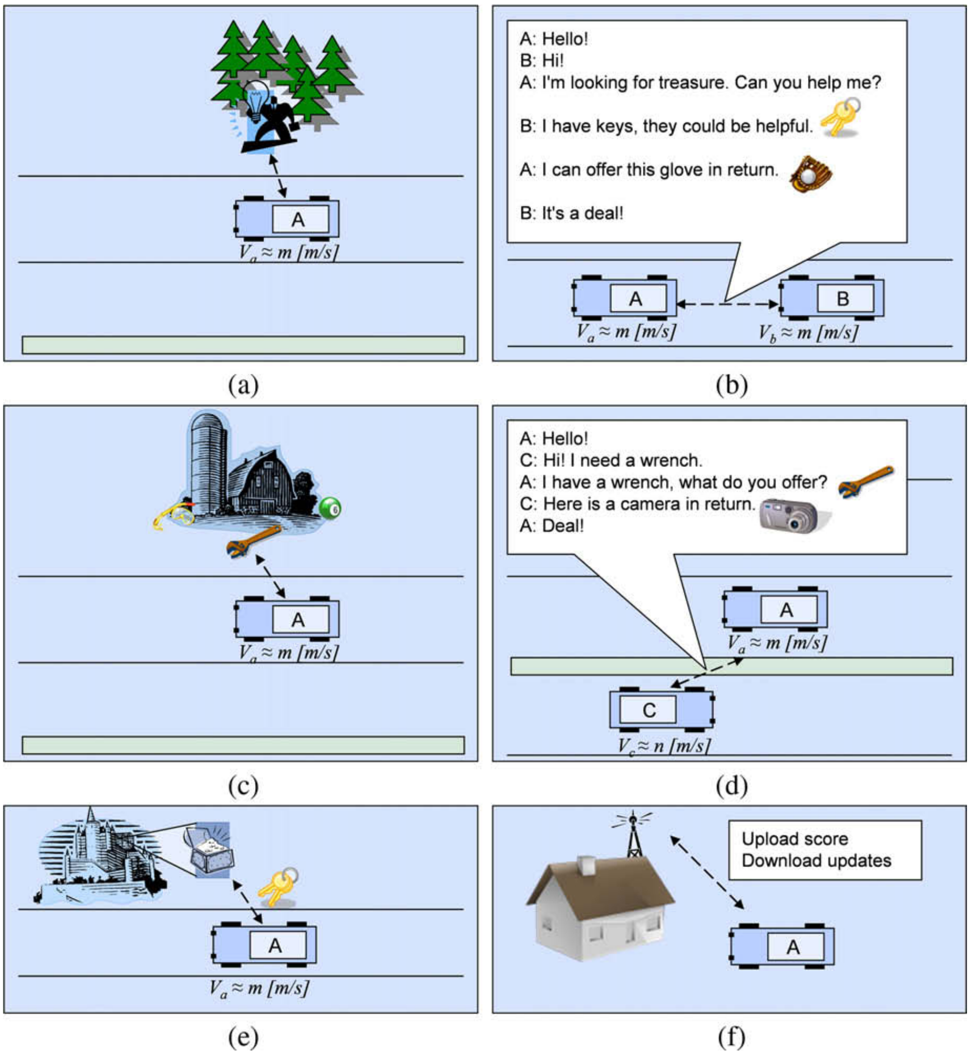


Fig. 8. VANET game example.

of points. When he returns home, connects to a hotspot on a gas station, or connects to an Internet-enabled RSU, the game automatically uploads the player's current score to the central server on the Internet, at the same time downloading the newest version of user-created objects and other updates for the game (Fig. 8f).

6.7. Traffic safety

In designing a game for a VANET environment, it is of utmost importance to account for the traffic safety hazard, traffic flow, and even fuel consumption issues such application could introduce. For this reason, the success of any VANET game will depend on the ability of enabling gameplay that does not interfere with traffic safety in any way; game designers will have to make maximum effort in designing the games that (a) do not distract the driver (either by excessive noise, movement, or by players requesting the driver to utilize a certain driving style or route), and (b) have no benefit from purposely following a specific route that is beneficial for the player, but could be suboptimal from the traffic flow/fuel consumption standpoint.

7. Potential stakeholders

The DSRC radio equipment will most likely be installed in the majority of personal vehicles. However, it will only provide for the connectivity, not specifying the equipment used to present the data to driver and passengers. We envision that, besides the pre-installed on-board devices in vehicles, a plethora of different devices will be able to connect to the DSRC equipment using wired (e.g., Ethernet) or wireless (e.g., Bluetooth, in-vehicle WiFi, infrared, etc.) interfaces, in order to run different, non-safety applications. Therefore, from a business perspective it will be of utmost importance for VANET game designers to account for *cross-platform operability*, by designing games that can be played on different devices and platforms (e.g., notebooks with different operating systems, Personal Digital Assistants, game consoles, iPhone, GPS devices, just to name a few).

Besides the obvious stakeholders in the game business, the game development companies, there are several other potentially interested parties:

- Manufacturers of automotive navigation systems could increase the value of their products by implementing the support for VANET games, especially since VANET games could benefit greatly from positioning systems by allowing for a more interactive location-based gameplay.

- Game console makers could expand their business into a potentially large new market.
- Personal vehicle manufacturers could benefit from offering value-added entertainment service in their vehicles.
- Various businesses next to the road (e.g., gas stations, food franchises, clothing stores) could use location aware games to advertise their business and products directly to the passengers in cars, when the vehicles are approaching their location.

8. Conclusion

In his seminal paper published in 1991 [37], Mark Weiser envisioned that pervasive computing will become an integral part of our lives and devices will be seemingly integrated around us allowing for an experience diametrically opposite to virtual reality – technology enhanced real world. In this paper, following Weiser's pervasive computing vision, we propose a paradigm shift in multiplayer gaming from a computer-generated, virtual reality surroundings, to a real world, mixed reality environment, that offers players the richness of technology support that is available in games today, combined with the real world experience that is inherent in a moving vehicle.

To that end, we have analyzed the empirical data on travel, occupants in vehicle and interstate traffic volume, to shed some light on possible game audience, real world connectivity, and connection duration between vehicles on US roads. Based on the analysis of empirical data, we performed simulations to determine the QoS characteristics of VANETs that are most important for games. We then identified the key technical challenges in enabling games over VANETs. Recognizing the challenges and opportunities the VANET environment implies for games, we have proposed a new paradigm for games in VANETs, one that adapts to the specific environment's constraints and makes use of its inherent dynamic characteristics.

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Ozan K. Tonguz received the BSc degree in electrical engineering from the University of Essex, England, and the MSc and PhD degrees in electrical engineering from Rutgers University, New Jersey. He currently serves as a tenured full professor in the Department of Electrical and Computer Engineering, Carnegie Mellon University (CMU). Before joining CMU in August 2000, he was with the Electrical and Communications Engineering Department, State University ofNew York, Buffalo (SUNY/Buffalo). He joined SUNY/Buffalo in 1990 as an assistant professor, where he was granted early tenure and promoted to associate professor in 1995 and to full professor in 1998. Prior to joining academia, he was with Bell Communications Research (Bellcore) in 1988–1990, doing research in optical networks and communication systems. His current research interests are on high-speed networking (Internet), wireless networks and communication systems, optical communications and networks, satellite communications, bioinformatics, and security. He has published close to 300 technical papers in IEEE journals and conference proceedings. He is well known for his contributions in wireless communications and networks as well as optical communications and networks. His recent work on the Integrated Cellular and Ad Hoc Relay Systems (iCAR) is internationally acclaimed as well. He is the author (with G. Ferrari) of the Wiley book (2006) entitled "Ad Hoc Wireless Networks: A Communication-Theoretic Perspective." He was also the architect of the "High Performance Waveform (HPW)" that was implemented in Harris RF Communications' AN/PRC-117f UHF band man-pack tactical radio. His industrial experience includes periods with Bell Communications Research, CTI Inc., Harris RF Communications, Aria Wireless Systems, Clearwire Technologies, Nokia Networks, Nokia Research Center, Neuro Kinetics, Asea Brown Boveri (ABB), General Motors (GM), and Intel. He currently serves or has served as a consultant or expert for several companies (such as Aria Wireless Systems, Harris RF Communications, Clearwire Technologies, Nokia Networks, Alcatel, Lucent Technologies), major law firms, and government agencies in Europe, USA, and Asia in the broad area of telecommunications and networking. He is also a codirector (Thrust Leader) of the Center for Wireless and Broadband Networking Research, Carnegie Mellon University. More details about his research interests, research group, projects, and publications can be found at http://www.ece.cmu.edu/ tonguz/. In addition to serving on the Technical Program Committees of several IEEE conferences (such as INFOCOM, SECON, GLOBECOM, ICC, VTC, and WCNC) and symposia in the area of wireless communications and optical networks. He currently serves or has served as an associate editor for the IEEE Transactions on Communications, IEEE Communications Magazine, and IEEE Journal of Lightwave Technology. He was a guest editor of the special issue of the IEEE Journal of Lightwave Technology and IEEE Journal on Selected Areas in Communications on multiwavelength optical networks and technology, published in 1996, and a guest editor on the Special Issue of the Journal of Mobile Multimedia on advanced mobile technologies for health care applications (2006). He is a member of the IEEE.

Mate Boban is a PhD student in electrical and computer engineering in the dual PhD Carnegie Mellon | Portugal program. He received his Diploma in Informatics from the University of Zagreb, Croatia. He spent 18 months as a Fulbright scholar in the ECE department, Carnegie Mellon University in 2007-2009. His research interests include wireless ad hoc networks, protocol design, cooperative communications, realistic simulation and modeling, and novel distributed applications.